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Guide to Life Usage Monitoring and Parts Management for Aircraft Gas Turbine Engines

RATIONALE

This document is being cancelled because there has been no progress since 2003 and the committee has no one to lead a WG to update it. Engine OEMs and Certification Authorities are concerned it could be used to develop a new system against that would no longer meet current standards.

NOTICE

This document has been declared "CANCELLED" as of September 2011. By this action, this document will remain listed in the Numerical Section of the Aerospace Standards Index.

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INTRODUCTION

The idea of engine monitoring is not new. For years, military aircraft have used cycle counters, and pilots in military and commercial sectors have manually recorded cockpit parameters in order to enable maintenance and engineering personnel to detect signs of trouble. Changes in maintenance philosophies in the 1970's, from hard-time to on-condition, were accompanied by a requirement for a more sophisticated monitoring capability. Technological advances, made possible by the rapid development of digital electronics, have enabled comprehensive, automated monitoring to become the norm.

In recent years, increasing priority has been given to the development of life usage monitoring by both commercial and military operators. This action has been motivated not only by the continuing need to prevent failures but also to reduce life cycle costs through more effective utilization of engine parts. In military operation, the diversity of mission profiles amplifies the need and complicates the task of life usage tracking. However, the same basic requirements for monitoring life usage apply to both commercial and military operators. Monitoring includes on-board data collection, on-board processing, ground-based processing and data management.

Because of user interest and need, SAE Committee E-32 has developed this Guide to Life Usage Monitoring and Parts Management for Aircraft Gas Turbine Engines.

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1. SCOPE:

The effectiveness of Engine Life Usage Monitoring and Parts Management systems is largely determined by the aircraft-specific requirements. This document addresses the following areas:

- a. Safety
- b. Life-limiting criteria
- c. Life usage algorithm development
- d. Data acquisition and management
- e. Parts life tracking
- f. Design feedback
- g. Cost effectiveness

It primarily examines the requirements and techniques currently in use, and considers the potential impact of new technology to the following areas:

- a. Parts classification and control requirements
- b. Failure causes of life-limited parts
- c. Engine life prediction and usage measurement techniques
- d. Method validation
- e. Parts life usage data management
- f. Lessons learned
- g. Life usage tracking benefits

1.1 Purpose:

SAE ARP1587 provides general guidance on the design considerations and objectives of monitoring systems for aircraft gas turbine engines. A major function of these Engine Monitoring Systems is to monitor the usage of life-limited parts in order to maximize available life and to enhance aircraft safety.

The purpose of this document is to review the current approaches to Engine Life Usage Monitoring and Parts Management. The document also serves to provide a summary of the many varied requirements of aircraft turbine engine life usage monitoring and parts management (see Appendices A and B) and a description of the means by which these requirements can be achieved more effectively through the use of engine monitoring systems.

1.2 General Considerations:

- 1.2.1 Life Usage: The failure of an engine part may be due to inherent causes such as the accumulation of damage due to cyclic and steady-state stresses resulting from temperature, speed, differential pressure, and vibration. In many cases, the effects of these stresses can be estimated and, therefore, the amount of life used or life remaining in a part can be approximated with reasonable confidence.

For these inherent failure causes, the approach generally used to determine the initial design life estimate of an engine part is to:

1.2.1 (Continued):

- a. Submit the proposed design to heat transfer, stress, and life analyses
- b. Subject sample parts to rig testing
- c. Subject production standard engines to full-scale simulated service endurance tests

These steps are supplemented by further analyses in the laboratory and flight test investigations to confirm or modify initial design estimates of failure resistance and operating environment, respectively.

Life usage monitoring depends on two key aspects:

- a. Life Prediction, whereby the finite life is determined against a life criteria (creep life, LCF life, etc.)
- b. Life Measurement, by which the rate of life consumption is determined

Analytical techniques are widely used to predict the service life of gas turbine engine parts. However, the actual life of parts in service depends upon the severity of cyclic or steady-state operation or both. In the absence of quantitative life usage data, the initial life usage assumptions are necessarily conservative to assure engine integrity. These initial assumptions are later re-evaluated using data acquired primarily from lead-the-fleet sampling programs. This includes, but is not limited to, subjecting service run parts to rig tests.

