



AEROSPACE INFORMATION REPORT

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Superseding AIR4174

(R) A Guide to Aircraft Power Train Monitoring

RATIONALE

The aviation industry uses available and emergent technologies for power train monitoring to affect flight safety, power train and aircraft reliability, availability, maintainability, life cycle cost, and mission effectiveness. This Aerospace Information Report (AIR) provides information and descriptions of common practices based on lessons learned. AIR4174A updates the information contained in the base document.

FORWARD

Power train monitoring has been utilized for some time through flight crew reports, periodic analysis of oil samples, vibration checks, borescoping, and cycle counting. Most of the effort was accomplished by the ground crew. With the advent of airborne monitoring systems, the collection of data and analysis can become automated resulting in a more thorough record of the condition of power train components.

With increased knowledge gained from the monitoring of aircraft, more applications in the monitoring of the power train components have been developed and implemented. The miniaturization of electronic devices has resulted in small lightweight computers mounted on board the aircraft. Such devices have made it possible to monitor the power train components, make computations, and record data for ground analysis as well as report in real time to the flight crew of any disparities. The data can also be transmitted to a ground station so the ground crew can be ready to take any necessary corrective action as soon as the aircraft lands and thus increase aircraft availability.

Preferably, the power train monitoring would be considered during the design stage. However, even as an add on, the system should be viewed as a part of an integrated condition/performance monitoring system on the aircraft and as a part of a total process involving flight safety, line maintenance, fleet management and configuration control.

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1. SCOPE

The purpose of this SAE Aerospace Information Report (AIR) is to provide management, designers, and operators with information to assist them to decide what type of power train monitoring they desire. This document is to provide assistance in optimizing system complexity, performance and cost effectiveness.

This document covers all power train elements from the point at which aircraft propulsion energy in a turbine or reciprocating engine is converted via a gear train to mechanical energy for propulsion purposes. The document covers aircraft engine driven transmission and gearbox components, their interfaces, drivetrain shafting, drive shaft hanger bearings, and associated rotating accessories, propellers, and rotor systems as shown in Figure 1. For guidance on monitoring additional engine components not addressed, herein (e.g., main shaft bearings and compressor/turbine rotors), refer to ARP1839.

This document addresses rotary and fixed wing applications for rotor, turboprop, turbofan, prop fan, and lift fan drive trains on both commercial and military aircraft.

Information is provided to assist in:

- a. Defining technology maturity and application risk
- b. Cost benefit analysis (Value analysis)
- c. Selection of system components
- d. Selection of technology
- e. Managing interface requirements
- f. Defining information flow requirements

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 International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR46	The Preparation and Use of Chromel-Alumel Thermocouples for Aircraft Gas Turbine Engines
AIR65	Thermoelectric Circuits and the Performance of Several Aircraft Engine Thermocouples
AIR1828	Guide to Engine Lubrication System Monitoring
AIR1900	Guide to Temperature Monitoring in Aircraft Gas Turbine Engines
ARP1839	A Guide to Aircraft Turbine Engine Vibration Monitoring Systems
ARP4176	Determination of Costs and Benefits from Implementing an Engine Health Management System

ARP5120	Aircraft Gas Turbine Engine Health Management System Development and Integration Guide
ARP6275	Determination of Cost Benefits from Implementing an Integrated Vehicle Health Management System
AS5391	Helicopter Health and Usage Monitoring System Accelerometer Interface Specification

