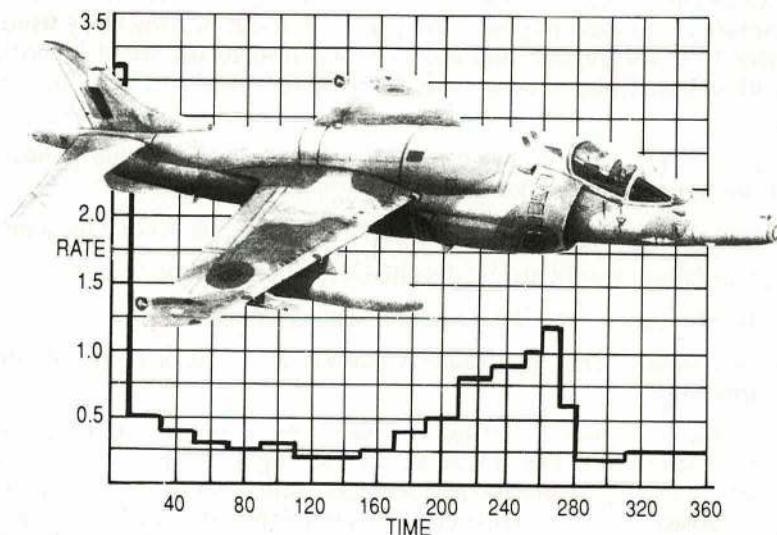


CHAPTER 3

ENGINE HEALTH MONITORING



Introduction

1. Engine health monitoring is a relatively new approach to aircraft engine maintenance. Its purpose is to keep engines under constant observation by continually monitoring them for wear and deterioration throughout their service life. This is achieved by using a number of inspection and monitoring techniques, some of which are new, and have been devised specifically for this purpose, and others that have been used for many years, but whose examination procedures have been updated. Two examples of updated procedures are: the examination of engine oil filters, and magnetic detector plugs. Engine oil filter examination was carried out on the earliest types of engine, and magnetic detector plugs, which collect ferrous metal particles contained in the engine oil, have also been used for many years. However experience has shown that their potential for establishing *trends in engine wear* was, until recent years, either overlooked or not completely appreciated.
2. To determine engine wear trends it is necessary to maintain records of the types and amounts of metal particles arrested by these collection devices. Such records were never kept. Wear trend recording is now considered to be an important part of engine health monitoring. In fact, it can very often indicate the possibility of the imminent failure of an oil system component.
3. Engine health monitoring covers the whole spectrum of engine operation, and includes:
 - Monitoring the engine oil as it circulates through the oil system.
 - The recording of engine performance, and instances of parameters being exceeded during flight.
 - Accurately assessing the low cycle fatigue consumption of the engines major rotating assemblies.

4. These and other inspection monitoring techniques may be included in the monitoring programme of an engine. An engine or module that is being maintained 'on condition' invariably requires one or more of the health monitoring techniques to be carried out during its maintenance programme.

On Condition Maintenance

5. In recent years ease of maintenance has become a major consideration in the design and operation of aircraft gas turbine engines. The present trend is moving away from the practice of a fixed overhaul life for engines and components. Instead the trend is moving toward a policy of 'condition based maintenance' usually referred to as 'on condition maintenance' (OCM).

6. Components that are selected to be maintained under a 'Fixed life policy' must satisfy one or more of the following conditions.

- That the component has a history of failure after it has been in service for a period of time.
- That an incipient failure would not be detected by condition monitoring.
- That the results of component failure would be catastrophic.
- That component replacement at scheduled periods would be a financial advantage, and improve serviceability.

7. All engines and components that do not meet any of the above requirements will be maintained on an 'on condition basis'. OCM permits an engine to be in operation continuously and be subject only to minor repairs and adjustments, until a major fault or the possibility of a component failure arises. In order to proceed with confidence with an OCM policy, the engine condition must be constantly monitored, and the onset of any mechanical failures detected at an early stage.

Factors Affecting Engine Condition

8. There are a number of factors that affect an engine's condition throughout its life. These can be sub-divided into groups as follows:

- Factors which arise through engine usage:
 - Mechanical wear.
 - Erosion.
 - Corrosion.
- Factors that can be evaluated throughout the engine or component life.
 - Low cycle fatigue.
 - Thermal fatigue.
 - Creep.
- Unpredictable failures.
 - Random faults.
 - FOD.

9. The factors in the first group can be assessed by the application of engine condition monitoring techniques. Those in the second group can be monitored by the use of in flight data recording systems. The third group can often be detected by a combination of both of the above procedures.

Condition Monitoring

10. Condition monitoring is a procedure that uses a variety of inspection techniques for gathering, assessing and recording information concerning the internal condition of aero engines and their related components during their operational service. A number of techniques may be applied to each type of engine, and one technique can very often be used to supplement another.

11. The purpose of condition monitoring is to detect an impending mechanical failure in its early stages, thus enabling remedial action to be taken before serious damage is sustained. Condition monitoring increases reliability and alleviates the possibility of an in flight failure occurring.

12. **Inspection techniques.** The inspection techniques used during condition monitoring can be divided into three groups; these are as follows:

- **Oil system monitoring;** engine and gear boxes, (bearings, gears and shafts).
 - Magnetic detector probes.
 - Oil filters.
 - Spectrometric oil analysis.
 - Ferrography.
- **Visual examinations;** compressors, turbines, inlet guide vanes, and combustion chambers.
 - Boroscope.
 - Video.
- **In flight monitoring;** engine and components, and engine systems.
 - Engine usage monitoring system (EUMS MK 1 and MK 2).
 - Engine monitoring system.
 - Quantitative debris monitoring.
 - Low cycle fatigue counter.

EARLY FAILURE DETECTION

General

13. Early Failure Detection (EFD) is the collective term used to describe the techniques and procedures that are used to monitor the oil system of gas turbine engines and gear boxes for failure. Failure of the oil washed components, such as gears, bearing and shafts, can usually be attributed to local over-stressing and fatigue.

14. The high stress levels that are experienced in aircraft engines during operation, places great demands upon their component parts. Rapid throttle operation and changes in aircraft attitude, result in stress loadings of varying intensity within exceedingly short periods of time. This may be illustrated for example by the stresses generated between the contacting surfaces of ball and roller bearing races, which may be subjected to stresses as high as 24600 kgf/cm² (350 000 lbf/in²). The working surfaces of gear teeth, may also be highly stressed typically from zero to 14000 kgf/cm² (200 000 lbf/in²) during the meshing cycle. Such high stress concentrations promote wear and occasionally component failure.

15. **The failure process.** Oil lubricated components such as gears and bearings normally fail due to surface fatigue and the failures follow a predictable pattern. The process commences with the appearance of minute cracks in the working surfaces which are caused by the repeated application of cyclic loads. The cracks propagate across and into the effected surface until minute fragments of the surface, which are bounded by the cracks, are lifted and carried away by the lubricating oil. The resulting pit in the affected surface becomes a stress concentration and further degradation of the surface progressively occurs. The particles shed from the damaged surface gradually increase in size and quantity, as the component surface deteriorates. The process continues until the part is structurally weakened to the point of failure. It is not expected in these instances for failure to occur abruptly, but it is likely to be preceded by small local failures, and the shedding of surface material.

16. The continual circulation of the lubricating oil retards failure and secondary damage, by carrying away the failed particles, thus preventing the contamination of sound components. The period from the initial surface rupture to complete component failure is known as the 'Failure Detection Period'.

Magnetic detector probes

17. It will have become apparent from the foregoing paragraphs that the engine oil, as it circulates through the lubrication system is an obvious source of information on the condition of the oil washed engine components. If this information is gathered and analysed it will give adequate warning of most of the internal component failures that occur. To this end magnetic detector probes (MDPs), that can be removed for examination are installed at selected points in the oil system. The magnetic probes attract and retain ferrous particles that are carried around the system in the oil flow. The MDPs are removed at prescribed intervals, and the metal particles that have been arrested by them are examined and analysed. The results of the analysis give a reliable indication of the wear and condition of the engines oil system components. This EFD technique is currently the one most widely used by the RAF in support of engine health monitoring.

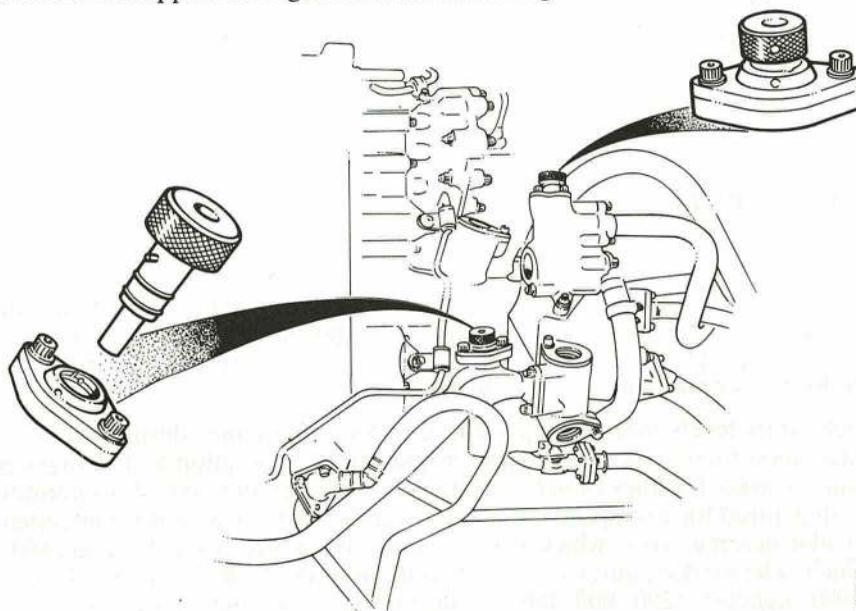


Fig 7.3.1 Magnetic detector probes

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18. **Description and operation.** The magnetic detector probe, (also referred to as the magnetic chip detector) is an assembly consisting of a housing and a removable detector probe (Fig 7.3.1). The housing, which incorporates a spring loaded valve, is fitted into the engine oil system or the component being monitored. The detector probe consists of an aluminium alloy or steel body that is machined to accommodate a small, but strong magnetic probe. The body has grooves machined around its outer surface which retain oil sealing 'O' rings. It may also incorporate small protruding pegs or bayonets that retain the detector probe within the housing (Fig 7.3.2). This type of detector probe is removed for inspection by manual inward pressure, and a partial turn of its knurled base. As the probe is withdrawn from the housing, the spring loaded valve closes, preventing the loss of engine oil. This is a simple operation, but it must be carried out with care to ensure that the ferrous particles attached to the magnetic probe are not distributed or lost during the removal operation.

