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Procedia CIRP 11 (2013) 130 – 134

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2nd International Through-life Engineering Services Conference

Data Mining and Knowledge Reuse for the Initial Systems Design and Manufacturing: Aero-engine Service Risk Drivers

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Abstract

Service providers of civil aero engines are typically confronted with a high cost of maintenance, replacement and refurbishment of the service damaged components. In such context, service experience becomes a key issue for determining the service risk drivers for operational disruptions and maintenance burden. This paper presents an industrial case study to produce new knowledge on the relationships between degradation and component design to manufacture. The study applied semantic data mining as a methodology for an efficient and the consistent data capture, representation, and analysis. The paper aims at identifying the service risk drivers based on service experience and event data. The analysis shows that the 3 top mechanisms accounting for 32% of the mechanism references have a strong Pareto effect. The paper concludes with missing information links and future research directions.

Selection and peer-review under responsibility of the International Scientific Committee of the “2nd International Through-life Engineering Services Conference” and the Programme Chair – Ashutosh Tiwari

Keywords: Aero-engines; Data mining; Semantic analysis; Degradation mechanism; Service feedback

1. Introduction

Service providers of aircraft engines are confronted with a high cost of maintenance, replacement and refurbishment of service damaged components. These components are complex, high-value, and technology intensive, which have a direct impact on the cost of ownership. This has led manufacturers and service providers, including Rolls-Royce plc (R-R) to a re-evaluation of their maintenance costs and strategies for the product availability and reliability for its entire life cycle. In this context, a need for improving the availability and safety of aircraft engine components requires effectively addressing any disruption and unplanned maintenance burden.

This requires access to the data from the existing engines in the field and services, for knowledge reuse from both the service and design community for new or revised product development as well as maintenance cost reduction. Often, such knowledge is in unstructured form or in a free-form text format, making it difficult to capture or reuse for both the service and design communities. There has been a significant effort made recently to design automated systems for information retrieval and knowledge acquisition from existing documents, reports, and real-time service data for the service providers in the aerospace industry.

This paper presents an industrial case study to produce new knowledge on the relationships between degradation and component design to manufacture based on the previous experience. The study applies semantic data mining as a methodology for a fast and consistent data capture, representation and analysis. The paper aims at identifying the service risk drivers based on service experience and event data.

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doi:10.1016/j.procir.2013.08.002

In the next section, a background of the related work is given followed by current approach methodologies of information retrieval techniques applicable to service experience and event records. The paper then analyses the findings and identifies the critical service drivers and causes for engine removal and operational disruptions. Based on the findings the paper attempts to establish causal relationships between mechanisms and product design and manufacturing processes. The paper concludes with key recommendations and future work.

2. Related Work

It is observed that cracking, thermal and mechanical fatigue, wear, erosion, and corrosion are among the key degradation and damage mechanisms for the aircraft and industrial gas turbine engine components [1; 2]. Harrison [3] and Zhao [4] have made an effort to establish links between maintenance cost and deterioration mechanisms and pointed that the aircraft engine component deterioration as a key driver of life cycle cost (LCC). According to a survey conducted by a service provider on the aircraft engine market in 2009, approximately half of the total cost of aircraft engine maintenance is driven by the aerofoils and related family of component [5].

In the literature several authors discussed certain aspects of the service information that are beneficial to designers. Norman [6] stated that previous operating experience could contribute towards forecast reliability and availability. Jones and Haynes [7] analysed the importance of field failure data collection through the product's life and analysis of this data to evaluate the product's reliability. Petkova [8] discussed the flow in the service information feedback to the manufacturer to establish causal links for the improvement of product quality. Jagtap [9] found that the in-service information required by the design community mostly comprises deterioration information, including mechanisms, deterioration effects, deterioration cause, and deterioration location.

As previously mentioned in this paper, there is a need for in-service experience information retrieval in a structured way, so that the captured data becomes easy to represent and analyse. This enables users to produce Pareto charts of service issues or events, identify component risk drivers and damage mechanisms. The knowledge gained from previous experience and events can be reused for new or revised product design, manufacture, assembly, repair and overhaul functions.