The simplest method of measuring life usage is to record engine running time. A slightly more sophisticated approach is to record both running time and mission profile, which recognizes that some flights are more severe in terms of fatigue than others. More complex methods include use of airborne data acquisition systems, which provide complete usage records for a fleet of aircraft, and microprocessor-based Engine Monitoring Systems capable of calculating life usage in real time. Clearly, the chosen degree of sophistication depends on the required life measurement accuracy and this, in turn, will typically be determined by perceived cost savings and safety requirements. The optimum is to be able to measure, on an engine-by-engine basis, all parameters which impact life consumption and, using accurate life algorithms, determine usage for individual fracture critical components. To gain a worthwhile benefit, the life prediction and life measurement systems adopted need to have a similar degree of accuracy.

1.2.2 Parts Management: During the life of a gas turbine engine, occasional removals from service are required to facilitate scheduled and unscheduled repair/overhaul.

In order to minimize engine down-time during repair, parts are often replaced with new or repaired parts conforming to equivalent or improved design standards. Consequently, parts that are removed for rework or inspection are sometimes re-allocated to other engines undergoing repair. Thus, after several engine rebuilds, the constituent parts can be very different from the initial complement supplied by the manufacturer. For modular engines, the ability to exchange complete modules tends to compound this further.

1.2.2 (Continued):

This degree of interchangeability demands the use of well organized asset management systems to track the utilization of life-limited parts. These systems may range from simple card index systems to computer-based information management systems capable of interfacing with airborne engine monitoring systems via specialized data transfer equipment.

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
AIR1873	Guide to Limited Engine Monitoring Systems for Aircraft Gas Turbine Engines

2.1.2 U.S. Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-1783

2.1.3 Other Publications:

RB.211 Propulsion Systems Manual, Chapters 70-01-10 (Maintenance) and 5-10-01 (Time Limits)
(Available from Rolls-Royce)

3. PARTS CLASSIFICATION AND CONTROL REQUIREMENTS:

Engine parts that have finite lives are identified early in the engine design process. If these parts were allowed to continue indefinitely in service, they would eventually fail at some point in time, possibly causing significant damage to the engine or airframe. These parts are accordingly given service life-limits that are not to be exceeded in order to assure safe operation.

A Failure Modes, Effects, and Criticality Analysis (FMECA) is used to determine the sensitivity of an engine to parts failures. This FMECA is part of the Reliability Centered Maintenance (RCM) process. If the failure of a life-limited part is likely to affect safety of flight, it is then classified as a "critical life-limited part". Parts that rotate and are subject to significant Low Cycle Fatigue (LCF) are generally classified as critical parts. Similarly, if the FMECA shows that the failure of a life-limited part does not affect safety of flight but nevertheless is likely to seriously affect engine performance, reliability, or operating costs or both, it is then classified as a "non-critical life-limited part".

3. (Continued):

Critical life-limited parts for a particular engine type would generally remain common for single and multiengine aircraft applications. However, parts that are listed as noncritical for a multiengine aircraft may be listed as critical for a single-engined aircraft.

Most engine parts, life-limited or otherwise, require inspection throughout their service lives to check for signs of damage due to cracks, impact, corrosion, erosion, etc. Moreover, life-limited parts require strict adherence to rigorous control procedures to ensure that no component continues in service beyond its safe life-limit. For critical life-limited parts, regulations require that each part be traceable throughout its service life history and that complete inspection records be maintained. Therefore, each critical life-limited part is marked accordingly with a unique serial number for identification.

4. FAILURE CAUSES OF LIFE-LIMITED PARTS:

An engine part is life-limited if it is likely to fail through extended usage under normal design operating conditions. In general, safe life-limits are imposed across the fleet if the failure mode is inherently related to engine usage. Inherent failure causes can include one or any combination of the following:

- a. Low cycle fatigue
- b. High cycle fatigue
- c. Thermal fatigue
- d. Creep

In addition to these inherent failure causes, other causes can lead to the premature failure or rejection of a component. These non-inherent causes are mostly related to external factors not normally encountered by all engines in the fleet. These causes include:

- a. Foreign object damage
- b. Handling damage by operators
- c. Corrosion
- d. Erosion
- e. Fretting
- f. Rub, wear, friction
- g. Material defects
- h. Manufacturing defects
- i. Maintenance mishandling
- j. Acoustics/operating environment

In many cases, premature failures can be avoided by better component design, engine/component health monitoring and detailed inspections. Within the scope of health monitoring, fault detection and diagnosis is not discussed further in this document (see AIR1873).