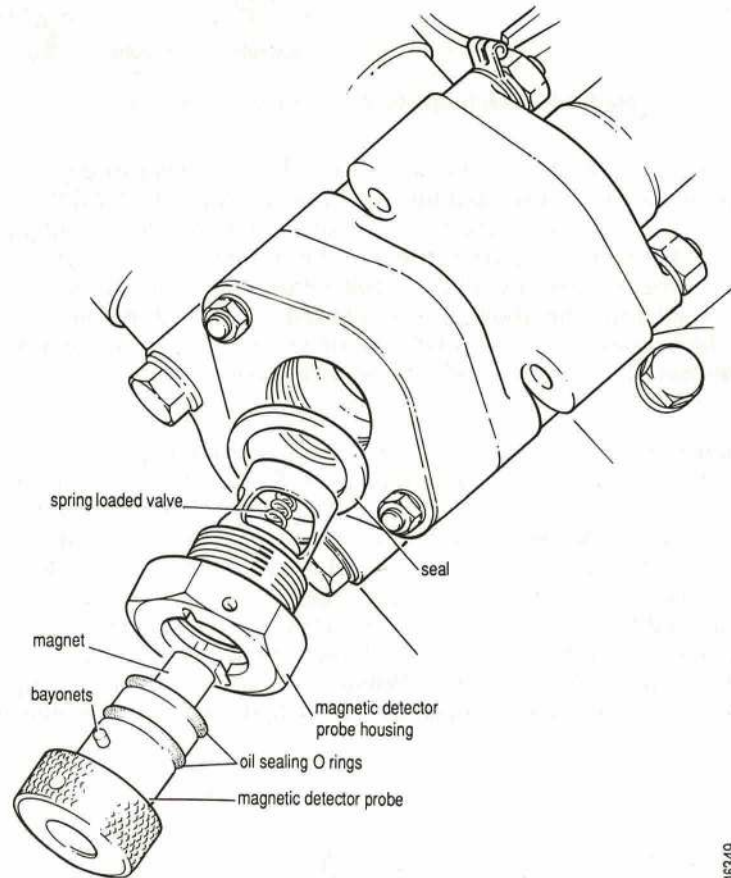


Fig 7.3.2 Magnetic detector probe and housing

19. The effectiveness (or catch efficiency) of the MDPs depend largely upon two factors which are: the strength of the magnetic probe, and its position in the oil system. Ideally MDPs should be positioned where the oil flow rate is locally reduced and slightly turbulent. Such conditions are created by incorporating a small chamber at selected points in the oil system into which an MDP is located (Fig 7.3.3a). Another location that ensures a good catch efficiency is to situate the MDP on the outside bend of an oil pipe, where the metallic particles in suspension have a tendency to be centrifuged towards the probe tip (Fig 7.3.3b).

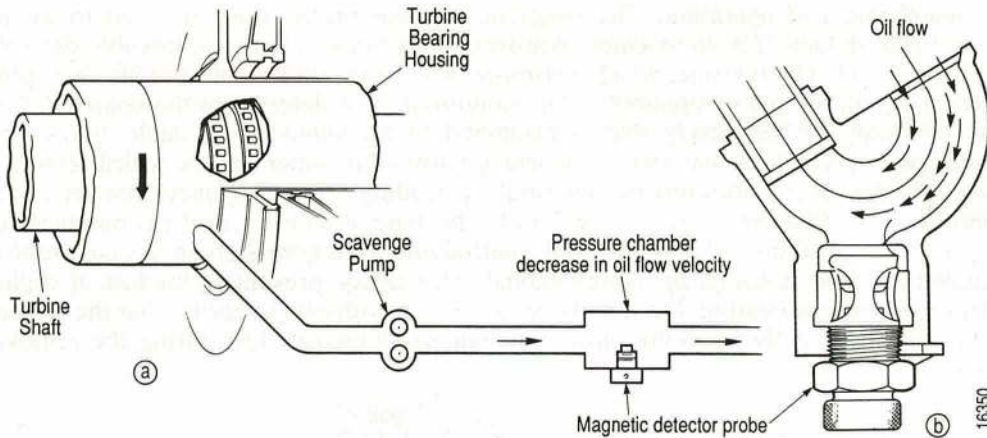


Fig 7.3.3 Ideal magnetic detector probe locations

20. The catch efficiency of MDPs also varies with different types of engine. During tests carried out on an oil system constructed for test purposes, into which MDPs were correctly located, the catch efficiency was found to be in excess of 80 per cent of all particles of 200 microns and larger that had been introduced into the system. In a well designed oil system, fitted to the newer types of operational gas turbine engine, a catch efficiency of 70 per cent of the particles 200 microns and above, can be expected. This figure however, is somewhat lower on some older types of engine where the oil system was not originally designed for MDPs, but MDPs have been introduced by a Service modification.

21. **Electric MDPs.** Electric MDPs (Fig 7.3.4), were introduced to provide an in flight warning to the pilot if an excessive accumulation of ferrous particles is present in the oil system, which could possibly indicate an incipient engine failure. Electric MDPs have external electrical wiring that is connected to the base of the plug which energizes two electrodes within the MDP. Generally, the magnetic probe serves as one electrode, and the side wall of the probe body serves as the other, (there are variations to this arrangement). The probe is insulated from the body by a di-electric material. Ferrous particles that are attracted to the magnetic probe, if they are large enough or in sufficient quantity, will bridge the gap between the two electrodes. When this occurs, a circuit is completed, and an indicator illuminates on the caption panel in the cockpit, warning the pilot of a possible imminent failure.

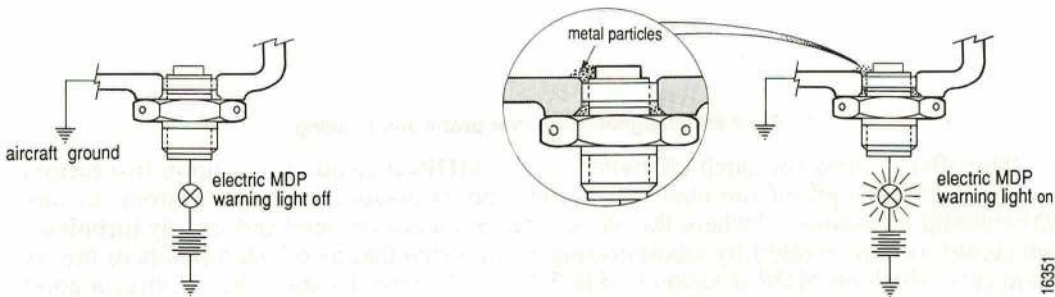


Fig 7.3.4 Electric magnetic detector probe

22. These types of MDP were used with varying degrees of success by civil aircraft operators. It became apparent during their operations that a warning on the caption panel, indicating that the electrodes had been bridged, did not necessarily indicate an impending component failure. It could be, (and often was) caused by an accumulation of 'normal wear fuzz', which are microscopic ferrous particles that are generated in all power gear train systems. However, these indications caused serious concern to flight crews who, in a number of instances carried out emergency landings, which subsequently proved to be unnecessary. In recent years their design has been improved, and they are now used by the Service in aero-engines and gear boxes on some types of helicopters.

23. **Removal and inspection of MDPs.** On removal the MDP is given an initial examination by the technician to ascertain if the amount of debris deposit collected on the plug is acceptable. If this is so, the MDPs are placed in a special container, (taking care not to disturb the debris particles), and the required documentation is completed. The plugs are then despatched to the Early Failure Detection Centre (EFDC). If when removing the MDP, the technician considers that the amount of metallic debris indicates a serious build up he will inform his supervisor, who, if necessary, will quarantine the aircraft pending further investigation. The MDP is then placed in the container and dispatched to the early failure detection centre for priority attention. When an MDP is removed from an oil system for examination it is immediately replaced with a serviceable, clean MDP that is provided in the special storage container.

24. **Magnetic drain plugs.** Magnetic drain plugs have been adapted from conventional oil drain plugs on some types of older engines. The drain plugs have been redesigned to include a magnetic probe protruding from the centre. Magnetic drain plugs are usually screwed into the oil sump housing, and safety wire locked. As would be expected, their catch efficiency is not as high as those in purpose designed systems.

Oil Filters

25. Before the introduction of EHM, it was standard practice for engine filters to be removed periodically, examined for excessive metal particle deposits, and then cleaned and refitted. Any particle deposits, found in the filters were washed away and disposed of during the cleaning process. This procedure has been revised. When an oil filter is removed from an engine, it is replaced with a serviceable clean item provided by the EFDC. An initial examination of the removed filter is carried out by the technician, and it is then passed to the EFDC for further examination, in a similar manner to the MDPs (see para 23). To ensure that all evidence of wear, or of an impending failure is collected, if it is possible the oil residue in the filter housing should also be removed for analysis. This is achieved by using a syringe or some other approved method, and transferring the oil into a clean container. The container is then sealed and labelled and passed to the EFDC with the filters.

WARNING

The synthetic oils used in the vast majority of gas turbine engine oil systems contain additives which if allowed to contact the skin for prolonged periods, can be toxic through skin absorption.

CAUTION

Gas turbine engine synthetic lubricating oils are injurious to paint work and to certain types of rubber, and must not be allowed to contaminate those parts of the engine not normally in contact with oil. Any oil spill during maintenance and servicing must be removed immediately.

Early Failure Detection Centre

26. The unit Early Failure Detection Centre is a specially equipped centre, that is supervised by a SNCO, and manned by qualified operators. Their main function is to analyse the metallic debris collected by MDPs and oil filters removed from aircraft engines and gear boxes. They assess the wear trends of the components being monitored and record the results obtained. If the metallic debris analysis indicates that there is a cause for concern or that a component failure is imminent, the appropriate engineering authority assesses the information provided by the EFDC and takes the necessary remedial action. This action may take a number of forms. It may, for example, be decided that the engine should be very closely monitored, by increasing the frequency of the MDP and filter inspection. Alternatively it may be decided that the engine and/or gearbox should be removed and returned to the manufacturers for investigation. Whatever course of action is taken, it depends heavily on the information, and recommendation that is provided by the EFDC operators.

27. **EFDC operators.** In order that the EFDC operators can give an accurate assessment of the particle analysis, they require a high degree of training on both the instruments that they will be using, and the engines and gearboxes that they will be monitoring. The operators are selected technicians, normally Service NCOs who are required to spend six months in the EFDC, receiving on-the-job training from fully qualified operators. The training includes visits to engine repair shops and overhaul facilities.

28. **EFDC facilities.** The EFDC is divided into two rooms (or areas). One room accommodates the cleaning equipment and a ventilation system where the MDPs and filters are cleaned and processed. The other is the 'clean room' where the particles are analysed, and the records and charts are stored. The equipment accommodated in the clean room includes a low power stereo binocular microscope and a debris tester. The microscope is used for identifying the metal particles, and the tester quantifies the amount of debris collected by individual MDPs and filters.

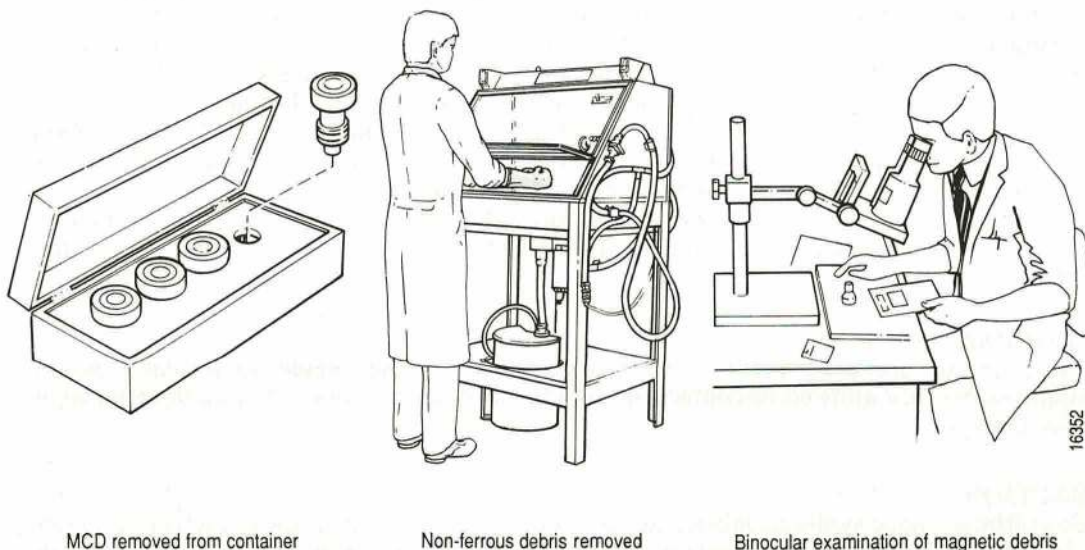


Fig 7.3.5 Cleaning and examination of magnetic detector probes

29. **Cleaning the MDPs and filters.** (Fig 7.3.5). On arrival at the EFDC the soiled MDPs and filters are removed from the storage container and placed in a transit holder, for handling and cleaning. The magnetic tips of the MDPs are very carefully rinsed in a mixture of White Spirit and Trichloroethane to remove oil and non-magnetic debris, (which is retained) and allowed to dry. The ferrous particles remain on the magnetic tip during this operation, and consequently great care must be exercised by the operator during the cleaning operation.