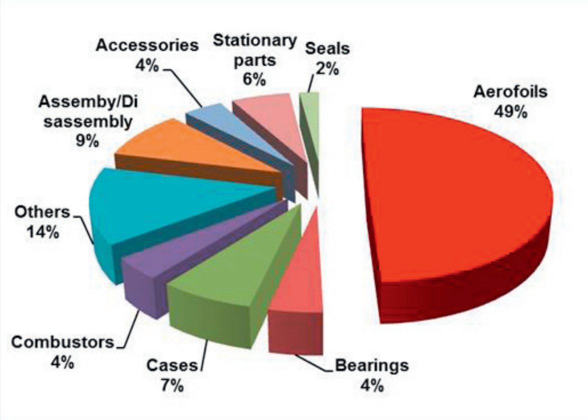

Figure 1: MRO Aircraft Engine Components Cost Breakdown, adopted [5]

3. Methodology

A number of studies focusing on information retrieval (IR) and knowledge acquisition (KA) from reports, web documents, and electronic repositories, have been undertaken in engineering and in the service context. The authors use text mining tools based on keywords and ontologies within the engineering domain to extract information from different text documents. Kaplan and Berry-Rogghe [10] applied the causal analyser extractor tool to several texts to produce a representation of the causal relationships in texts from different domains. Lanfranchi et al. [11] and Dadzie et al. [12] explored a Hybrid Search (HS) strategy to retrieve knowledge, mixing keyword-based searches (KS) and ontology-based searches (OS) inside legacy of event reports (ER), and Technical Variances (TV). Kim et al. [13] proposed an automatic approach to identify cause and effect relationships through expressions of causality, using techniques of natural language processing (NLP) and probability in root cause analysis reports in the engineering domain.

The evaluation of these tools suggests improved access to service and maintenance information can be extracted from unstructured data to structured documents. Jagtap [9] stated the importance of such text mining tools based on ontologies and information extraction methods are useful to understand deterioration mechanisms and contributing factors.

The semantic data mining method was used for this study, the tool is developed by the industrial collaborator with a purpose for an effective and faster data capturing methodology, for representing and analysing a large set of textual information that facilitates corporate user needs. Currently, the semantic data mining tool integrates into Microsoft Excel with a built-in capability to search and query. The database consists of thousands of predominantly unstructured text documents.

3.1. Approach

The service information based on experience and event records from the civil aerospace sector were made available for the study by the industrial collaborator. The majority of the reported cases consists of service issues and events recorded from the customer support, maintenance, repair and overhaul activities. These are part of a group of logging data from the first line of customer services, including on-wing support, repair shops, online engine health monitoring support, and etc.

In order to make a good analysis of the total population of records, a tailor-made database was created with a purpose to generate an index of service degradation mechanisms. This allows identifying critical service risk drivers, mitigations to be defined to minimise the threats to operational disruption, maintenance burden, and feedback to the design and service engineering community. The following steps were used for the data capture, representation and analysis:

Step 1: Selection of the data required
This step consists of three processes which are: access to data, which come in raw format, then converting selected files from a raw format to MS Excel format, and then store the data in a user database for initial screening.

Step 2: Data extraction
This step consists of five processes, including creating a customised database, semantic data mining, initial evaluation, and data training:

a. creation of template to support service knowledge, based on a MS Excel programme,
b. applying the semantic data mining tool with a set of experience and event information defined,
c. initial evaluation of the extracted information, for data cleansing, filtering, and normalising the extracted information for further evaluation,
d. training the semantic tool and selected data through iterative methods to evaluate the tool response effectiveness,
e. applying the semantic tool again and populating the database according to pre-defined templates.

Step 3: Data analysis and knowledge reuse
This step uses the extracted data for representation and analysis (i.e. Pareto charts) to support service knowledge reuse. This step consists of the following process steps:

a. Structured representation of the data for user analysis and target audience,
b. Pareto analysis of degradation drivers, using a combination of underlying mechanism information to establish causal links (e.g. feature degradation combination effects),
c. Customising the database on service knowledge under the degradation mechanism so that it can be accessed for design reviews and new product development.

4. Results and Discussion

The results of the semantic data mining from experience based records produced a good overview of the reported events and issues from civil aero-engines. These events have been classified per type of information impacts on the cost of ownership and results are shown in Table 1.