4.1 Low Cycle Fatigue (LCF):

Low cycle fatigue is normally associated with significant stress excursions caused by repeated cycling between different stress levels within the material's elastic limit, eventually leading to failure. It is widely agreed that LCF failure occurs in less than 10^5 cycles, where a cycle is usually defined as an excursion from min to max stress and back to min. Excursions within the min to max stress range will typically occur more frequently during a component's operating life and, while not as significant as a complete cycle, these partial cycles nevertheless contribute to LCF and should, therefore, also be measured.

LCF stresses can be caused by centrifugal loads, torsional loads, gas pressure loads, and thermal gradients; each can act independently or in combination with one another, and produce the net stresses for a specific engine operating condition. The majority of rotating parts, in particular shafts and disks, are subject to LCF.

Non-rotating parts such as pressure vessels, mounts, and supporting structure also experience LCF stresses from recurring loads due to pressures and maneuvers/inertia.

For most rotating parts, the predominant load is centrifugal and, therefore, RPM dependent. Because centrifugal load is proportional to RPM^2 , the stress change due to an RPM change at or about the takeoff rating is substantially greater than that due to an equal RPM change at or about engine idle. Correspondingly, throttle movements in higher RPM bands are substantially more damaging than comparable throttle movements in lower RPM bands. Consequently, military engines usually exhibit higher LCF usage rates than commercially operated engines because of the large number of high-power throttle movements required for military aircraft.

4.2 High Cycle Fatigue (HCF):

Compared with LCF, high cycle fatigue is caused by lower stress amplitudes but at a much greater frequency ($>10^5$ cycles). Typical causes of HCF are vibration and flutter. An HCF stress is often superimposed on an LCF stress and is accounted for by applying a percentage factor to the LCF damage, thus further reducing the overall life. At the design stage, efforts are made to ensure that HCF will not occur under normal operations, or at the very least, characterize it sufficiently to ensure that the stresses will not be the life limiting failure mode of any component. Typically, this involves ensuring that components do not resonate either alone or through interaction with neighboring components. Knowledge of modal vibrations is obviously key in this task. However, aircraft, especially military, often operate in different roles and regimes than were originally defined. Thus, HCF can be unknowingly introduced into day-to-day operations. While HCF tends not to initiate cracks, a flaw in a component (typically a blade) could quickly propagate to failure under the effects of HCF. Understanding HCF failure modes requires a thorough knowledge of component stresses (both steady-state and cyclic), temperatures, and material properties. Although HCF is well recognized, it is not well understood, is difficult to model and measure, and its detection using on-board engine monitoring systems is currently under development.

4.3 Thermal Fatigue:

Thermal fatigue stresses are induced by thermal gradients and differential expansions. Thermal fatigue is similar to LCF in that relatively large stress levels can be induced, which can augment or negate the mechanically originated stresses in a part. The largest thermal stresses usually occur during transient temperature conditions as, for example, during engine start-up or rapid power changes. Accelerations and decelerations are the prime contributors toward thermal fatigue because, in these conditions, the rate of change of the gas temperature is rapid and generates high thermal gradients, particularly in hot section parts.

Many engine parts directly experience high gas temperatures, either by total immersion in the gas stream as in the case of turbine blades and vanes, or locally through partial immersion as in the case of high pressure compressor and turbine disks. In either case, thermal gradients will occur, which cause thermally induced stresses. This is because the geometric configurations of many engine parts cause different heating and cooling rates that, in turn, cause differential expansions within the part. For this reason, thermal fatigue is sometimes seen as a subset of LCF but, in this document, it is kept separate for clarity.

4.4 Creep:

For aircraft that fly mission profiles with long cruise segments and/or long periods at high power settings, creep can become a more life-limiting criterion than LCF. In commercial airlines, creep is generally not a problem in cruise but would be more prevalent during the takeoff and climb transients.

Under application of a sustained load at elevated temperatures, metals can show a gradual but permanent dimensional change. This is the result of slip occurring along crystal structures in the crystal itself, together with flow of the grain boundary material. The ramification of this process is the possible change in dimensions of a turbine component, to the point where the load bearing area of the component can no longer withstand the peak operating stresses. If allowed to continue unchecked, this condition will result in failure.