30. The oil filters are washed in a suitable container, with clean White Spirit and Trichloroethane, until all debris is removed from the filter. The contents of the container are then filtered through a cone shaped filter paper, supported in a funnel, and allowed to dry. With the aid of a magnet, and with further cleaning, ferrous and non-ferrous particles are separated, and prepared for inspection.

WARNING

Trichloroethane (Genklene) has a narcotic effect, therefore the working area must be well ventilated. Trichloroethane (Genklene) also undergoes a chemical change and forms harmful products when subjected to the high temperature of a flame or is inhaled through a lighted cigarette or pipe.

31. **Debris particle examination.** The debris particles are examined for identification with a binocular microscope by using 20 to 45 magnification for general work, and higher magnification for detailed examinations (Fig 7.3.6). From the size, shape, crystalline structure and surface finish of the particles, the operator can determine the source of the particles, whether they originated from gears, bearings or a shaft. The examination will also show if the particles are the result of normal wear, or the fatigue process. The operator is also able to recognize the residue resulting from fretting corrosion, which may indicate a possible spline failure. Chemicals may be used occasionally to assist in the material identification of light alloys, eg certain acids, and caustic soda solution.

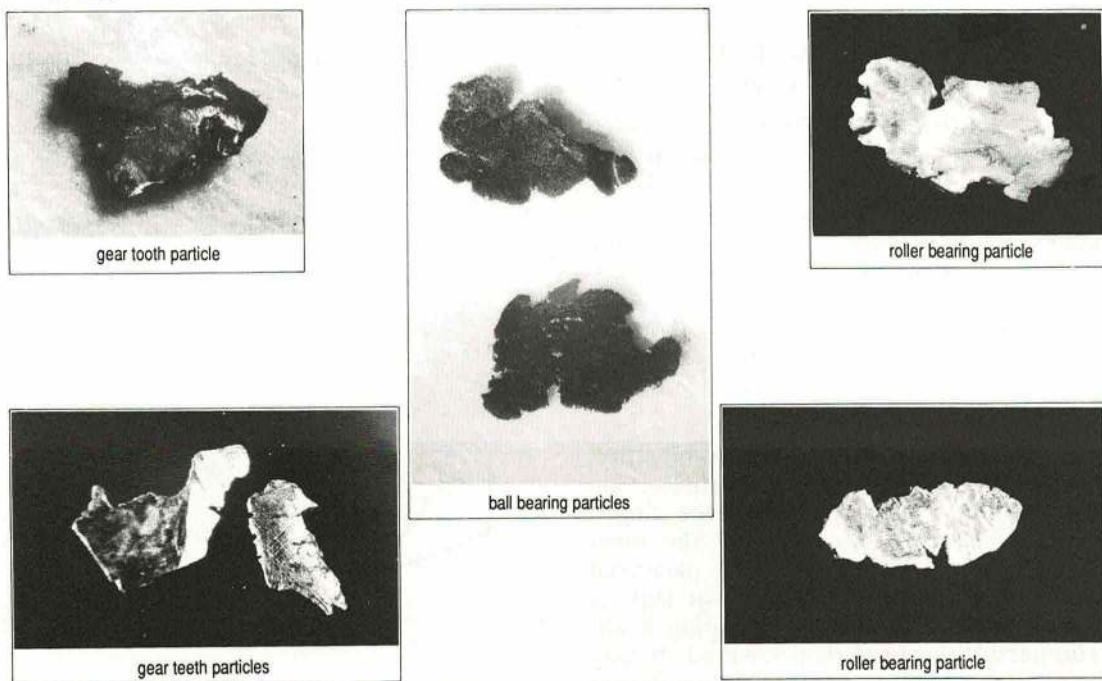


Fig 7.3.6 Magnified metallic debris particles – engine and gearbox oil systems

32. Normal wear particles consist of minute flakes and fine grindings, that are consistent in size, and are generally less than 25 microns in size, fatigue particles will vary in size but are typically between 250 and 500 microns at their largest dimension. If the particles are the result of fatigue, by comparing the mixture of fatigue debris, and the ratio of small to large particles, the operator is able to assess the severity of the failure up to the time of the inspection.

33. If the occasion arises that the EFDC supervisor requires a more precise identification of debris material than can be obtained by using the unit EFDC equipment, an independent analysis may be requested from a specialist laboratory. The laboratory, which is operated by the Ministry of Defence, is equipped with an extensive range of specialist equipment and uses techniques such as 'scanning electron microscopy' in support of their analysis; which is a technique capable of a greater depth of analysis than EFDC equipment. If the request is of an urgent nature, the laboratory will notify the originator unit of the results of the analysis, by telephone, within 12 hours of receiving the sample for analysis.

34. On completion of the visual examination and assessment, the metal particles are quantified to establish the exact amount of debris in the sample. The particles are removed from the MDPs and filter, and transferred to a small piece of transparent adhesive tape, great care being taken not to lose any of the sample particles. The tape and particles are then stuck onto a 'sample deposit slip'. When more than one piece of tape is required to collect all of the particles in the sample, each additional piece is mounted on a separate deposit slip, and suitably annotated to show that they are from the same sample.

35. **MDP test.** After the debris has been removed, the MDPs and filters are cleaned and serviced. They are then examined, and if necessary the oil sealing 'O' rings are replaced. The MDPs are then tested to ensure that the magnetic strength of the detector probes is sufficient to meet the specified requirements. The simple test requires the magnetic probes to lift and hold a number of carbon steel balls, (usually two or three) of a given diameter, that are linked together to form a chain. When the MDPs fail to lift the balls, they are scrapped.

36. After examination and satisfactory testing, a protective sleeve is placed over the magnetic probe of each MDP. The filters are usually sealed in a small plastic bag which both protects, and keeps them clean.

37. **The debris tester.** The instrument used on most units to quantify magnetic particles is the debris tester (Fig 7.3.7). Briefly the debris tester is a small, portable instrument contained in a case. It has a calibrated display meter, the necessary operating controls, and a measuring head that is protected by a hinged perspex cover. Contained within the lid of the case is a test piece used for calibration purposes. Power is provided by eight, dry cell batteries.

38. **Quantifying the particles.** To quantify, or measure the amount of particles, the debris tester is switched on and the hinged perspex cover raised, exposing the measuring head. The sample to be measured which is attached to the deposit slip, is placed face down on the measuring head. The perspex cover is then lowered. It may be necessary to move the sample to different

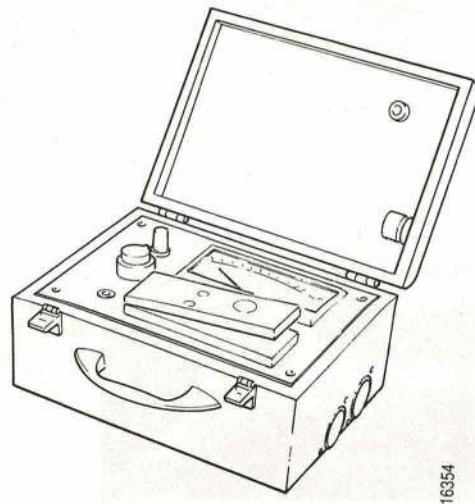


Fig 7.3.7 Debris tester

positions on the measuring head, to obtain the maximum reading on the display meter scale. When the maximum reading is achieved, the scale reading is recorded on the sample slip. The sample quantity, or measurements, are recorded in Debris Tester Units (DTUs).

39. **Documentation.** It is essential that accurate records of the metallic particle deposits, are compiled and retained for future reference. The particles that are secured to the deposit slip by the adhesive tape, are therefore kept in a condition that would permit them to be reassessed, if this should subsequently be required.

40. The supporting data is also entered on the record slip and must include: the date, component details, particle quantification and wear rate, and the technicians written assessment of the test results. On completion of the test, the record slips are attached to a record sheet. There is no specified mandatory format for record sheets, although a number of suggestions are offered in Specialist Air Publications. Two types of record sheets in current use are illustrated by Figs 7.3.8, and many variations of these have been evolved to suit the requirements of the various units.

STC FORM 1181A *AERO-ENGINE/EQUIPMENT MAGNETIC PROBE RECORD			
*AERO-ENGINE OR EQUIPMENT TYPE	SERIAL No	CARD SER No	MAGNETIC PROBE No
HRS ON INSTALLATION		DATE INSTALLED	A/C No
*ENGINE EQUIP	A/C		
1			
2			
3			
4			
5			
6			
*delete as necessary			
STC FORM 1181A			
A/C No _____	DATE _____		
ENGINE/EQUIP HRS _____			
PLUG/FILTER/GEARBOX/CSDU _____			
REMARKS _____			

STC FORM 1240 EFDC HISTORY CARD			
ENGINE SERIAL No _____		CARD SER No _____	
INSTALLATION DETAILS			
A/C No _____	A/C No _____	A/C No _____	
DATE _____	DATE _____	DATE _____	
A/F HRS _____	A/F HRS _____	A/F HRS _____	
ENG HRS _____	ENG HRS _____	ENG HRS _____	
Date _____ Hrs _____	REMARKS	Date _____ Hrs _____	REMARKS
M.O.e		M.O.e	
1. Internal Gearbox _____	1	1. Internal Gearbox _____	1
2. Turbine Bearings _____		2. Turbine Bearings _____	
3. External Gearbox _____	2	3. External Gearbox _____	2
Sub Total _____		Sub Total _____	
B/F Total _____	3	B/F Total _____	3
Total _____		Total _____	
1	2	3	1
Date _____ Hrs _____	REMARKS	Date _____ Hrs _____	REMARKS
M.O.e		M.O.e	
1. Internal Gearbox _____	1	1. Internal Gearbox _____	1
2. Turbine Bearings _____		2. Turbine Bearings _____	
3. External Gearbox _____	2	3. External Gearbox _____	2
Sub Total _____		Sub Total _____	
B/F Total _____	3	B/F Total _____	3
Total _____		Total _____	
1	2	3	1
Date _____ Hrs _____	REMARKS	Date _____ Hrs _____	REMARKS
M.O.e		M.O.e	
1. Internal Gearbox _____	1	1. Internal Gearbox _____	1
2. Turbine Bearings _____		2. Turbine Bearings _____	
3. External Gearbox _____	2	3. External Gearbox _____	2
Sub Total _____		Sub Total _____	
B/F Total _____	3	B/F Total _____	3
Total _____		Total _____	
1	2	3	1

Fig 7.3.8 Examples of EFDC record sheets

41. **Debris trend plotting.** A number of graphs are used by EFDC operators to assist them in making their test assessments of the debris particles. Two typical examples are:

- Total debris accumulation curve.
- Wear trend histogram.

42. **Total debris accumulation curve.** The total debris accumulation curve (Fig 7.3.9) is a simple curve that is obtained by adding the DTU results from the current check, to the total quantity recorded from previous checks. When the total is plotted against the engine running hours, the curve follows an ascending line. Changes in the slope of the curve correspond to changes in the wear rate.

43. **Wear trend histogram.** Changes in wear can be effectively illustrated by a histogram (Fig 7.3.10) on which the columns depict the average wear rate for each succeeding inspection.