The service and operational information does not have a direct impact on operational disruption and maintenance. This type of information mostly consists of service issues. E.g. materials and consumables, procurement, standard practices, tooling, assembly, etc. Conversely, the degradation mechanism information has a direct impact on the operational disruption and maintenance burden. From the observation, the cause of early removals, disruptions, scrap, and maintenance burden is covered by the degradation mechanism information, which is only 28% of the total population.

Table 1: Applied classification per type of information

Information	Total Population	
Service & Operations	23,908	72%
Degradation Mechanisms	9,505	28%
Total	33,413	

4.1. Analysis of Degradation Mechanisms Reported

It is known from previous studies reported in the literature that certain degradation mechanisms occur more frequently than the others. This analysis makes an effort to establish links for a given component. There are the feature degradation mechanism combinations that are more likely to occur than others. Such information enables the designers to focus on the appropriate analysis to prevent the degradation mechanisms at the conceptual design stage.

All the reported events have been reviewed for the degradation mechanisms and subsequently the underlying critical features, causal information and the effects of such mechanisms (see Table 2).

Table 2: Applied degradation mechanism information under service experience base records

Degradation Information	Total Population	
Features	3,458	37%
Root Cause	2,196	23%
Effects	1,730	18%
No Information	2,121	22%
Total	9,505	

Pareto charts were plotted to determine the distribution of occurrences in the degradation mechanisms in service. The following observations were made from the previous experience and event records under degradation information.

4.1.1. Distribution of degradation mechanisms

The study identified a total of 76 types of degradation mechanism terms, where a large percentage of mechanisms happened very seldom (≤ 1%). Figure 2 shows the distribution of the top 20 potential mechanisms that may cause early engine removal, disruption, scrap, and maintenance burden based on service inspections recorded. This includes mechanisms such as size, corrosion, bend, leak, etc. Therefore, by concentrating on these mechanisms, the designer can be assured that the major degradation types have been taking care of. Further, it is being observed that often a combination of multiple mechanisms is seen on a single event.

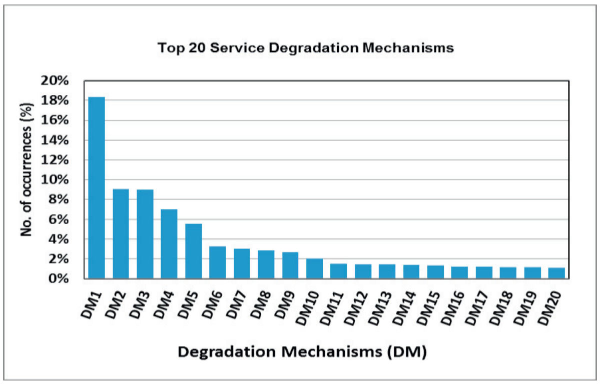

Figure 2: Distribution of Degradation Mechanisms (DM)

4.1.2. Distribution of degradation across components

Considerable financial cost of ownership is associated with early removals of critical components. Typically these components are part of rotary assemblies and structural casings [2]. As per the analysis and observations, it is noticed that *DM1* from Figure 2 is the predominant degradation mechanism across the aero-engine components. Therefore, a distribution across components including blade, segments, casings, vanes, and so forth are examined and then analysed (see Figure 3). Such analysis enables the designers to identify critical component reliability issues and availability at the early stages of the product life cycle.

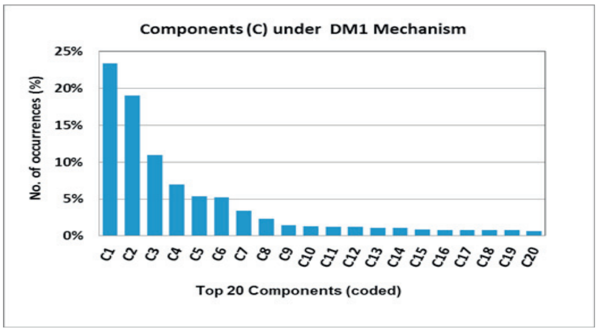

Figure 3: Distribution of degradation across components under "DM1" mechanism

4.1.3. Distribution of features across degradation

An interesting result is obtained from the analysis of the underlying features, as seen from Figure 4. It has been observed that a large number of features are contributing to degradation mechanisms which have an impact on functional performance and component service life. Figure 4 shows cumulative percentages of degradation mechanisms for each aero-engine design feature. There is a minority of features that exhibit more mechanisms both in type and the occurrences. The "*DM1*" and "*DM2*" are among the all top 20 features analysed. As such, designers can focus their efforts on these features that are most critical in design than the others.