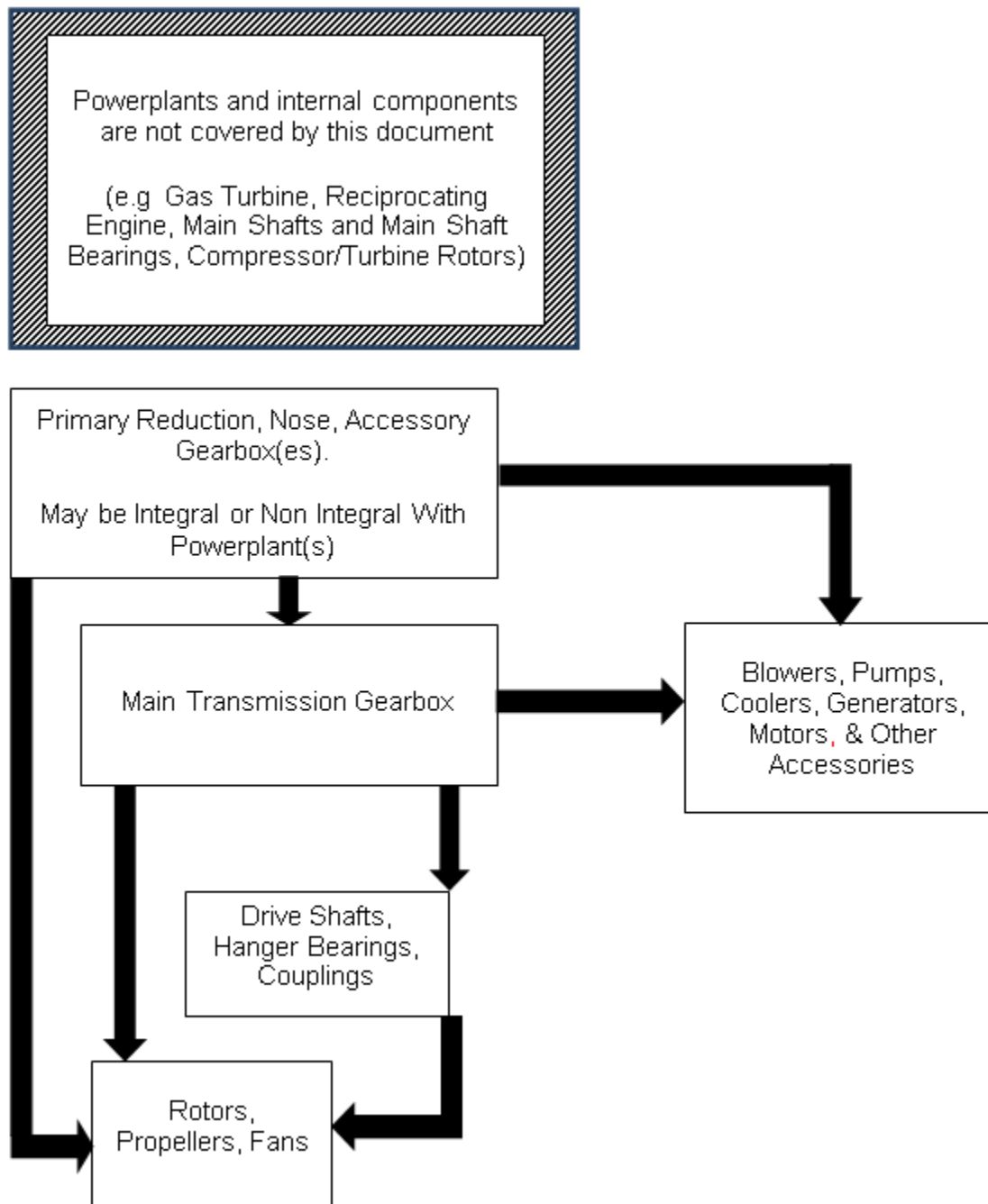


Figure 1 - Typical power train components

2.2 Terminology

AC	Alternating Current
AIR	Aerospace Information Report
ARP	Aerospace Recommended Practice
C	Celsius
DC	Direct Current
DTA	Damage Tolerance Analysis
F	Fahrenheit
FMT	Fixed Mount Tracker
IEPE	Integrated Electronics Piezo Electric
KHz	Kilohertz
LSC	Line Scan Camera
µm	Micron
/rev	Per Revolution
RMS	Root Mean Square
RPM	Revolutions Per Minute
RTD	Resistance Temperature Device
SAE	SAE International
TBO	Time Between Overhaul
TV	Television

3. APPROACHES TO MONITORING

3.1 Purpose of Monitoring System

The power train monitoring system can have several purposes. Its principal use is to detect and identify failure modes during their early stages and to present credible information to appropriate personnel in a timely manner. This information should result in appropriate action being taken to correct the source of the failure before it becomes either critical, resulting in loss of power transmission, or catastrophic. Such failure modes can result from fatigue stresses, from wear, loss of lubrication, incorrect assembly or maintenance, or a number of other causes. In addition, monitoring systems can be used to directly aid maintenance, such as the use of onboard rotor track and balance systems on helicopters to reduce the need for special maintenance flights for rotor track and balance.

The uses of monitoring system information are many. Figure 2 shows the principal data uses in a complete monitoring system infrastructure. Each data use has distinct, but often overlapping, requirements for the quality, quantity and type of presentation data.