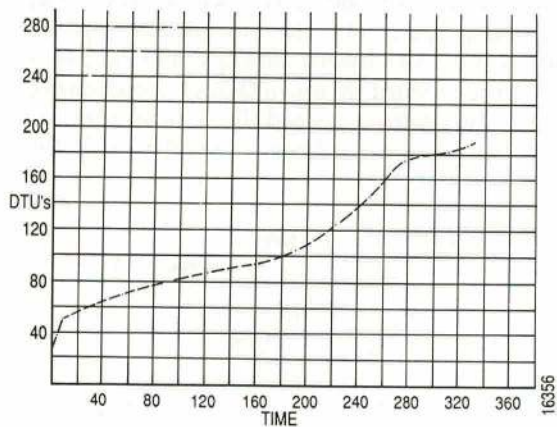


Fig 7.3.9 Total debris accumulation curve

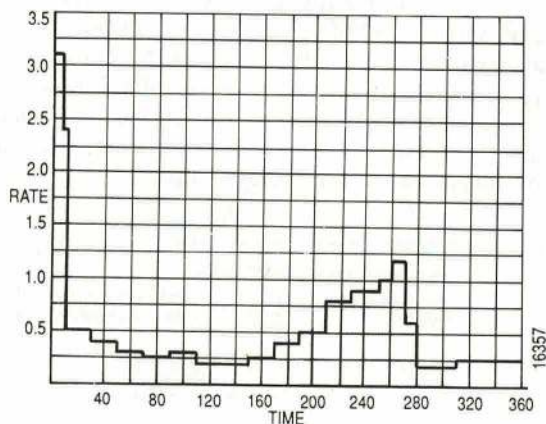


Fig 7.3.10 Wear trend histogram

44. **Additional EFDC functions.** The EFDC has a number of other functions that vary with the type of aircraft located on the unit. The following are some of the tasks that the EFDC may be called upon to carry out.

- Control the spectrometric oil analysis programme.
- Testing of hydraulic fluid for contamination.
- Testing of engine oil for fuel contamination.
- Raising charts and graphs for vibration analysis results and maintaining records.

Spectrometric Oil Analysis Programme

45. The purpose of the Spectrometric Oil Analysis Programme (SOAP) is to determine the degree and rate of wear, and to detect signs of possible impending failures of the oil washed components. It has been previously stated that when moving metallic parts are in contact with each other, wear of the parts occurs. As a result of this wear, microscopic particles of wear metal are produced from the parts and disperse into the lubricating oil. The wear particles are too small and too numerous to be removed by the previously described MDPs or filters, they therefore remain in suspension in the engine or gearbox oil. It is the wear particles that range from one up to ten microns in size that are analysed by SOAP.

46. The SOAP procedures require a sample of engine or gear box lubricating oil to be taken from the oil system at periodic intervals and to submit the sample for analysis at a central laboratory. The SOAP sample is taken from the oil tank by using a small disposable plastic syringe, or by some other approved method. The sample item is transferred into a plastic bottle securely capped and passed to the EFDC. The EFDC sends the sample accompanied by the necessary documentation to the MOD central laboratory for analysis. The analysis assesses the amounts and types of metal particles in suspension in the engine or gear box oil.

47. **SOAP sample analysis.** The analysis of the oil sample is carried out by the RAF SOAP team, who are SNCO's specially trained to carry out the task. The type of machine used to analyse the oil sample is an atomic emission spectrometer (called an Inductively Coupled Plasma Spectrometer), which is capable of detecting the main basic metallic elements (known as trace elements) of the metal particles contained in the oil sample and the quantities in which they occur.

48. **Spectrometers.** The atomic emission spectrometers operate on the principle that all basic metallic elements radiate light at their own characteristic wave length when they are excited by the application of heat. The spectrometer burns a sample of engine oil, and by analysing the radiated light establishes the types of element contained in the sample, (e.g. chrome nickel, iron, copper etc). The intensity of the radiated light produced by this process determines the quantity in parts per million of each element contained in the sample. If, for example, a metallic particle is an alloy of three different metals, then the particle will radiate light on three different wavelengths when analysed by the spectrometer.

49. The results obtained from the spectrometer analysis are entered into a computer that is programmed to compare these readings with the stored results obtained from previous analyses on the same engine. As each succeeding analysis is carried out and entered onto the computer record, a wear trend of the engine oil system components is established. The computer is programmed with a number of 'Alert parameters' which are the maximum amounts of particles that are permitted in the oil sample. When these limits are reached the computer automatically flashes an alert, and issues a printout of the stored record.

50. The SOAP team will only pass the results of the analysis to the EFDC of the originating unit if the results of the oil sample are abnormal. In such cases the SOAP team liaise with the unit EFDC either by telephone or signal. The team may possibly request further information, or they may make recommendations on further action that the unit may need to take based on the SOAP test results.

51. **Taking the oil sample.** The diagnosis of the health of an engine or component by SOAP, can only be reliable if care is exercised when the SOAP sample is taken, and if the documentation is correctly completed. To be of any use whatsoever, it is essential that the oil sample is representative of the oil circulating through the engine or component when it is in use. Great care and attention must be taken therefore, to ensure that the sample, and the sampling kit, are not contaminated with oil or metal particles from any other source. The sample must also be taken whilst the oil is hot, and within 15 minutes of engine shutdown. It must also be taken before replenishment oil is added to the system.

Ferrography

52. Ferrography is an engine health monitoring technique that is used to analyse samples of engine and gear box oil. It detects the type and quantity of metallic particles (measuring from 5 to 100 microns in size) that may be circulating through the system in the oil. The technique entails diluting a sample of engine or gear box oil with an emulsifier, and passing the sample through an instrument that is designed to extract the wear particles magnetically from the fluid.

53. **Ferrography principle.** Ferrography is based on the principle that if a sample of used

engine oil flows through an inclined tube, that is positioned in a magnetic field of varied strength, the magnetic particles in the sample will be deposited along the tube, according to their size. The *largest particles* will be arrested as they enter the field where the magnetic force is *weakest*. The remaining particles will be deposited along the tube as the field strength increases, the smallest particles being the last to be arrested. The simple method of varying the magnetic field strength depends upon the angle at which the tube is inclined in the flux field that emanates from the source magnet (Fig 7.2.11). There are two types of ferrography, these are:

- Direct reading ferrography.
- Analytical ferrography. (Indirect reading).

54. **Direct reading ferrography.** A sample of lubricating oil taken from an oil system is pumped through a precipitator tube (Fig 7.3.12), the fluid being allowed to run to waste after the metal debris has been extracted from the sample. Two photo sensors measure the concentration of large and small particles at two points of the tube, and the results are viewed on a digital readout indicator. Particles larger than 10 microns will be deposited at the upper end of the tube, where the magnetic field is weakest. The results are displayed on the indicator

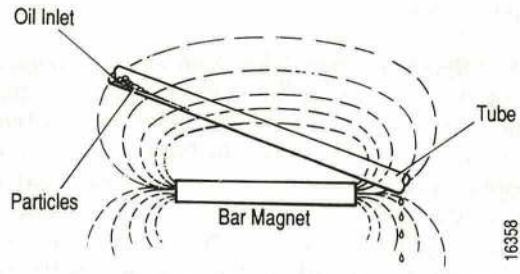


Fig 7.3.11 Ferrography principle

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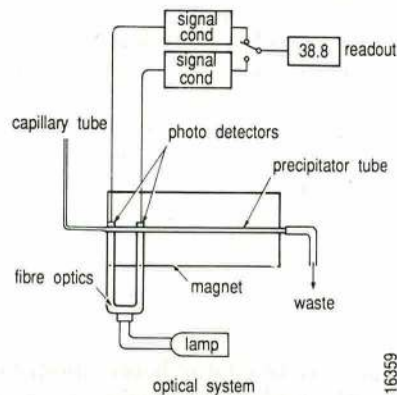
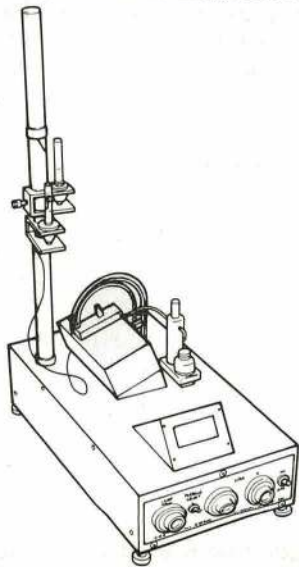


Fig 7.3.12 Direct reading ferrography

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as readout 'L'. The second sensor, which is located further along the tube where the magnetic force is stronger, measures particles up to 10 microns in size, and is displayed as readout 'S'. The values of 'L' and 'S' then are compared with the results recorded from previous sample checks. A significant departure from the normal wear pattern may indicate a potential component failure, and an in-depth analysis of the results will then be required.

55. **Analytical ferrography.** Analytical ferrography employs a principle similar to direct reading ferrography described in Para 54, but it is a far more accurate and reliable technique. There are two major differences which are: firstly the precipitator tube, and the optical sensors, are replaced by a chemically treated slide, that is supported at an angle above and within the magnetic field of a permanent magnet (Fig 7.3.13). Secondly the debris particles are analysed by operators.

56. **Analysing the sample.** A sample of engine oil is diluted with emulsifying fluid and heated. Heating the oil sample reduces its viscosity; which encourages it to flow, and also decreases the adhesion of the oil to the particles. The sample is then agitated to disperse the particles, and then pumped over the slide. As the oil flows down the slide, ferrous particles are separated from the oil and deposited, influenced by the magnetic field. The particle deposits adhere to the slide reducing in size as the field strength increases. When the complete sample has passed over the slide, it is removed from its mounting, and analysed by experienced operators, by using a binocular microscope. Electrostatic force binds the particles to the slide enabling it to be handled and analysed without the particles becoming detached from the slide. However, a fixing solution is available if required.

57. Analytical ferrography is an interpretive technique and the success of the analysis that is carried out depends upon the experience and efficiency of the operator. The major advantage of ferrography is that it isolates particles from the oil sample from between 5 microns and 100 microns in size, and fills the gap between SOAP, and the MDPs and the oil filters (Fig 7.3.14). However the advantages of this are outweighed by a number of disadvantages. Firstly, each sample takes approximately one hour to analyse, thus making it a time consuming technique in comparison to SOAP and MDP techniques. The technique also suffers from poor repeatability.

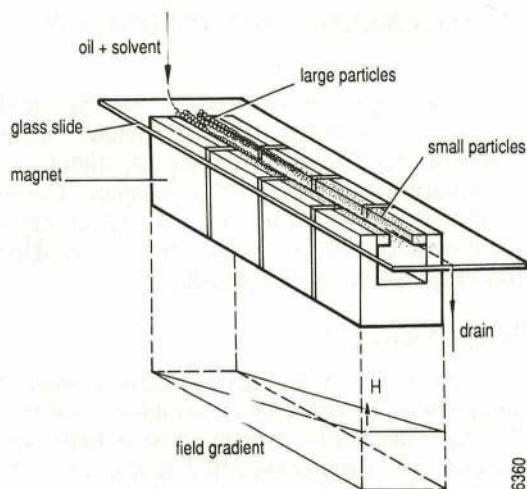


Fig 7.3.13 Analytical ferrography

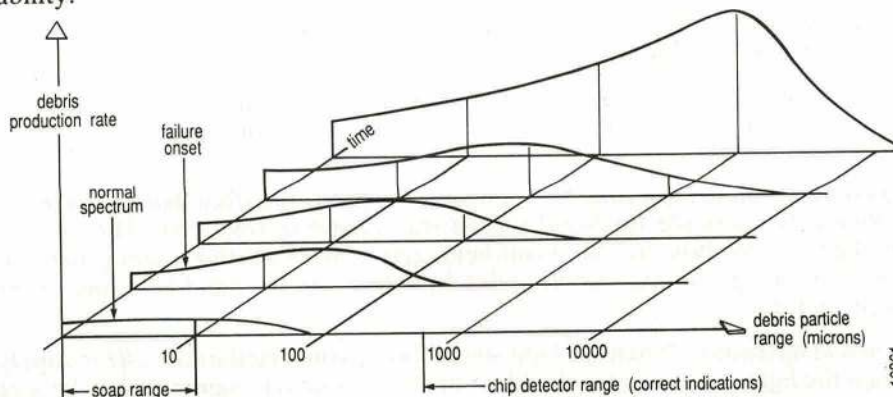


Fig 7.3.14 Debris particle spectrum

VISUAL EXAMINATION TECHNIQUES

General

58. All engine maintenance and servicing depends largely upon visual examination. Although in recent years great advances have been made in fault detection equipment, and in condition monitoring techniques, there are and always will be, areas requiring visual examination by the trained technician. The majority of visual examinations can be performed effectively by using a hand torch and an inspection mirror. There will be times however, when it will be necessary to employ visual aids. These range from optical viewing aids, to techniques that employ video photography.