It is generally agreed that when plastic strains are introduced, the operating life of the component depends on the plastic strain and the high temperatures in which these strains are experienced. However, the maximum operating temperature is the single most important variable. Increasing the maximum temperature for a given temperature range will significantly reduce the remaining life to failure. For example, at elevated metal temperatures, the creep life of a part can be halved for a metal temperature increase of only 15 °C. Time duration at maximum temperature is another variable that greatly impacts creep life. As with HCF, common design practice is to eliminate creep as a life limiting factor during normal operation. Unlike HCF, however, creep is well understood, more easily modeled and predicted and therefore more easily eradicated as a life-limiting feature.

5. ENGINE LIFE PREDICTION AND USAGE MEASUREMENT:

Since the failure of certain engine parts is, at the very least, hazardous and potentially catastrophic, the application of effective failure prevention methods is imperative. A traditional methodology is to correlate engine life usage with time in normal operation to derive the time before next scheduled removal. At overhaul, some engine parts may be removed for cause, while others may be removed because of the statistical probability that failure will occur before next overhaul. These statistical probabilities are necessarily weighted for safety reasons; and therefore, parts are often removed with useful life remaining. Moreover, life drivers tend not to correlate closely with operating time. Thus, for reasons of maintaining safety and improving economy, the development of life usage monitoring systems incorporating accurate algorithms is necessary to determine the appropriate discard time for critical and non-critical components, particularly for military applications where the flight profiles can vary significantly.

5.1 Design Methodology:

As mentioned earlier, common design practice is to eliminate HCF and creep as life-limiting factors for normal operations. Abnormal operation, however, such as failure-induced flutter, over-temperatures or over-speeds can cause HCF or creep to become the life limiting factor. For this reason, many modern condition monitoring systems are designed to detect these abnormal conditions and alert the maintenance personnel. The remaining life-limiting factor, LCF, cannot be avoided as it occurs during normal operation. The approach normally used by engine manufacturers to verify the longevity of a life-limited part for a new engine design includes:

- a. Definitions of material properties and their distributions.
- b. Stress and heat transfer analyses of the proposed design using computer modeling techniques having various degrees of sophistication, including the estimation of pressure and temperature environments and the stresses they impose. These data are then used together with correlated test data to produce an initial life prediction.
- c. Bench, rig, and spin pit tests to verify the stress analysis data and to confirm life estimates. However, the difficulty of simulating real engine conditions and the lack of statistical significance of the number of test articles places more reliance on analytical methods.
- d. Instrumented bench and flight development engine testing to verify the estimated environmental conditions and stress levels.

The safe life of a critical life-limited component is the estimated life to first measurable crack. It can also be expressed as a proportion of the life for a crack to propagate to a critical crack size. The data provided by stress analysis are combined with empirical Stress/Cyclic (S/N) data, range-mean relationships and cumulative damage laws to produce an estimate of life to first crack. Rig and engine testing are helpful in validating fatigue life-limits and in determining whether life-limit adjustments are necessary. This analysis continues after an engine is in production so that parts life data are accrued ahead of service experience.

5.1 (Continued):

This work has been put on a more quantitative basis through the use of the science of fracture mechanics. The fact that all alloys contain impurities, flaws and defects to some extent forms the basis for fracture mechanics. The theory of fracture mechanics is that these impurities can develop into cracks that grow as a function of crack type and fluctuations in repetitive stress.

A crack in an engine part is stable up to a certain critical length, at that point it propagates to failure. The critical length depends on the particular material, but is always inversely proportional to the square of the stress. Thus, for an increase in stress, there is a corresponding decrease in critical length.

A stress intensity factor is used to relate the gross area or overall stress field to the physical geometry of the crack. Using the stress intensity factor, the material properties are generated which give the amount of crack growth for each applied cycle. This growth can then be summed to permit a calculation of crack size at any time in the life of an engine part. The critical condition occurs when the stress intensity factor reaches the fracture toughness value or the vibratory threshold value, at which point the crack will become unstable and propagate through the part.

