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The Development of Technological Support for RAF Early Failure Detection Centres

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Abstract: Because of staffing policy within the Royal Air Force, personnel are rotated on a regular basis. This can often result in an experienced member of a team being replaced by someone with minimal knowledge of the job. This is true of Early Failure Detection Centres (EFDCs) which perform first line Equipment Health Monitoring (EHM) at RAF air-bases. Experience is probably one of the most powerful tools in EHM and, in particular, debris monitoring; therefore, there is an ongoing need for the development of condition monitoring systems and techniques that will assist RAF EFDC staff new to the post. The RAF use a number of modern analytical techniques in their EFDCs, including optical microscopy, image analysis, Scanning Electron Microscopy with Energy Dispersive X-Ray (SEM/EDX) micro analysis packages and Energy Dispersive X-Ray Fluorescence (EDXRF) analytical equipment. Therefore, the need exists for equally sophisticated, but user-friendly tools that will aid the EFDC operative in the everyday job of EHM. For a number of years the Mechanical Engineering Department, University of Wales Swansea and the Defence Evaluation and Research Agency (DERA) Fuels and Lubricants Centre, Pyestock have been collaborating on such projects, funded by the Ministry of Defence. The aim of this paper is to give a summary of the work so far and to outline intended future programmes.

Key Words: Computer aided ; CASPA; CAVE; debris analysis; Early Failure Detection Centres; equipment health monitoring; Royal Air Force; Wear Particle Atlas.

Introduction: Wear particle analysis is a powerful technique for non-destructive examination of oil-wetted parts of an engine. The particles contained in the lubricating oil carry detailed and important information about the condition of the machine. This information may be deduced from particle shape, composition, size distribution and concentration. The particle characteristics are sufficiently specific so that the operating wear modes within equipment may be determined, allowing prediction of the imminent behaviour

of the machine. Often, action may be taken to correct the abnormal wear mode without overhaul, whilst a timely servicing can prevent costly secondary damage.
The Royal Air Force operate a number of aircraft types that are not amenable to spectrometric oil analysis. Therefore, the routine analysis of wear debris collected on magnetic drain plugs situated within the aircraft's lubrication system is the primary condition monitoring technique. Interpretation of the morphological characteristics of debris is vital in Equipment Health Monitoring and requires a combination of analytical, metallurgical and engineering expertise, relying heavily on the experience of the operator. The regular turnover of personnel in RAF EFDCs means that there is insufficient time for an individual to develop the necessary skills required to carry out this type of specialised analysis. This has led to the need to introduce procedures which assist in formalising the decision-making process in order to provide systematic and objective methods of analysis. This is an area that computer-based systems are ideally suited and has provided the basis of the development work at Swansea. While some of the techniques described in this paper have been reported previously, it is worthwhile recapping on this past work and giving a brief resume of recent progress [1].

Computer-Aided Morphological Analysis: The purpose of utilising computer-aided systems for analysing particle morphology is to establish the reliable identification of a specific wear particle, linked with a capability to document the information and prepare a report defining the results of the overall analysis of the sample. Coupled with other information about the sample, it should also be possible to formulate an accurate diagnosis of the wear condition and identify the associated fault in the system.
Morphological analysis requires that debris is examined using an optical microscope, enabling the analyst to determine the pertinent attributes of the sample. The particular features of interest are particle size (plain dimension and thickness), outline shape and edge detail, surface features and colour [2]. This type of examination is time-consuming, tedious and invariably subjective, but essential if the type, cause and severity of wear is to be determined. With these points in mind, a number of methods have been developed exploiting modern computerised procedures, incorporating the use of neural networks and image analysis techniques.

CASPA: The Computer Aided Systematic Particle Analysis (CASPA) system has been developed as a Windows-based software package that trends and classifies wear debris [3]. This is achieved by means of a number of dialogue boxes that questions the operator, leading to the diagnosis of the debris type-Figure 1. The first box, *Module Record* contains a chronological list of the debris samples collected from one source i.e. sample point or engine. The *Sample Record* stores the engine operating hours, the debris concentration (as measured e.g., by the Wear Debris Tester, or the Particle Quantifier [4], and any comments relevant to the interpretation of the sample.
The *Particle Dialogue Box* prompts the operator to describe the particle under observation by means of a number of descriptors, these include particle shape, edge detail, surface texture and colour. From these features the system is able to identify the particle type and give the result to the operator in the *Diagnosis Box.*
There are a number of benefits to a diagnostic tool of this nature. Namely, it establishes a systematic and objective procedure to arrive at a reliable identification of a specific particle type, whilst linked to a capability to prepare a report defining the results of the overall analysis of a sample. Major advantages of CASPA is that, as an expert system it may be

used by inexperienced personnel, while repeated use will train the operator in the recognition of specific wear types.