Optical Viewing Aids

59. Optical viewing aids, (or boroscopes) enable remote viewing of areas on aircraft and engines where access for examination is difficult or inaccessible. The basic equipment consists of a viewing probe, coupled to a light source box, by a flexible light guide cable. The equipment is usually supplied as a kit, complete with a special carrying case. Although there are a number of different models of boroscopes in use throughout the Service, they fall into two basic categories.

- Fibrescopes (flexible).
- Endoscopes (rigid).

60. **Fibrescopes.** Fibrescopes (Fig 7.3.15a) are fibre optic instruments consisting of two cables through which glass fibre cores are passed, and a hand held control section. The control section has an eye piece fitted to it, that is provided with an adjustment for depth of field and focus. It also embodies an angulation control, for controlling movement of the viewing end of the instrument, (the viewing end of the instrument is called the 'Distil tip').

61. The glass fibre cores, known as bundles, consist of many thousands of thin flexible glass rods. The two glass fibre bundles are manufactured by different processes, and each performs a different function. These are:

- The light guide.
- The image guide.

62. **The light guide.** The light guide consists of a continuous glass fibre bundle that conducts light from the light source box, through the control section to the outer distil end of the instrument.

63. **The image guide.** The image guide transmits the image being viewed, and is located between the control section and the distil end.

64. Located at each end of the image guide is an optical system. At the distil end, a lens focuses the image, and gives a field of view of 51 degrees. The control section, located at the other end, houses an adjustable eye piece.

65. The glass fibre bundles are sheathed in neoprene, protected from damage by steel mesh. The inner sheath being made up from a close wound spring steel coil. The cable section between the light source box and the hand-held control is called the 'Light guide', and the cable carrying the two glass fibre bundles (side by side) from the hand-held unit to the distil tip, the 'Insertion tube'.

66. **Principles of operation.** When the light source box is connected to the 240 ac supply, light passes through the light guide bundle, illuminating the area under examination. The area to be examined is scanned by looking through the eye piece and the image guide bundle; a clear view is obtained by adjusting the focus control. Scanning of the area is achieved by operating

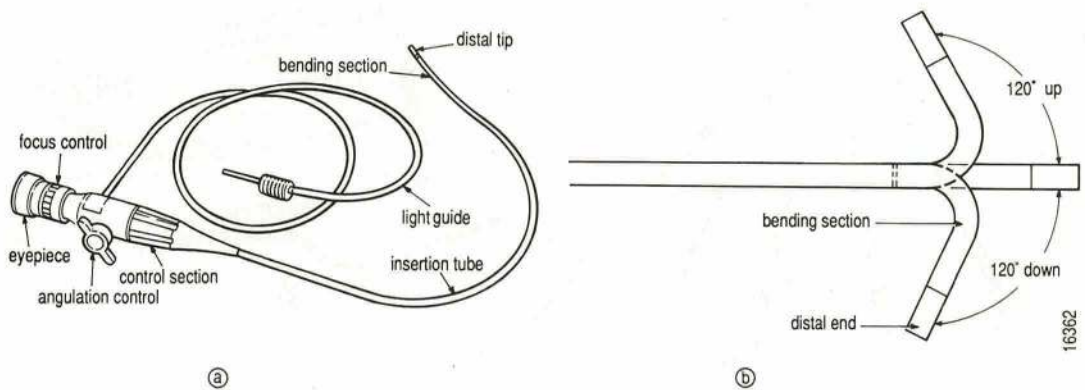


Fig 7.3.15 Fibrescope

the angulation control, which controls the movement of the distal end through 240 degrees (120 degrees in two directions) (Fig 7.3.15b). The fibre scope can be coiled through 360 degrees and still produce a clear image.

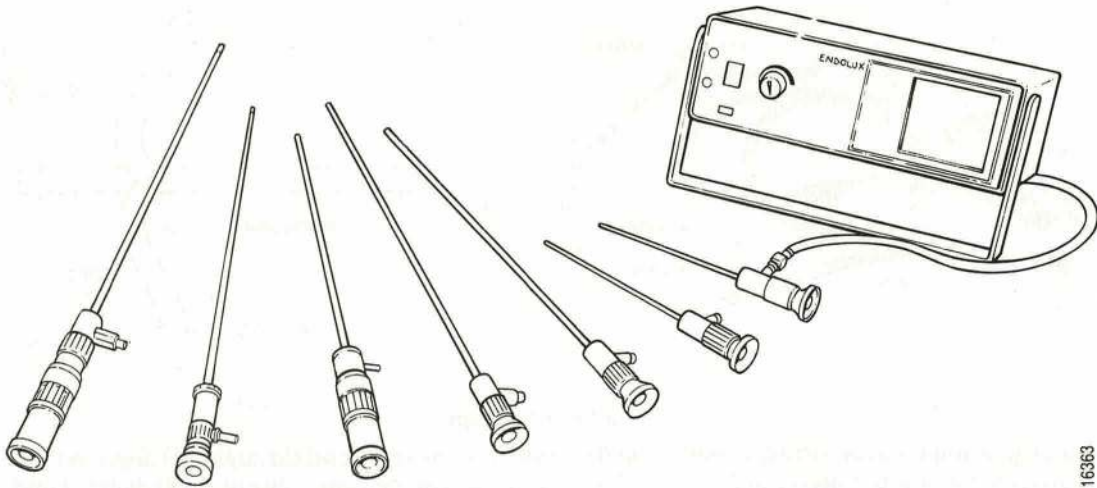
67. **Retrieval tools.** The latest models of fibrescope that are coming into service, have a built-in retrieval tool. The retrieval tool control cable passes through the centre of the insertion tube, terminating at the distal end with a retrieval claw. The claw is operated by a small lever on the control section. This enables the retrieval of foreign objects and debris (FOD) eg nuts and bolts, to be carried out in areas which hitherto may have been inaccessible. The retrieval tool can be operated whilst continuing to view the object to be retrieved.

68. **Handling of fibrescopes.** Fibrescopes are high cost instruments that require careful handling, and should never be used by unqualified personnel. There are a number of precautions that should be observed to prevent the possibility of damage. These are:

- Avoid rough handling and sharp knocks to the instrument, these can result in broken fibres in the glass fibre bundles.
 - Broken fibres in the light guide will cause a reduction of light transmission.
 - Broken fibres in the image bundle will result in black spots appearing in the viewing eye piece causing a partial loss of the image, which may mask defects.
- Great care must be exercised when inserting or removing the insertion tube, do not force it into a tight curve, which could also result in broken fibres, or the fibrescope becoming trapped.
- Fibrescopes are not recommended for use in areas of water, oil or fuel.

69. **Endoscopes.** Endoscopes are optical viewing aids that have a rigid probe that is connected to a light source box by a flexible light guide (Fig 7.3.16). The rigid probe has a focusing attachment with an eye piece located at one end, and a lens at the other. The image being viewed is relayed by a further system of internal lenses, housed within the probe body. Light is provided through a glass fibre bundle, operating in a similar fashion to the fibrescope, with the exception that the light guide cable from the light source box to the probe, is detachable. This arrangement enables a selection of probes to be fitted. The probes are supplied in various lengths, and the angle of viewing is adjusted by changing the lens piece at the probes end. Endoscopes are supplied in kit form, and transported in a special case.

70. On some models of endoscopes the light source is provided by a six volt rechargeable battery, which is carried in a leather shoulder case. The battery life between charges is three hours giving the instrument the operational flexibility required for use in the field.



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Fig 7.3.16 Selection of endoscopes

Video Viewing Aids

71. The latest visual aids techniques to be introduced into the RAF are video visual aid systems. This type of aid displays an image on a video monitor in both black and white, or colour. Since its introduction the technique has been successfully employed on aircraft fuel systems. It has correctly identified the source of fuel leaks from integral fuel tanks, and has saved the Service many hundreds of man hours, when compared to the number of man hours that were being expended when using other examination techniques.

72. **Video viewing (solid state system).** The solid state video viewing system consists of a probe, a video processor, and a visual display unit monitor. The flexible probe carries the light to the examination area, and houses at its tip a fixed focus lens, and a silicon chip sensor, called a 'charge coupled device' (CCD) (Fig 7.3.17). The CCD operates in a manner similar to a miniature TV camera, and transmits an image electronically to the video processor, which converts the signal for display on the video monitor. Light is provided by either glass fibre optic light guides, for colour reproduction, or light emitting diodes (LED) for black and white, depending upon which probe is selected. For examinations requiring a six metre length probe or less, a fibre optic probe is used. Lengths of six metres to 16 metres require the use of probes fitted with LEDs, limiting the image to black and white.

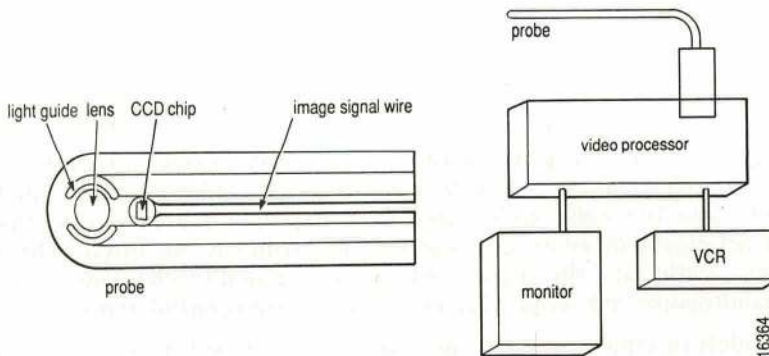


Fig 7.3.17 Visual aid video system

73. The CCD chip incorporates thousands of light sensitive cells. The video image produced is achieved by each cell measuring the change in light potential, reflected by the subject, and converting it into an electrical signal. The signal is passed through amplifiers and filters to the video processor. A strobe lamp in the processor pulses the three primary colours, red, green, and blue in sequence, illuminating the inspection area. The resulting images are sensed by the CCD and a signal is transmitted to the processor which combines them into a composite coloured picture for viewing. The picture reproduction on a nine inch screen gives a sharp, clear image, and allows a number of technicians to view the image simultaneously. Colour reproduction also assists the technician in identifying such defects as corrosion.

74. A video recorder, that uses VHS video cassettes, can be included in the system, it will receive and record the signal from the processor. This enables pictures of examinations, to be replayed for future reference and comparison.

75. The latest video systems that have been approved by the Service for engine and aircraft maintenance, will enhance the capabilities of technical personnel, enabling them to determine the internal condition of engines and airframes with greater accuracy and ease. The equipment however is extremely expensive, costing many thousands of pounds. Therefore the care that must be taken when handling and using this equipment, cannot be over-emphasized.

ENGINE MONITORING

General

76. One of the requirements of a unit's health monitoring programme, is to establish the magnitude of the internal stresses that are imposed on the major rotating assemblies of the gas turbine engines, during the day-to-day operational flying of the aircraft. The components that cause the greatest concern are the LP and HP compressor and turbine assemblies. The variations in high rotational speed, compounded with the high temperature of the environment in which they operate, promotes the severest of operational conditions, particularly upon the turbines.