A fully effective monitoring system would be conceived and implemented as an integral part of a system influencing safety, aircraft reliability, maintenance, fleet management, mission planning, design feedback and other areas.

A monitoring system may address any one or all of these data uses. Maximum cost effectiveness is achieved when all data uses are considered and their individual requirements taken into account at an early stage in the design of both the elements to be monitored and the monitoring system itself.

The first data use provides information to the flight crew. The requirements for such data would be for:

- a. The data to be directly related to the ability of the aircraft to safely continue its mission. To minimize the workload, any information presented to the flight crew would be limited to that requiring action. Other information would be reserved for use by the maintenance personnel.
- b. The data to be of high integrity to avoid false alerts.
- c. The presentation of the data to the flight crew to be in a form that is readily understood. This means that the flight crew data would not be presented in raw engineering units.
- d. Each data presentation to be linked to a specified course of action to be taken by the flight crew.

Flight crew data can range from simple binary indication of an event or exceedance to a computed result derived from a number of highly processed parameters. In all cases, the data presented to the crew together with significant supporting parameters can be recorded for further analysis by the functions described in the other data uses.

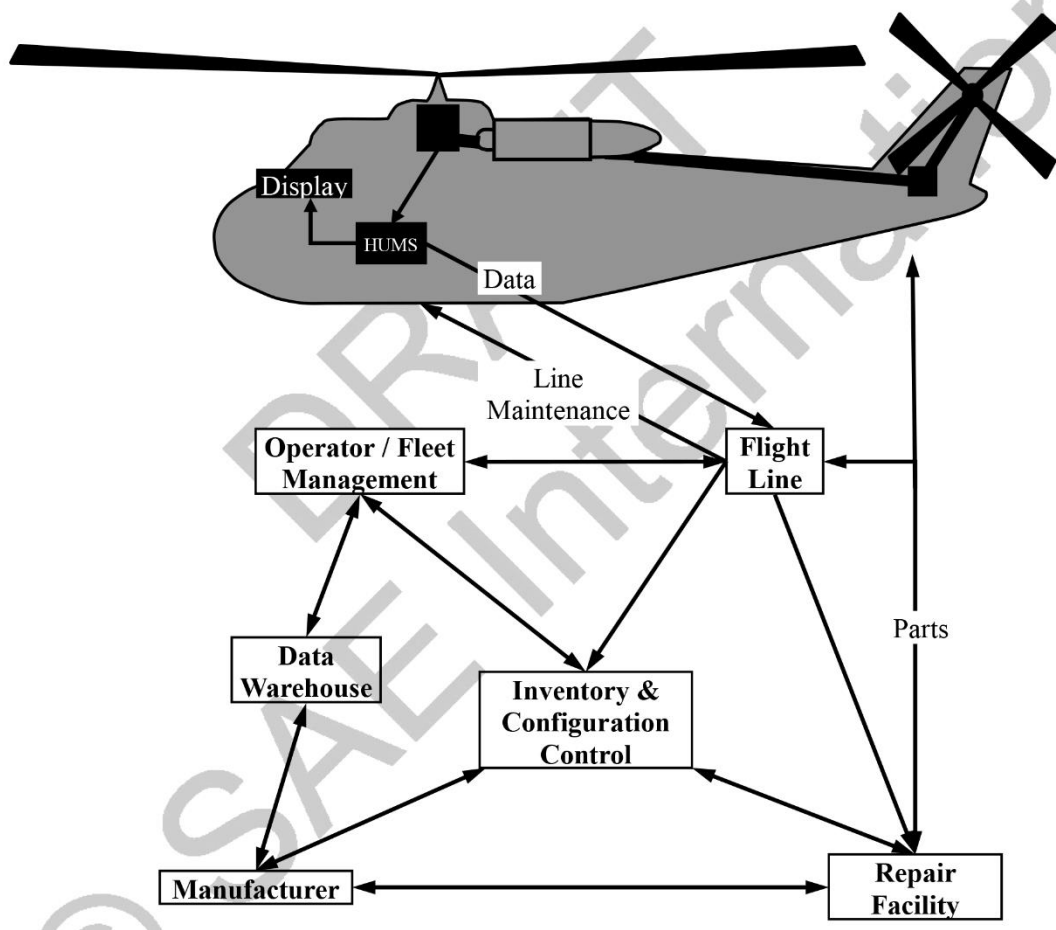


Figure 2 – Monitoring system data uses

The second data use provides information to flight line maintenance personnel. The requirements for such data would be for:

- a. The data to include information related to any indications given to the flight crew.
- b. The data to lead the maintenance personnel to the part or parts requiring inspection/adjustment/repair/replacement. This usually requires a deeper level of diagnostic processing, often of multiple parameters. The results of the processing together with the raw input parameters would then be recorded. Systems are often designed to be interactive and permit the operator to consider other parameters which may not have been included in the system computation.
- c. Documenting the process of analyzing the data and interacting with the system.
- d. Interactive systems to enable the ability to add or modify the data base and/or algorithms used by the monitoring system. Such systems require strict controls over the extent and content of such modifications.
- e. Involving the mechanic in fault isolation after automatic fault detection. These systems would document the fault isolation session.

The third data use provides all of the above information to an inventory and configuration management control system. This is typically based on a central computer to permit more specific analyses required to facilitate spares planning and fleet management decisions. This system requires numerous inputs which are not all available from the on-board system such as:

- a. Details of parts in stock, remaining useable life, and their storage locations.
- b. Lead times and costs for replacement spares.
- c. Details of parts used on flight line.
- d. Repair order in process.
- e. Configuration control data.

The fourth data use could require most of the above data plus the analysis tools necessary to correlate indicated failure modes with results of repair investigations by the manufacturer, fleet operator, and repair facilities. Providing the information to a data warehouse for storage where the data can be accessible to analysts at the Operator's and Manufacturer's facilities enables operations trending, warranty information, and return on investment studies. In part, this data use operates as a system that monitors the function and success of the on-line monitoring system itself.

The objective of the fourth data use would be to identify the need for design/engineering actions to remedy recurring failure modes and to improve the function of the monitoring system process itself.

The fifth data use is to provide the fleet operators/managers with fleet wide data to allow management decisions to be generated from data analysis such as decisions to change aircraft locations to facilitate efficient power train maintenance while maintaining the current level of operations.

3.2 Monitoring Functions and Techniques

The monitoring system may be designed to perform basic health and usage monitoring diagnostic, prognostic, status information functions, failure detection, and accommodation for mission optimization or get-home capability. To accomplish these functions there are techniques which fall into six basic categories. The techniques will often be used in combination to support or corroborate each other. The six categories are defined in the following sections:

3.2.1 Inspection

Inspection encompasses all parameters which can be detected by human sight, sound, smell and feel. This category has a basic difference from all other; it often cannot be performed during flight. Another drawback is the substantial effort required to inspect enclosed parts such as gearboxes. However, it is simple and very beneficial for couplings and drive train supports. Any complete monitoring system would include provisions for the input of human inspection data. For example, visual inspection provisions in overboard seal drains to inspect for excess dripping.

3.2.2 Discrete Event Monitoring

Discrete event Monitoring is typically a binary or “on-off” monitoring approach, currently done on all aircraft. Examples include the various inputs displayed showing system status, limits, position, etc. Ideally, event monitoring would be capable of recording the status of monitored parameters before, during, and after an abnormal event occurrence. Where continuous parametric data is captured, tagging events with times and dates is necessary for subsequent analysis.

3.2.3 Exceedance Monitoring

Exceedance Monitoring is the monitoring of various parameters or sensors to determine when limits are exceeded. Output data could be either binary or analog. Examples are over torque or over speed, high temperature, and high or low oil pressure. Exceedance Monitoring has been standard practice for many components. Over torque can indicate excessive fatigue cycle events in a gearbox or shaft. Low pressure can indicate lubrication problems, such as an oil pump failure, clogged filter, oil loss, or low oil levels.

3.2.4 Condition Monitoring

Condition Monitoring includes those techniques which detect problems by evaluating certain characteristics which result from an incipient failure mode. Important techniques which apply to the power train are vibration monitoring, oil debris monitoring, oil condition monitoring, fluid level monitoring, and filter blockage monitoring.

Vibration monitoring is typically applied to rotating mechanical components due to their propensity to generate vibration and fail earlier than static components. Many of the potential failure modes of gears, bearings, and shafts will produce detectable vibration signals. Algorithms have been developed to cover a wide variety of these failure modes and can be used to provide good fault isolation of the rotating components. Many of these algorithms require computationally intensive signal processing.