Fracture mechanics relies on Non-Destructive Examination (NDE) to find cracks before engine assembly and during engine inspections. To verify defect size and distribution, quantification of sub-surface defects is done before engine development. Applying fracture mechanics to the design of an engine part, based on the part having a sub-surface defect just below the level that can be readily detected with accurate NDE techniques, then enables the life of the part to be calculated. The cycles remaining before the critical condition is reached can then be calculated. Based on this calculation and verification by test, the re-inspection and/or retirement of a part can be scheduled. Records must be kept of cyclic usage in service.

5.2 Derivation of Service Life Usage:

At initial production, the widely used method of determining the service life of life-limited parts is based on estimates of engine usage rates for mission type and mission mix. Analytical predictions are used to set the inspection interval and the retirement fatigue life. Because it is not currently possible to detect or measure cracks in most parts while installed in the engine, the calculated crack propagation phase is usually not included in the estimate of fatigue life. The fatigue life of critical parts is thus based on time to crack initiation and must therefore be reliably established in order to avoid not only uneconomical premature retirement but also failure during engine operation. This is accomplished by evaluation of high time parts and refinement of analytical techniques. These parts are taken from bench development engines, accelerated service test engines, and production engines and are sometimes tested to destruction. These test programs can be used as evidence in support of life-limit recommendations that are reviewed periodically and, if appropriate, adjusted accordingly. With analytical support, favorable test and service experience may lead to life extensions. Conversely, if experience indicates that life-limits are too high, they may be reduced.

5.2 (Continued):

Recommendations for life usage monitoring are based upon the need to accumulate data on service history and associated mission profiles for specific engine parts. Such data banks enable the assessment and correlation of life prediction with actual engine usage. This approach usually involves the recording and analysis of engine usage data during service operation. This can result in the adjustment of service lives and inspection intervals. This procedure is already practiced for military engines and provides a monitor on fleet trends should service usage change.

Recent advances in analytical techniques, coupled with the advent of lightweight on-board computers, have created the conditions for a more accurate and individual treatment of engine life usage prediction.

5.3 Mission Profile Analysis:

Missions are composed of common basic modes including engine start-up, taxi, takeoff, climb, cruise, landing, and shut-down. Other elements may need to be considered if the engine is used for VTOL or thrust reversing. Engine life usage must be determined for each flight mode. The life usage during each of these flight modes will depend on the type of aircraft and whether it is performing in a military or commercial role.

Mission profile analysis is typically performed by:

- a. Recording the relevant in-service engine and aircraft parameters to refine the initial theoretical mission profile.
- b. Reconstructing, analytically, the mission ingredients until they have a high statistical probability of fitting a large percentage of actual mission profile data, including extreme points.

The collection of data for different classes of aircraft can have additional benefits including the establishment of design goals for new engine types.

5.4 Life Optimization:

Most engine manufacturers have service life extension programs for life-limited parts. This is achieved by re-analysis of stress data, inspection of high-time service parts, and sampling and testing of parts from lead-the-fleet engines parts where available.

The initial life of a particular engine part is declared when the predicted safe life has been substantiated through detailed analysis, rig testing or service sampling programs or both. If increases to life are established, the manufacturer amends his overhaul manual to reflect this.

5.4 (Continued):

If engine operation is less severe than that on which the initial life-limits are based, then benefits, in addition to the general 'life growth' program of the engine manufacturer, can be enjoyed. Both hourly and cyclic life benefits can be realized for the components that reach their peak stress levels during takeoff. By using an appropriate life factor, agreed to by the manufacturer for the specific engine power level, extended use of critical life-limited parts can be achieved. Conversely, where an engine is subjected to high stress levels, for example, crew training or operating above maximum rated power, the critical part life usage must be increased in accordance with the rules of the engine manufacturer and appropriate regulatory agencies.

Examples of the application of life adjustments for commercial airline operators of one particular engine type are:

- a. When takeoff power is limited to between 90 and 95% of normal takeoff rated power (i.e., 5 to 10% de-rated), a rotating component life factor of 0.93 may be applied to both the cyclic usage and the hourly usage, thus providing a life dividend to the operator.
- b. When the actual takeoff power used is greater than the normal takeoff power rating, it is necessary to record this flight as being equivalent to six cycles at normal takeoff power rating. (Note that each OEM will recommend their own penalty, for their particular engine type, to the airline operators.)
- c. Conversely, when rotor speed or temperature limits are exceeded, operators are obligated to remove the engine for dimensional or metallurgical inspection. Further usage of affected parts is dependent on the degree of limit exceedance, duration of event and inspection findings. Parts may be returned to service at a decreased remaining life or scrapped depending on the manufacturer's recommendation.