77. A turbine blade failure is rarely critical, because the turbine casings are designed to contain blade fragments. However turbine disc failures are seldom contained within the engine casing, hence incidents of this nature are always serious, and can be catastrophic. The exacting conditions under which the engine turbines operate affect them in a number of ways; those that are of major concern are:

- Low cycle fatigue.
- Creep.
- Thermal fatigue.

Low Cycle Fatigue

78. Low cycle fatigue (LCF) damage is a major life limiting factor of gas turbine engine rotating components, particularly the turbine and compressor discs. It is caused by variations of stress resulting from changes in engine speed, and elevated temperatures. It therefore follows that LCF damage is dependant on the way that the engine is operated. An engine which is subjected to frequent changes of speed, with the consequent changes in stress levels, will consume more LCF life than an engine that remains for long periods at one power setting, e.g. cruising. The end of LCF life is characterized by the appearance of small cracks which progress very quickly and if they remain undetected can lead to failure of the components with possible hazardous consequences.

79. **LCF cycle.** An LCF cycle is defined as the travel from zero to a specified maximum stress

condition, (ie 100% turbine revs/min) and back to zero, and is termed a 'Reference cycle'. The travel from zero to maximum revs/min, will induce substantially more rotational stress in a component than the travel from zero to 40% revs/min, for centrifugal stress is proportional to the square of the shaft speed.

NOTE: For example, twice the shaft speed induces four times as much stress within the components and four times the shaft speed will generate 16 times as much stress.

80. **Part cycles.** Part cycles also consume component life and hence are added to the cumulative figure of component counts. A part cycle, for example, may be the rotation of a component from zero to 60% revs/min and return to zero. Or it may be from 50% revs/min to 90% and return to 50% revs/min.

Creep

81. Creep is the cumulative effect on a metallic material of time, and stress at high temperatures. Turbine blades, particularly high pressure turbine blades, are affected by creep. The high centrifugal loadings imposed upon the blades at elevated temperatures, cause a slow plastic deformation of the metal to occur, which results in an extension in blade length that can eventually lead to blade failure.

82. The ideal creep curve diagram (Fig 7.3.18) illustrates the three stages of creep caused by the conditions described in Para 81. There is an initial rate of creep, which decreases during the primary phase. This is followed by a steady increase in creep throughout the secondary phase. During the final or tertiary phase, the accumulating deformation of the blade material results in a rapid, progressive increase in creep rates, finally resulting in failure of the blade.

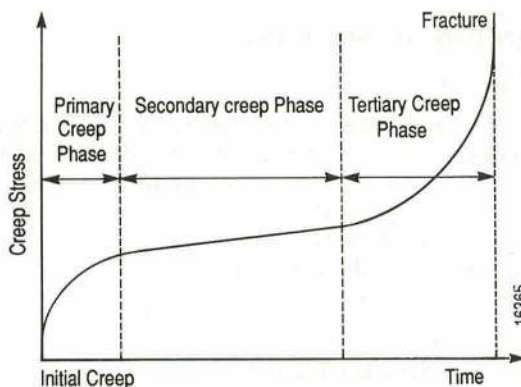


Fig 7.3.18 Idealized creep curve for turbine blades

83. Tertiary creep is the result of two interrelated major changes in the material that weakens the blades. Firstly the metals that are included in the blade alloy to increase hardness, are affected by continual exposure to high temperature, which alter their particle distribution, causing loss of strength. Secondly, as creep occurs, minute holes develop in the material surface, which effectively reduces the load bearing area, causing further weakness, which induces further creep. The enlarging and joining of these creep holes is the cause of creep failure. Apart from blade cracking, and signs of deterioration, the engine technicians' main concerns with creep, are the checks associated with the decrease in blade tip clearance.

Thermal Fatigue

84. Turbine blades experience higher temperatures than any other rotating component within the gas turbine engine. In order that they may function satisfactorily without overheating, and to prolong their operating life, small cooling passages are incorporated within each blade, through which compressor cooling air is passed. Because of the cooling air flow, the internal surface of the blades are relatively cooler than the external surfaces, which are subjected to the exhaust gas flow passing directly over them. This leads to differential temperatures across the blade section, causing a thermal stress gradient to be created.

85. In operation the blade tries to expand along its length, but because of temperature differences, some parts of the blade will be subject to greater expansion than others, but are constrained from doing so. The cool core of the blade creates thermal compressive stresses on the blade surface, and the blade outer surface induces tensile stresses towards the blade centre. The interaction of these stresses, plus the centrifugal stresses due to rotation, is most noticeable at the blades trailing edge, where metal thickness is minimal, and therefore more responsive to temperature change and stress. The result is a breakdown of material structure, and thermal fatigue (Fig 7.3.19).

Engine Monitoring Systems

86. **General.** Before a compressor or turbine disc enters service, it has been given an initial safe cyclic life, in reference cycles, by the engine manufacturer. This figure is arrived at by theoretical analysis and supplemented by rig tests. However, it is Service policy to apply an exchange rate and convert the reference cycles supplied by the manufacturer into flying hours. Until recent years the exchange rate was based upon theoretical calculations, which included a large safety factor to ensure that fatigue failure could not possibly occur. This was necessary at that time because there was no practical means of measuring the amount of reference cycles consumed during the various types of flying sortie performed by the aircraft. Hence, expensive components were often scrapped, when in fact they had many more flying hours remaining of usable life that could have been used, had the recording system been more reliable. The Service was aware of the problem, but had to err on the side of safety. In the early 1970's the RAF commenced trials, in conjunction with the engine manufacturer, to investigate the feasibility of an inflight, low cycle fatigue monitoring system, for the major engine rotating components. The early results obtained from them were very encouraging, and continued research led to the introduction of the 'Engine usage monitoring system'.

87. **Engine Usage Monitoring System Mk1.** The Engine usage monitoring system (EUMS) Mk 1 is a method of measuring and recording LCF consumption of an engine during flight. It is the most established and widely used engine monitoring system in current use with the RAF.

The system consists of the following:

- Sensors.
- Data acquisition unit (DAU).
- Quick access recorder (QAR).

88. **Sensors.** The system normally requires at least six parameters to be monitored. The output signals from the various sensors are transmitted to the data acquisition unit. The parameters are:

- Low pressure turbine shaft speed.
- High pressure turbine shaft speed.
- Compressor inlet temperature.

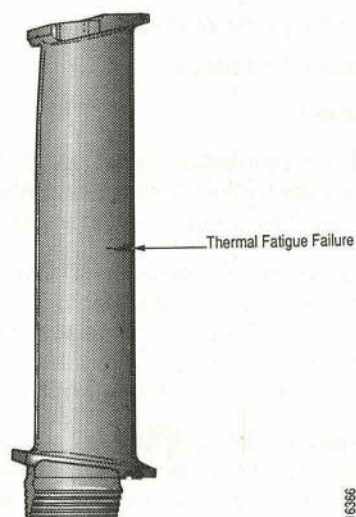


Fig 7.3.19 Effect of thermal fatigue on a turbine blade

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- Turbine gas temperature.
- Indicated airspeed.
- Altitude.

89. **Data acquisition unit (DAU).** The DAU receives the six signals from the sensors, and converts the signals from an analogue to a digital format. The digital signals are converted into computer binary code, and transmitted to the quick access recorder.

90. **Quick access recorder (QAR).** The QAR is a dual channel digital cassette recorder. It accepts the coded digital signal from the DAU, and records the information on high quality C60 cassettes. The recording speed of the QAR enables continuous recording for two hours, (the recording is made at half the normal speed). For aircraft engaged on missions of longer than two hours in duration, three hour cassettes, or twin recorders may be used.

91. **Data recovery.** The cassettes that are retrieved from the EUMS equipped aircraft after landing, are sent to the ground data processing station at the engine manufacturers. They are then placed in a computer facility and replayed. The computer accepts the binary code, and converts the digital signal back into an analogue format, thus returning the parameters to their original form when recorded during flight. The readings are then entered into a plotting machine that prints the parameters in graphical form (Fig 7.3.20).

92. The operators at the ground processing station then have the two requirements necessary for LCF analysis. These are: an accurate print out of all the relevant engine parameters recorded throughout the flight, and the sortie profile that the aircraft was engaged upon. Over a period of time as similar examples of sortie patterns and aircraft readings accumulate, an accurate projection can be made of the amount of LCF that will be consumed for all of the sortie patterns that the aircraft will be engaged upon. It is this projected information that is used by the RAF when applying an exchange rate to convert the reference cycles provided by the manufacturer into aircraft flying hours.

93. EUMS is not intended to be installed in every aircraft in a fleet. It is designed to be used on a sampling basis, being fitted to a small percentage of aircraft that are selected to represent the units flying role. The EUMS installation will remain in the aircraft for as long as is necessary, which may be a period of years; until it is decided by the engineering authority concerned with the task that no further benefit can be obtained from its continued operation.

94. **Flight servicing.** Propulsion tradesmen are not involved in the flight line servicing or maintenance of EUMS. The electrical tradesmen are responsible for replacing the recorder cassettes after each flight, and ensuring that the QAR is serviceable. The unit EUMS Project Officer, or a delegated NCO, is responsible for returning the cassettes, supported by the appropriate documentation, to the engine manufacturers for processing. He is also responsible for ensuring that clean cassettes are available when required.

95. **Engine Usage Monitoring System Mk 2.** The EUMS Mk 2 introduced a number of additional features when compared to the Mk 1 system, giving it enhanced capabilities. These additional features include:

- A microprocessor that provides the system with an improved data processing capability, enabling it to monitor and record a greater number of parameters.
- The incorporation of a four track recording system, and improved recording techniques, which considerably improve the systems' recording capacity. For example, the four track recorder has the capacity to store six times more data on tape than the single-track recorder previously used.