Oil debris monitoring is applicable to oil wetted components, and is an example of wear debris monitoring. Oil debris monitoring is used to detect the presence of principally metallic particles in the lubricating oil, thus indicating wear or other failure modes which cause the gear or bearing to lose material. Oil debris monitoring is further described in 4.2.10.

Oil condition monitoring may be used to test the lubricant for oil breakdown, the presence of water, and oil acidity through capacitance, resistance, impedance, and infrared fluid sensing instruments. Loss of anti-oxidant in oil can also be checked chemically. Oil condition monitoring is further described in 4.2.9.

Fluid level monitoring and filter blockage monitoring are other conditions monitored to provide both crew and maintenance personnel the fluid level and flow indications as noted in 3.2.3, 4.1.1, 4.1.9, and 4.2.8.

3.2.5 Combined/Fused Parameter Monitoring

This category includes several techniques commonly used on aircraft, all of which have in common the need to acquire data for a number of parameters and to apply a suitable analytic process to provide a measure of the system functionality. Fusion of vibration and oil debris monitoring data is an example of combined parameter monitoring. Helicopter rotor track and balance systems also require inputs for a variety of parameters, such as flight condition, blade azimuth, vibration levels, blade flap, and lag motions.

3.2.6 Usage Monitoring

Usage monitoring's objective is the establishment of the remaining useful life of dynamic components based upon measurements of pertinent parameters on the aircraft. There are various fundamental types of usage monitoring. The types can be differentiated by whether or not the life is to be determined by measurements relating to the severity of the load, structural usage lifing, or determined by operating time or operational usage monitoring.

Structural usage lifing can be accomplished by direct measurement of load, such as the monitoring of torque, or it can be accomplished by monitoring the time histories of flight regimes of the aircraft. Based upon known relationships between flight regime and component loading, typically obtained from flight test data, a loading history for the component can be determined. Methods are available for determining these flight regimes, the time spent in each regime, and the number of occurrences of each regime in an efficient way, basically in real time. Structural usage monitoring is discussed more fully in 4.2.4.

The analysis of this type of usage data must still consider life reduction factors since the actual fatigue strength of the individual part being monitored cannot be defined exactly. (Fatigue strength of a population of parts being statistical in nature.)

The simpler approach is operational usage monitoring. This approach uses the principle that component life, or times between overhaul (TBO) and replacement is based upon known readily obtainable parameters, such as flight hours, or number of takeoffs and landings. Such usage monitoring is relatively straight forward and can be fairly easily implemented. Fundamental to this type of usage monitoring is the concept that component life is typically based on a predetermined flight profile or flight spectrum of loads. When an aircraft flies in accordance with the predetermined flight profile, component life can be defined by a measurement such as flight hours. Deviation from that flight profile may result in a longer or shorter part life. To account for such deviations in flight profiles and their effect on component life, structural usage monitoring information may have to be combined with the operational usage to account for the loading or stress severity deviations.

Another usage monitoring approach is to use external and internal parameters to feed a part-specific model containing analytical failure mechanisms for each critical feature on the part to continually assess life usage and life remaining based on multiple failure mechanisms – low cycle and high cycle fatigue, thermal-mechanical fatigue, erosion, crack growth, etcetera.

4. POWER TRAIN COMPONENT MONITORING METHODS AND TECHNIQUES

4.1 Component Monitoring Methods

An aircraft may have monitoring or diagnostic systems covering many of its systems, and power train monitoring may be included as part of a larger monitoring system. However, this section will emphasize monitoring methods which are particularly useful for the power train.

The components which are typically part of a power train, and the parameters which could be used to monitor them are shown in Figure 3. The following summarizes how the parameters could be used. The various sensor technologies and techniques are discussed in 4.2.

4.1.1 Gearboxes

Torque and rotational speed can be used to monitor exceedance of gear train operating limits. Temperature, pressure, oil condition, and lubricant level can be used to define the conditions of the lubrication system. Vibration and oil debris monitoring can be used to assess the health of the gears, bearings, and shafts. Oil debris monitoring is most commonly relied on while vibration is coming into greater use, particularly for gear and bearing faults monitoring. Cycles or operating hours are parameters that may be used to track gearbox service life and overhaul intervals.

4.1.2 Shafts

Torque exceedances on shafts should be monitored. Vibration monitoring can be used to monitor shaft unbalance (1/revolution (1/rev)) or misalignment (2/rev). Cycles and number of operating hours can also be employed to measure/track shaft life.