To benefit from using reduced power takeoffs, it is necessary to keep detailed records of the power used for each flight. This can be an enormous data capture task for any recording system, but lends itself readily to analysis using an engine monitoring system. This approach requires the agreement of the engine manufacturer.

5.5 Life Usage Measurement:

With current, mature technology, it is feasible to measure engine life usage with engine monitoring systems. However, it is necessarily over-conservative because many approximations and assumptions are made. New and emerging technology, such as fast on-board computing capabilities and artificial intelligence, enables a much more accurate measurement to be made. This section discusses the requirements for computing engine life usage during flight in real-time or post-flight in a ground station using recorded flight data.

- 5.5.1 Low Cycle Fatigue: Any discussion of LCF life usage monitoring would be incomplete without mentioning the stresses caused by thermal gradients, differential expansions and centrifugal loads. Currently, work in the area of thermally induced LCF represents a major part of routine stress and life analysis of rotating parts. However, for simplicity, this document concentrates on mechanical LCF

5.5.1 (Continued):

If it is assumed that the most damaging stress levels in an engine part are primarily due to mechanical effects (that is, centrifugal forces due to rotor speed), then the main life usage parameter for that part is mechanically induced LCF. This would be true for a fan disk where thermal effects are negligible in comparison to centrifugal stresses. Figure 1 shows a schematic of the process used to determine the life usage of an engine part that is subjected to mechanically induced LCF. This procedure requires the use of an appropriate mathematical function that converts a speed cycle to fatigue, and a cycle counting technique that recognizes the major and minor speed cycles. The equivalent reference count is then calculated.

A reference cycle is usually defined as an excursion from zero to maximum RPM and back to zero as depicted in Figure 2. The reference line in Figure 2 defines the relationship between equivalent usage in reference cycles and peak rotor speed for a given zero-max-zero rotor speed excursion. Other lines define the usage in equivalent reference cycles for non-zero minimum rotor speeds. The usage for any one cycle can, thus, be computed.

In the very simple rpm/stress profile shown in Figure 3A, it is necessary to extract the major and minor cycles (Figure 3B) in terms of equivalent reference cycles (Figure 3C).

There are several methods for extracting the cycles from a LCF stress profile, but the Rainflow method is the most widely accepted and successful method. The success of the Rainflow method evolves from its ability to count all cycles, and to identify the minimum and maximum stresses and strains for each cycle. The variation of mean stress as well as the variation of the stress/strain range must also be identified. This is conveniently achieved using the Rainflow method, which calculates the mean of each cycle by averaging the highest and lowest peaks of each cycle.

To understand the principle of the Rainflow method, the time-history stress or strain profile is turned through 90° so that the time axis is vertically downwards (see Figure 4). The profile is now imagined to be a series of pagoda roofs, falling to the ground. The rainflow must stop if it begins at a peak that is a local maximum, and if it falls on another maximum peak that is more positive than the originating peak, as shown in case /1/. Similarly, if the rainflow begins at a peak that is a local minimum it must then stop when it falls on another minimum peak that is more negative (case /2/). The rainflow must also stop if it meets the rain from a roof above (case /3/).

For mechanically induced LCF, rotor speed alone is sufficient to determine the usage. However, cycle counting methods more sophisticated than the Rainflow method are needed to deal with thermally induced LCF because of the possibility of negative stresses, although Rainflow still works if the parameter used is calculated stress.