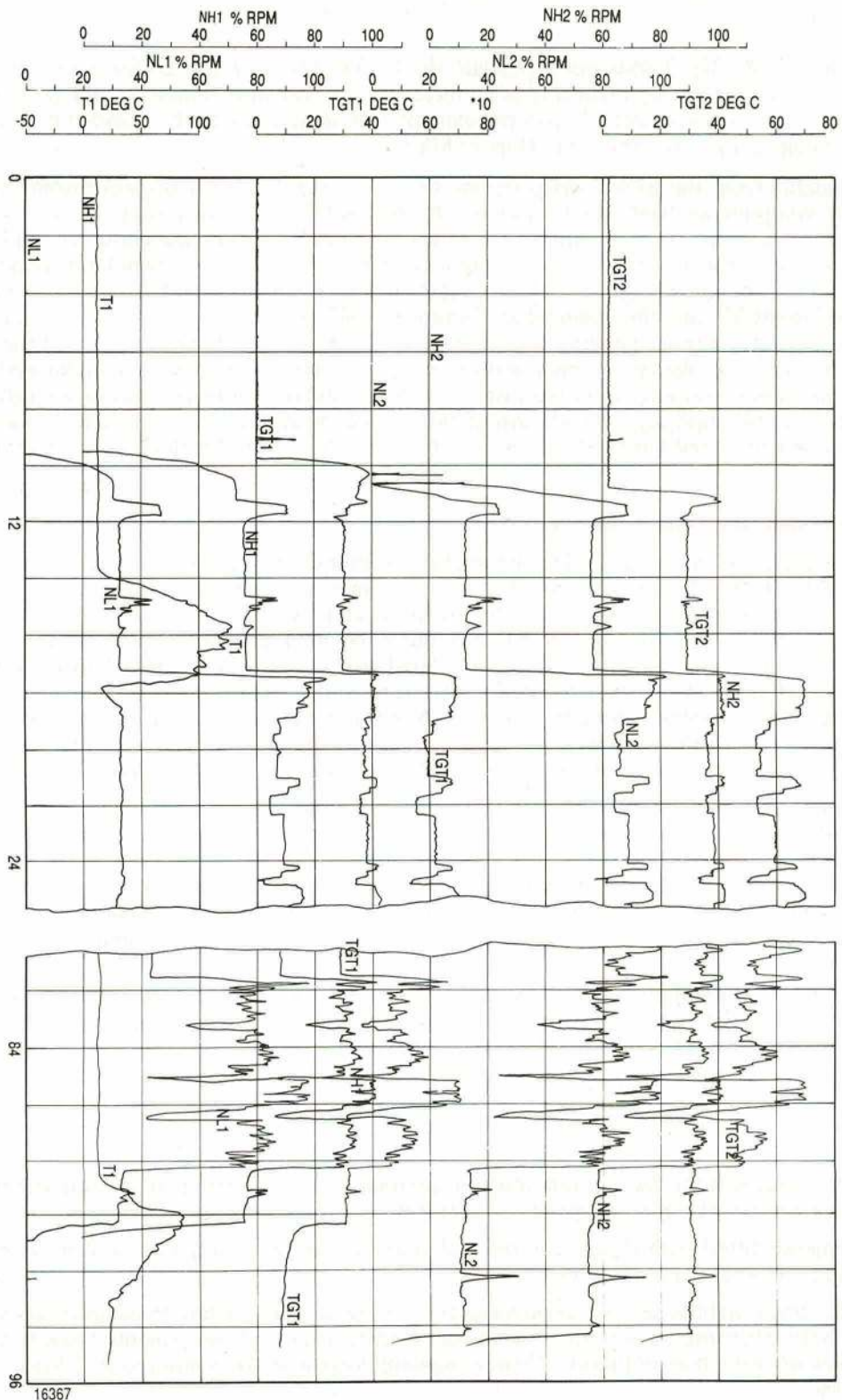


Fig 7.3.20 EUMS parameters graph for final analysis

96. The EUMS Mk 2 does not supersede the EUMS Mk 1. It is used for special projects where the monitoring and recording of an increased number of parameters, and greater data recording rates are required. It was for example, used to assist in the development of the digital engine control system of the Harrier Mk 5.

97. **Benefits from the EUMS programme.** The operating lives of many gas turbine engine rotating components have been extended by the RAF as a direct result of the EUMS programme. In some cases the life between overhauls has been more than doubled, and it has been estimated that the extensions to component life has also saved many millions of pounds. Furthermore, the knowledge that has been gained from the analysis of EUMS recordings has provided the RAF, and the engine manufacturers, with a greater appreciation of, and insight into, the stresses that are generated in the major engine rotating assemblies. When the RAF were convinced that the system provided a reliable indication of LCF usage, it embarked upon a wide programme of engine monitoring. To date, 14 different types of service aircraft have been monitored, requiring a EUMS installation in over 50 aircraft. The engine manufacturers have also accumulated knowledge from EUMS, that will assist in the design of engines in the future.

Engine Monitoring System-Harrier

98. **General.** The latest type of Harrier aircraft to enter the Service is fitted with an advanced Engine Monitoring System (EMS), that has been integrated into the aircrafts design. The EMS is an airborne computing system that monitors and records information on the integrity, condition, and life consumption of selected engine components. The system alerts the pilot whenever engine parameters are being exceeded that could be detrimental to the engines operation. It also *records* the exceeded parameters, and certain supporting information, for servicing and maintenance purposes. The EMS is continually monitoring all parameters that are associated with the engines performance. These readings are retained in the computers memory for a given number of seconds before being discarded (see para 104).

99. The main ground based elements of the system consist of a hand portable 'Data retrieval unit' and a micro-computer, termed the Harrier information management system. The data retrieval unit is used to download the recorded information from the aircraft. The Harrier information management system sorts and stores data of parameter exceedances, and the reference cycle usage of the components. It provides either a visual reproduction of the engine parameters that have been exceeded on a visual display unit (VDU), or a computer printout.

100. **Information inputs into the EMS.** Currently there are 25 different parameters that are monitored by the EMS, and each one of these has some influence on the engines performance. The inputs originate from four basic sources, these are:

- Direct analogue signals from transducers, and compressor delivery pressure.
- Digital signals from the cockpit mounted engine performance indicator. These are mainly engine generated parameters such as shaft speeds and engine temperatures.
- Digital signals from the aircraft mission computer. These consist of aircraft generated parameters, for example, airspeed and ambient air temperature.
- On engines fitted with digital control fuel systems, further information will be available from the 'Digital engine control system'.

101. **Life usage monitoring (low cycle fatigue).** The Harrier engine has 36 components which have a cyclic life limit. A number of which are classed as critical components because of the hazardous consequences of failure. These components are directly monitored by EMS and are as follows:

- LP compressor stage one disc.
- HP compressor stage one disc.
- HP turbine stage one disc.
- LP turbine stage one disc.
- LP shaft rear end spline.
- Combustion chamber outer casting boss.

The LCF usage on the remaining components is calculated from the usage on these critical components.

102. **Turbine blade monitoring.** The blades on both stages of the HP turbine are monitored for life usage, as follows:

- HP turbine stage one blades – thermal fatigue.
- HP turbine stage two blades – creep.

103. **Engine running hours.** Engine life is calculated in engine running hours. The hours are recorded from when 20% fan speed (F_N) is achieved during engine start, to engine shut down. Therefore all engine running time is recorded, including ground running.

104. **Incident monitoring.** Engine operation is monitored continuously for abnormal conditions. Abnormal occurrences are defined as 'incidents' and are divided into two groups, depending upon their cause. The first group consists of:

- First order incidents.
- Second order incidents.

The second group of incidents are of a different nature, these are:

- Vibration monitoring.
- Pilot initiated recording.

The computer is pre-programmed with all of the incidents that are likely to arise, and when any of these incidents occur, the recording will include what the particular parameter readings were, for four seconds prior to the incident being detected. The reading for the preceding four seconds being taken from the computer memory. For ground personnel therefore, the recording of the affected parameter will commence four seconds before the incident was detected. The duration of an incident's recording will vary with each type of incident.

105. When an incident occurs during flight, or during engine ground running a summary of the incident data is available on a cockpit screen called a 'Digital Display Indicator' (DDI) (Fig 7.3.21). All incidents are automatically recorded by the EMS for later analysis by the propulsion technicians.

106. **First order incidents.** First order incidents are defined as those incidents that involve only one parameter. This group of incidents consists of operational limit exceedances. For each type of first order incident the EMS produces an exceedance summary for the cockpit DDI (if requested), and an incident recording. Two examples of which are as follows:

Overspeed (OS). Maximum speed limitations for the engine are:

- LP rotor – 109% N_F .
- HP rotor – 105% N_H .

The summary includes:

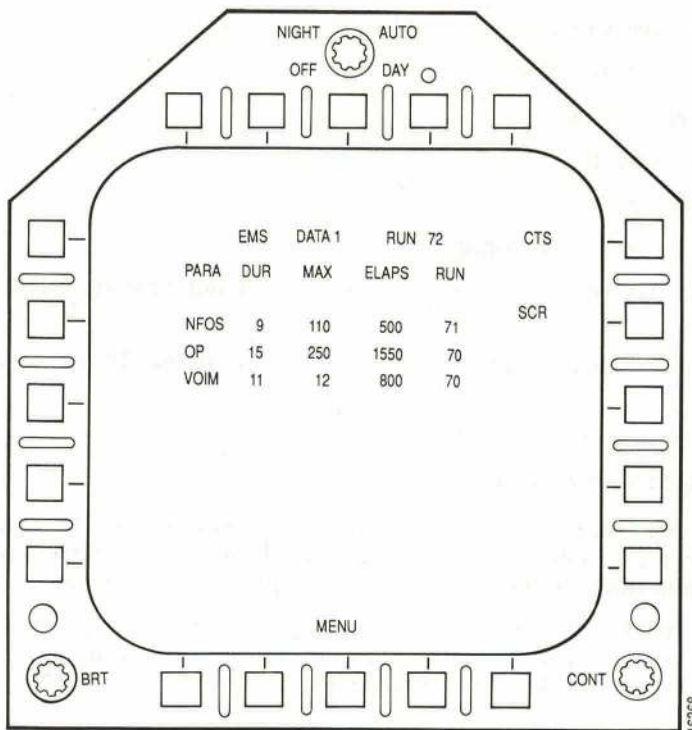


Fig 7.3.21 Cockpit digital display indicator

- Time spent above limits in seconds – (DUR).
- Achieved peak rotor speed value – (MAX)
- Time since EMS ‘Power up’ in seconds – (ELAPS)
- Engine run or flight number – (RUN)

Example:

PARA	DUR	MAX	ELAPS	RUN
N _F OS	4	109	1150	2
N _H OS	2	106	2245	1

Over temperature (OT). The maximum jet pipe temperature limitations is 765 degrees C Wet (W) or Dry (D). (The engine is equipped for water injection under certain conditions). The summary data includes,

- Time spent above limit in seconds (DUR).
- Peak temperature value (MAX).
- Time since EMS power up in seconds (ELAPS).
- Engine run or flight number (RUN).

NOTE: In addition the engine fan speed (N_F) at the time of peak temperature is recorded. Examples are:

PARA	DUR	MAX	ELAPS	RUN
OTW	15	782	252	3
N _F		102		
OTD	6	778	1812	1
N _F		101		

107. As the first exceedance incident is detected and recorded, a warning latch indicator is tripped on the aircraft refuelling panel (Fig 7.3.22). The indicator alerts the groundcrew who carry out the post flight refuelling of the aircraft that an exceedance incident has been recorded. A manual reset facility for the latch indicator is provided.

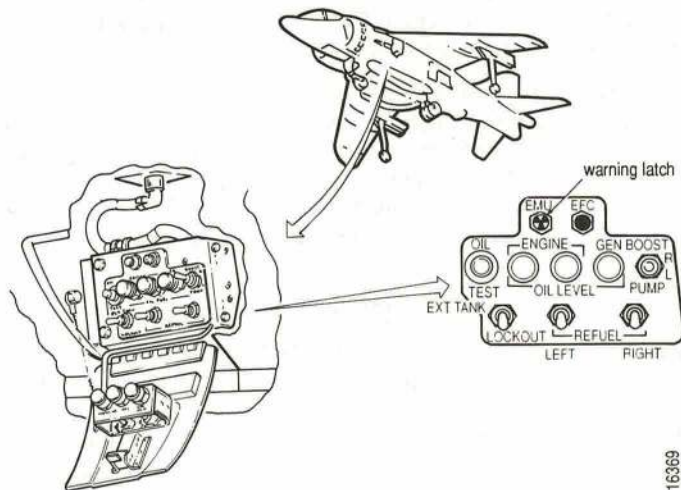


Fig 7.3.22 Ground warning indicator of engine exceedance incident

108. **Second order incidents.** Second order incidents are those incidents that involve two or more parameters. In most cases this type of incident will not be a simple exceedance. The production of an incident summary is required in addition to an incident recording, as detailed in the following example:

Engine surge. Certain flight conditions may induce an engine surge. A surge is apparent by a rapid change in HP compressor delivery pressure. Summary data includes:

- Corresponding altitude in feet (MAX).
- Time since EMS power up in seconds (ELAPS).
- Engine run or flight number (RUN).

Example:

PARA	DUR	MAX	ELAPS	RUN
SRGE		6500	4500	3

109. **Pilot initiated recordings (PREC).** This is a facility that enables the pilot, at his discretion, to record a short period of data, in the form of an incident record. When this option is used, a summary is also produced on the cockpit screen. Summary data includes time since EMU power up in seconds (ELAPS), and engine run number.

Example:

PARA	DUR	MAX	ELAPS	RUN
PREC			1175	2

110. **Vibration.** The EMS includes a vibration monitoring function. As with the first and second order incidents, when vibration parameters are exceeded, the EMU automatically provides a summary for the DDI and a recording of the incident. Vibration is assessed in two ways; to provide 'alarm' and 'Maintenance' level indications.