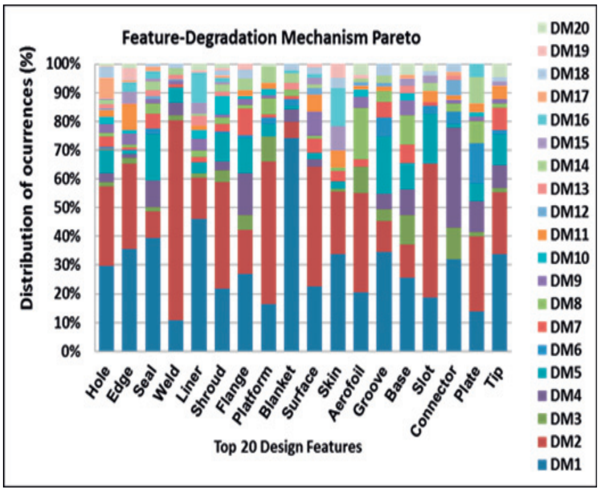

Figure 4: Distribution of features-degradation mechanisms

4.1.4. Distribution of causal information under degradation

The observation of the results from underlying causal information under mechanisms recorded, seen in Figure 5, shows that design is at the top for the root cause of certain mechanisms. However, one should be aware that the results of the analysis on causal information cannot be regarded as generally applicable to the entire population of aero-engines across the civil aerospace market.

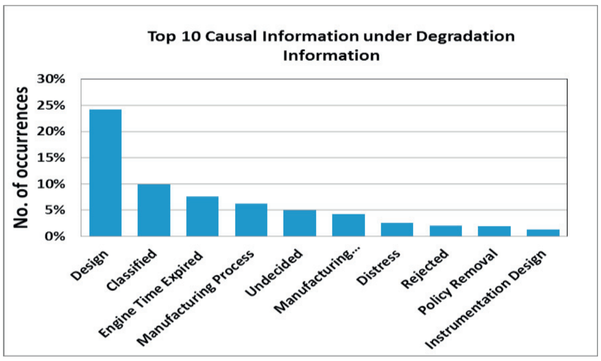

Figure 5: Distribution of causal information under degradation issues

Based on the literature [1-2], damages due to design, manufacturing and assembly, which are sources of pre-mature damage, are easier to manage as they are under the control of the manufacturer. Conversely, uncontrollable engine usage and abusage effects of the engine operational loads and component usage, proved to be a further important cause for early degradation process and damage. The majority of aero-engine components during operational takeoff and landing cycles experiences high thermal stress cycles, extreme thermal gradients, and high thermal strains increasing the likelihood of early damage and consequently an expensive component removal [2]. Therefore, a further root cause analysis (RCA) is essential to provide an effective analysis of cause of degradation.

5. Conclusion and Future Work

The concluding remarks of the paper can be summarised as below:

- Semantic data mining is a useful and quick method in the analysis of service events and issues to identify underlying information under the degradation mechanisms. It facilitates both the design and service community with a fast-track search activity in a very effective manner.

- The analysis of the service information based on previous experience was found to be useful in identifying critical service risk drivers that cause engine operational disruption and maintenance burden.

- The service data analysed under degradation information predominantly comprises of sources which represent proactive evidence of degradation mechanisms. For example, where inspections are carried out, it helps to look for the very early signs of degradation that have the potential - if left to develop - to result in some level of functional impact.

- This analysis shows that the 3 top mechanisms account for 32% of the mechanism references in the analysed data and that they have a strong Pareto effect.

- The other major observation was, as the point of service issue or event records describe symptoms and effects rather than causes, a causal rich database is required to fill the missing information.

The focus of the future work direction aims at making an effort to establish causal chains, including relationships between component degradation and design features to manufacturing processes.

Acknowledgements

This work was funded under EPSRC Centre for Innovative Manufacturing in Through-life Engineering Services, collaboration between Rolls-Royce Plc and Cranfield University.

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