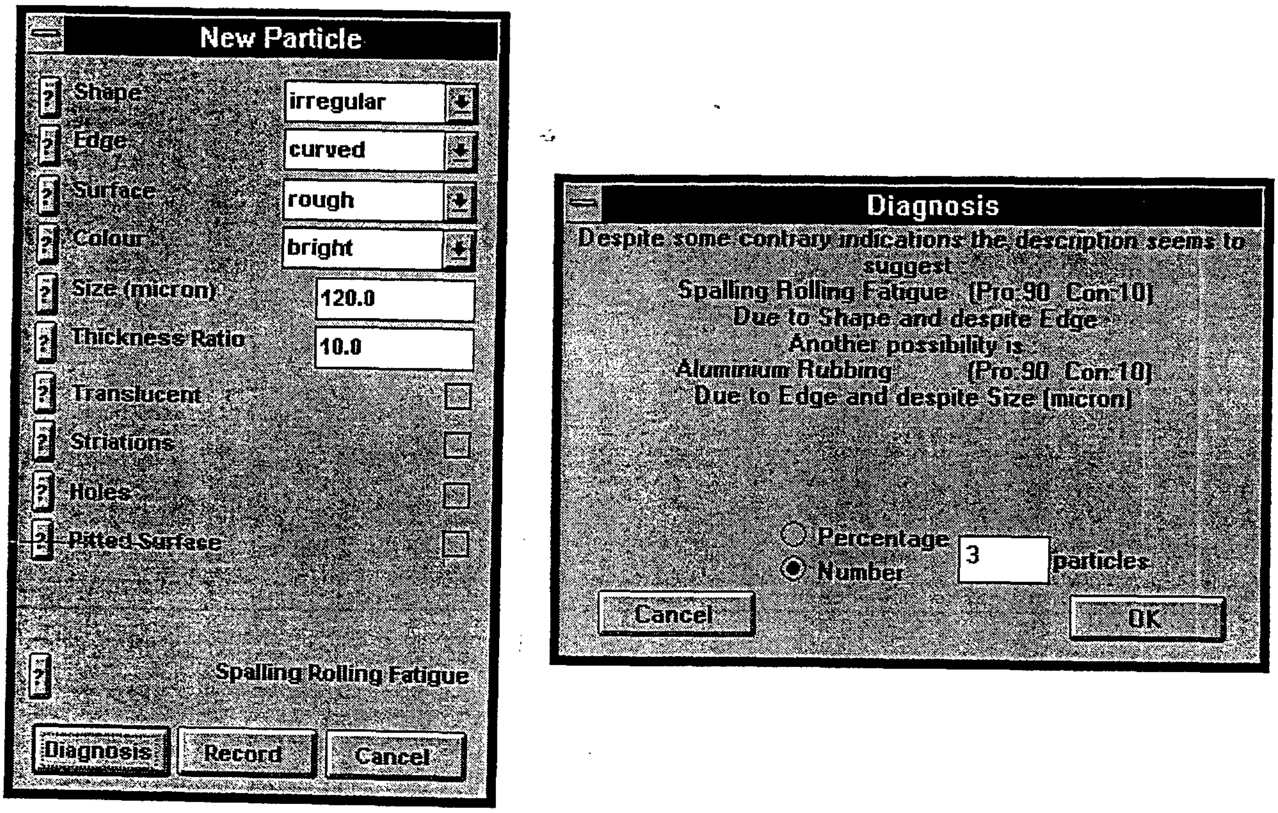

Figure 1 CASPA dialogue and diagnosis system

CAVE: The Computer-Aided Vision Engineering (CAVE) program has been developed as an automated particle recognition package to quantify analysis of a particles size and shape [5]. The system uses image analysis techniques to extract information about a particle from captured video images. The addition of neural network procedures has enabled the system to be trained to produce classification of particle shape, as well as recognising the surface features of a particle in relation to the associated wear mode.