111. Alarm levels are pre-defined values that are based on acceptable levels for production engines. Maintenance levels are established from the vibration levels associated with each engine in that particular airframe, and are averaged over the first six flights after installation of the engine into the airframe. During these flights, whilst the maintenance level is being established, the alarm level serves as the engine vibration limit. Thereafter whilst the engine remains in the aircraft, the maintenance level becomes the alarm level at which the vibration alarm is sounded.

NOTE: A cockpit warning light illuminates following a vibration alarm.

112. **Data retrieval unit.** The data retrieval unit (DRU) is a portable unit that extracts and stores the information that has been recorded by the EMU. It is also the means by which information is updated in an EMU, such as when new parameters are inserted following an engine change. The DRU system consists of the DRU itself, a rechargeable battery pack, and a 'Hand held unit' (HHU). It is carried in a reinforced carrying case, and supported by a shoulder strap (Fig 7.3.23).

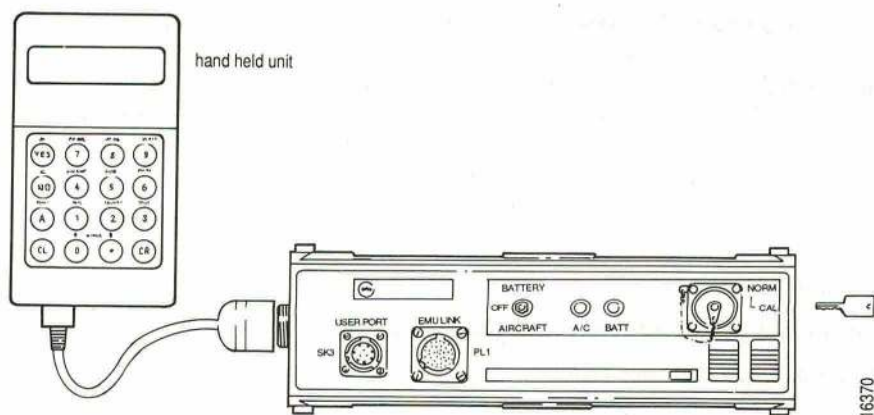


Fig 7.3.23 Data retrieval unit

113. **Extraction of data from EMU.** To extract the data recorded by the EMU the hand held unit (which acts as an interface between the EMU and the DRU) is connected to the EMU by

means of a lead. Power is supplied either by the battery pack, or the aircraft batteries, whichever is the most convenient. The HHU has a key pad fitted, through which the operation of the DRU is controlled. It also has a display window that presents a series of advisory messages that are necessary to control the down loading operation of the EMU. When connected to the EMU, it will initially display 'Awaiting user command', which is the starting point for all commands to the EMU. By pressing the relevant key, at the appropriate time, and observing the changing information appearing in the control window of the HHU, all the recorded information is extracted from the EMU. The DRU has the capacity to down load and store the recorded information from 83 aircraft. This procedure is normally carried out after the last flight of each day. When the task is completed, the DRU is passed to the trade manager, who is responsible for transferring the information from the DRU to the mainframe computer.

114. **Updating EMU parameters.** To update, remove, and add new information into the aircraft EMU, the DRU is changed from the Data extraction mode to the Privilege mode, by inserting a key into a lock on the face of the DRU and turning the key to the 'CAL' position. The required data can then be entered into the EMU, using the HHU. When this has been completed, the key is turned to the normal position and removed. The key is retained by the trade manager, who is responsible for changing EMU data. This procedure prevents the accidental altering and erasing of engine parameters.

115. **Harrier information management system.** The Harrier Information Management System (HIMS) is a micro computer based system that sorts, and stores data, updates records and information regarding component life usage. It also raises and records incident files. The HIMS is updated by the engine and aircraft information that it extracts from the DRU. The HIMS has a number of other functions that can be selected when required, these include:

- Analysing incidents, comparing similar incidents, and display parameters in a graphical format from before, during and after an incident.
- Monitoring component lives and consumption rates of the aircraft fleet.
- Matching flight details to EMS data.

116. **Cristie recorder.** When operating in the field, the DRU data is extracted directly onto tape using a Cristie recorder. The tapes are then sent back to mainbase to update the HIMS. Fig 7.3.24 illustrates a typical squadron layout of an EMS.

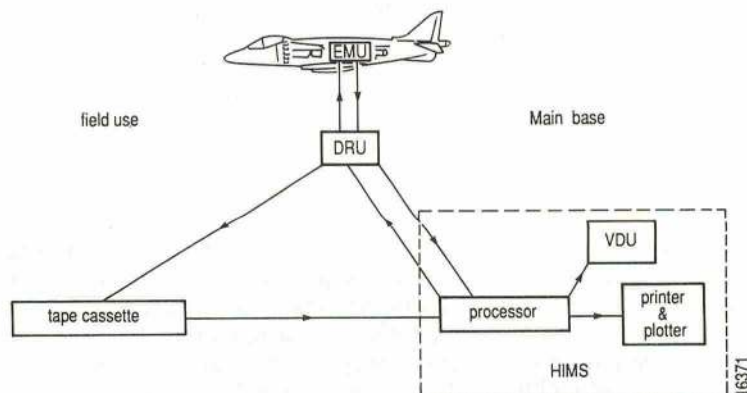


Fig 7.3.24 Engine monitoring system layout

Quantitive Debris Monitoring

117. Quantitive Debris Monitoring (QDM) is one of the latest techniques in the field of engine health monitoring. Its object is to monitor and assess the condition of the engine oil system internal components. The monitoring results are analysed by an airborne diagnostic system, that detects the onset of component surface fatigue, and alerts the pilot with an early warning of impending failure. The QDM system can be divided into three phases, which are dependant upon the following assemblies:

- Sensing assembly.
- Signal conditioner.
- Debris data processor.

118. **The sensor assembly.** The sensor assembly consists of a sensor, with a magnetic pole piece protruding from one end, that is surrounded by an electro magnetic coil. For maximum efficiency the sensors are positioned at a point in the oil system that will enhance particle capture (eg the inlet or outlet side of the scavenge pumps).

119. **Signal conditioner.** The signal conditioner comprises circuitry that includes an amplifier, a signal filter, and a signal peak detector. There are also two circuits provided for external adjustment. The adjustments establish the size ranges, or reference values, of the ferrous particles to be recorded. The smaller particle range is usually 300 microns and above, and is known as the total limit. The second circuit is normally set for 1000 microns and above, and is termed the large limit. If these are the ranges that have been selected, then 300 microns and 1000 microns become the 'threshold values'.

120. **Debris data processor.** The debris data processor (DDP), consists of circuitry that quantifies the input signals from the signal conditioner. It processes and transmits the signal to the cockpit, or flight deck instrumentation, for direct pilot readout. The DDP also makes a recording for later analysis by ground technicians.

121. **Quantitive debris monitoring operation.** Whilst the oil circulates in the system, the coil assembly that surrounds the sensors pole piece emits a magnetic field of a fixed value. The magnetic field is sensitive to the size of any particles that are passing through it. Ferrous particles in the oil flow are attracted to the sensors magnet, which results in a signal in the coil that is proportional to the mass of the captured particle. This signal is passed to the signal conditioner that amplifies, filters, and measures the input signal, then sends the resulting signal with the adjustable reference value voltages to the DDP. The DDP comparator receives the signals and reference voltages, and assesses the signal strength in 'counts'. The signals that are greater than the total threshold, but are below the large setting, will result in a count being registered on the total channel. Particles in excess of the large threshold will register a count on the large channel, plus a count on the total channel. The DDP computes the number of counts, and registers them as a function of time, and compares the results obtained with the externally set limits. In addition, the rate of particle generation is determined for each of the size ranges, these are also compared with limits that have been externally set.

122. As the surface fatigue failure of a component progresses, failure particles are generated in increasingly greater amounts in the two size ranges. The DDP determines when the pre-set limit amounts have been exceeded, and whether there is an accumulation of small or large particles, or both, and how rapidly the failure is progressing. Warnings are raised when necessary by alerting the pilot and recommending a particular course of action. Information is also available to the ground technician of the impending failure enabling maintenance action to be taken.

NOTE: A built-in test feature enables the system to be tested for accuracy.

Low Cycle Fatigue Counter

123. **General.** Although EUMS is currently the principle method of monitoring LCF on RAF aircraft gas turbine engines, it is not regarded as a system that can assess LCF usage on every aircraft engine with total accuracy. EUMS is used as a sampling programme that enables the RAF to project satisfactory estimates of LCF usage on a 'Fleet scale'. There are however, certain aircraft engaged in flying roles whose engines do require individual LCF monitoring. For example during aerobatic display flying, it is recorded that whilst performing certain formation manoeuvres, far greater LCF damage was sustained by the wingman's engine than the LCF damage recorded by the formation leader's engine. It was concluded that the reason for this was the constant throttle adjustment required by the wingman to maintain formation position. The 'Red Arrows' aerobatic team aircraft and also certain aircraft involved in test and research projects are each fitted with a monitoring system called a Low cycle fatigue counter, (LCF counter). It has been developed to enable individual aircraft to be monitored accurately for LCF, and to display the results. The LCF counter continuously assesses LCF and gives an instantaneous readout of the accumulated LCF damage in reference cycles.

124. **Description.** The LCF counter (Fig 7.3.25) is of modular construction, consisting of four modules. These are: a counting module, a data programming module, a microprocessor, and a power pack. The modules are housed in a case, and the complete assembly weighs less than two kilograms. It is conveniently located in the aircraft for access to enable servicing operations to be carried out.

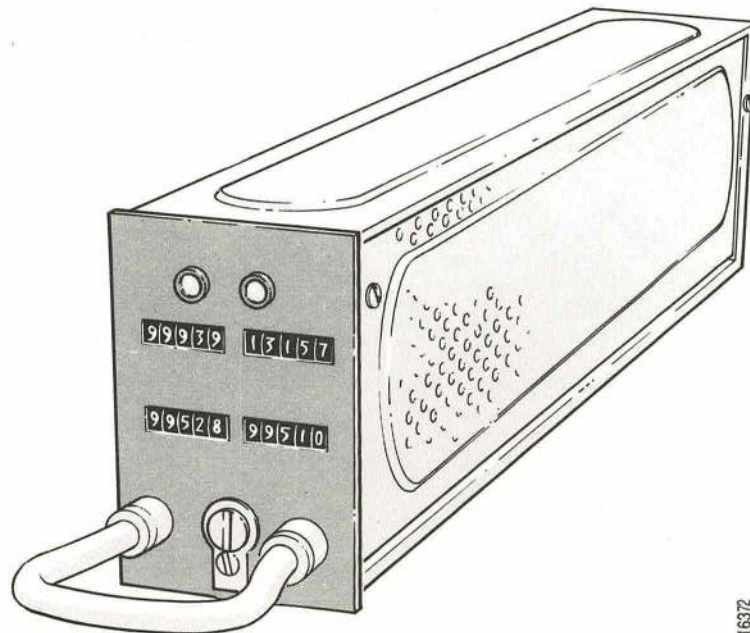


Fig 7.3.25 Low cycle fatigue counter

125. **Operation.** Speed sensors transmit signals of engine HP and LP compressor and turbine shaft speeds to the microprocessor module, which applies this input data to an algorithm (which is a mathematical formula) and computes the LCF usage in reference cycles. The resulting cycle counts are displayed in windows at the front of the unit in cumulative cycle

totals. The system monitors and assesses four components, LP and HP compressors and LP and HP turbines.

126. Built-in test equipment indicators are fitted to the front panel of the unit to give a warning of a malfunction or an incorrect data input. The data programming module is set up to be used with one particular engine, the serial number of which is visible through the window in the case.

127. Later LCF counter modules monitor an increased number of parameters, which includes temperatures. As a consequence these models give results to a greater degree of accuracy.



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