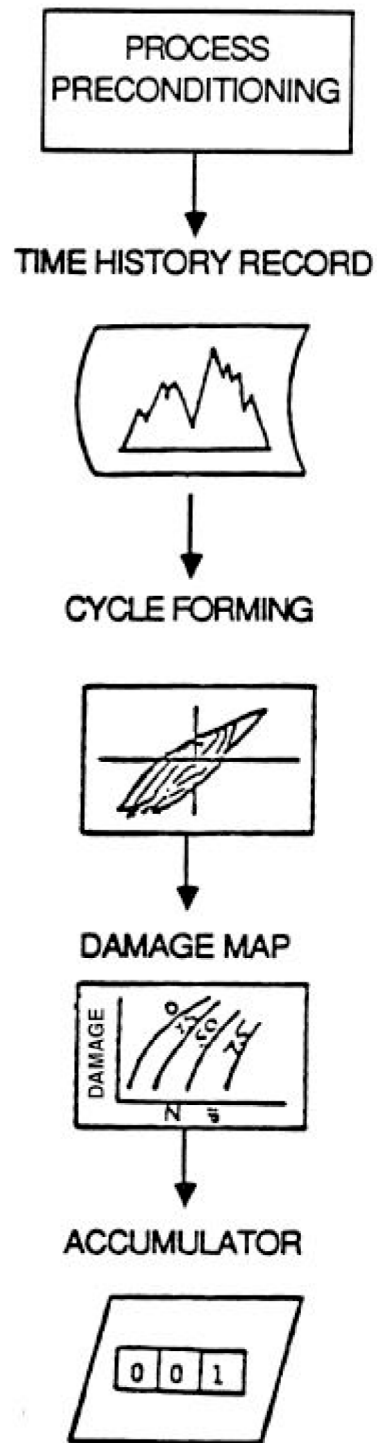


FIGURE 1 - Mechanical LCF Algorithm

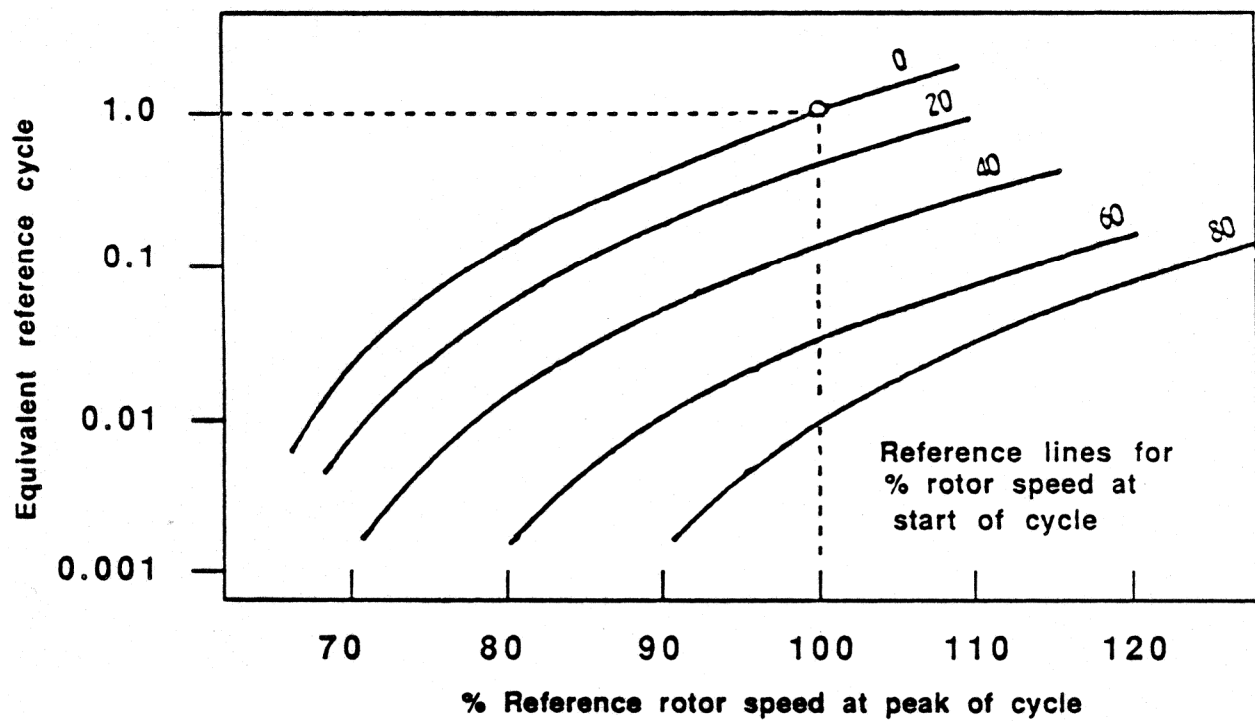


FIGURE 2 - Typical Map Structure