CAVE can be utilised to calculate various features of a particles shape including size (area and maximum length), aspect ratio (proportion of length to width), roundness factor (perimeter^2/4π area), Fourier coefficients of outline and outline curvature. Outline curvature is a useful, size-independent and rotationally neutral description of the shape of a particle. The statistical moments of curvature give a measure of a shape's regularity and edge detail and the first eight harmonics of the Fourier transform of the outline curvature have proved a satisfactory input for the neural net classification of particle shape.

Despite being developed primarily for the analysis of MDP samples, some difficulties have been experienced with the application of CAVE due to the current procedures for sample preparation in RAF EFDCs. This issue is currently being addressed, as it also affects the efficiency of other analytical techniques recently introduced by the RAF.

Wear Particle Atlas: The purpose of developing a series of annotated images is two-fold, it provides a reference document for debris associated with specific engine types and can also be used for tutorial sessions during the training of inexperienced personnel. The process used in the development was Hyper Text Mark-up Language to generate hyper-linked text and images, comprising scaled images of debris, galleries of "thumbnail" images with explanations of components and other relevant information [6].
Two type-specific Wear Particle Atlases (WPA) have been produced; one for the Rolls Royce RB199 engine and the other for the Allison T56. Both are formatted in a similar manner and provide information for the identification of various wear particle types found in each engines lubrication system. Each atlas provides information for the identification of these particles and the wear modes that generate them.

Visual CASPA: Incorporated within the current WPAs is technique called Visual CASPA. Like the earlier version of CASPA, this will aid the inexperienced operator in the identification of a wear particle type. Visual CASPA uses a decision tree method to analyse particles and requires the operator to select certain options from a list of morphological attributes based upon the unknown particle. These attributes are presented to the user in the form of stylised images. Once a particle has been selected for analysis, various questions are asked by the program, which narrows the search down to a specific particle type. At each stage, Visual CASPA will announce the number of particles that conform to the answers given so far. For example, if the particles shape was chosen to be irregular and the edge was considered rough, eighteen particles within the WPA have both theses attributes. These can be displayed at this stage or, by answering more questions, further particles can be eliminated. Once the number of conforming particles is small enough, a gallery of thumb nail images is displayed. From this, a match can be made and a full size image will be shown with a brief description of the particle.

Current Developments: Effective health monitoring often depends on the subjective assessment of a debris sample, because the links between morphology of wear particles and the wear processes that lead to their production are not fully understood. Debris monitoring depends on a knowledge of the processes of wear and failure, and how these processes generate particles with specific size distributions, morphologies and surface textures. There are many conditions possible in lubricated components which give rise to wear mechanisms from mild wear to severe scuffing and a variety of characteristic debris types. These need to be characterised by a controlled study of the effect of load, speed, environment and the type of lubricant, the results being used to produce a 'wear atlas' or map of the wear mechanism types and characteristic debris generated. Work has begun on the development of a Generic WPA for use by EFDC staff. This will involve the characterisation of the morphology of wear debris particles produced under controlled conditions, or alternatively, are taken from known conditions that can be verified as having occurred. The relationship between wear mode and the characteristics of the debris generated will be examined, with particular emphasis placed on relating particle morphology to predicting equipment health. The final version of the Generic WPA will contain high quality optical and SEM images of debris, with associated descriptive text and a decision tree similar to Visual CASPA, using stylised images of generic debris types and classes. Once the Generic WPA has been completed, it is intended that modules are added, specific to individual aircraft/engine types, containing images of typical debris, compositional and component specific information..

Conclusion: In the development of the techniques described in this paper, a number of points have had to considered. Any procedure devised for use within the EFDC environment must be clearly defined, easy to follow and quickly executed. Thought must be given to the compatability with other facilities and procedures already in place, while at the same time being helpful and reliable in assisting EFDC staff make a fast and accurate diagnosis.
With constant cut-backs on Defence spending, cost of new equipment is a major issue. There is no point, therefore, in developing a piece of equipment, no matter what benefits it offers, if it is prohibitively expensive to produce. The advantage of the systems discussed in this paper is that only a standard personal computer and an optical microscope are required to use them. With careful thought on the implementation and further development of these systems, it is expected that the RAF will be provided with a very powerful EFD diagnostics tool.

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