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IN-SERVICE INFORMATION FLOWS TO DESIGNERS

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ABSTRACT
This research is triggered by the emerging 'power by the hour'® paradigm, in which aero engines are effectively leased to airlines, with the manufacturing company remaining responsible for their maintenance and repair throughout their service life. By incorporating knowledge about the performance of existing products into the design phase of new products, it is hoped to tackle some of the in-service problems at the design stage. In the aerospace sector, it is standard design practice to utilise the experience gained from past projects, but that from in-service has not been given sufficient attention. In this context, the aims of our ongoing research are: (1) to understand the current flows of in-service information to designers; (2) to understand the in-service information requirements of designers; (3) to develop the most appropriate theories and methods to support designers in their new task of creating engines which will perform reliably and economically throughout their service life. This paper presents the results of the initial phase of research project and addresses the first aim of the research. In particular, this paper investigates the various in-service information sources available to designers, and their content. The information stored in these sources is examined to investigate its ability to answer the designers' questions regarding in-service information.

Keywords: In-service information requirements, in-service information sources, knowledge management, design for service, aerospace engineering

1 INTRODUCTION
In the global market of air transport, integration of products and services is now seen as being necessary for the long-term success of engine manufacturers. A fundamental shift is occurring in our collaborating company, away from the selling of products to the provision of services. The company now offers 'power by the hour'® contracts, under which it leases engines to airlines while remaining responsible for their maintenance. Engines designed for the 'power by the hour'® environment require long service intervals, ease of service and high reliability [1]. The maintenance cost of engines is has now become a crucial issue for engine manufacturers. The cost of spares and the lives of components are important factors affecting the maintenance costs [2]. The body of information about the various known failure modes of different components allows designers to improve the design of new engines.
Marsh [3] found that engineering designers in the aerospace industry spent, on average, 24% of their time acquiring and providing information. del-Rey-Chamorro *et al.* [4] have highlighted the importance of information search by designers in an aerospace domain. The complexity of aerospace products calls for a broad range of knowledge and information. According to Ulrich and Eppinger [5] a product development process can be described as an information processing system. It begins with input information such as the corporate objectives, capabilities of available technologies, product platforms, production systems, etc. Then it progresses by processing the information, formulating specifications, concepts, and design details through different actions. At the end, it delivers the information necessary to support production and sales. Gibson *et al.* [6] consider an organisation as an information processing system, and state that the principal element of this system is information and the objective that an organisation effectively receives, processes, and acts on in order to achieve desired performance.
In the aerospace sector it is standard design practice to utilise the experience gained from past projects. In-service information related to the failures and malfunctions of aero engines is utilised to avoid the same problems in future designs. A flow of in-service information to designers is thus crucial for

minimising in-service failures and can also reduce the cost of both planned and unplanned maintenance.

This paper presents the results of the initial phase of an ongoing research project. The research started by arranging meetings with the members of the aftermarket team and 'design for service' (DfS) team from the collaborating company. In total, 12 such meetings were arranged. These meetings allowed us to identify some of the in-service information sources. In addition, based on the findings of these meetings and the literature review, we identified a list of 39 questions that designers might ask regarding in-service information [7]. At a later stage, semi-structured interviews with three designers and three service engineers were conducted to understand the current flows of information to designers from the experience gained in service. After these interviews, one 'module review' meeting, in which members of the aftermarket team and DfS team provide in-service information to the designers, was attended. Sample copies of the documents containing in-service information were also collected and analysed.

The outline of the paper is as follows. Section 2 presents the relevant literature. Section 3 describes the different research methods of the empirical study, which allowed collecting data. Section 4 provides the results of the data analysis. Finally, the conclusions are presented in Section 5.

2 LITERATURE REVIEW

In this section, we present the relevant literature about the importance of in-service information in the design of next generation of products, in-service information required in design, some of tools for managing the in-service information, and the summary of the reviewed literature.

2.1 Benefits of in-service information in design

James [8] observes that the failure of an engineering component or structure can be due to incomplete, inaccurate, or inappropriate information related to one or more stages of the design process, or to poor management of the design process itself. Insufficient understanding of the requirements of the system may also lead to failures. By incorporating knowledge about the performance of existing products (successes as well as failures) into the design phase of new products, it is hoped to tackle some of the in-service problems at the design stage itself. Alonso-Rasgado *et al.* [9], with reference to the design of functional that is total care products; highlight the importance of service data collection and storage. Thompson [10] describes the importance of information related to maintenance for the design actions.

Service experience facilitates the prediction of the reliability, availability of products; and plays a significant role in the maintenance optimization. Norman [11] states that reliability or availability forecasts can be based on the past operating experience. These forecasts will be precise if the sample size is large enough and unbiased. Jones *et al.* [12] describe the importance of collection of field failure information throughout the life of a product and analysing the collected data to evaluate the reliability of the product in the filed. This facilitates improving the reliability of the next generation of products.

2.2 In-service information required in design

Sander *et al.* [13], in connection with high volume consumer products, state that in order to improve future products, the entire relevant service experience from the previous products should be evaluated, stored and used. They have identified five levels to analyse and control problems in the future products: level 0 (no information available); level 1 (how many problems?); level 2 (where do they originate?); level 3 (what is the root cause?); level 4 (what can be done to prevent recurrence?). Brombacher *et al.* [14] identify the information classes needed to evaluate information flows in order to improve the quality and reliability of product. These classes are: quantification (quantitative information should be available per product, e.g. the number of failures in field and production); identification (quantitative information should be available on primary and secondary failure location; primary location of the cause of the failure within the development process; whereas secondary location is the failure-location within the product); cause (information should be available for all main failures on root-cause level; for future products this information can be translated into risks); improvement (methods and tools should be available to foresee the reliability risks for upcoming products and to eliminate these risks).

A clear understanding of the causes behind the failures of existing products is important in the design of the next generation of products. Petkova [15] describes the field feedback of the consumer electronics products that companies need to make decisions related with the product quality.

2.3 In-service information management systems

Thompson [10] states that the operating records are vital information-sources for the designers. Redesign can help to solve the problem. The interviews with maintenance personnel and records kept by them provide useful information to the designers. He describes a plant data feed back system that is an integral part of the design activity (see Figure 1). It is an active system that allows the use of data from design and plant operation. It has an active element that receives data from plant operations, design reference, and generates output. The technical details of the plant, which are stored in the design reference, assist in understanding the designers' expectations of the plant's behaviour. Operating data are collected from plant operations and maintenance. This data is compared with the expectations of performance that are in the design reference. Regular reports of performance and the reports comparing the actual performance with the design reference expectations are generated. A database is created from the plant operating information such as failure rate data, maintenance times and history of maintenance actions carried out on the plant.

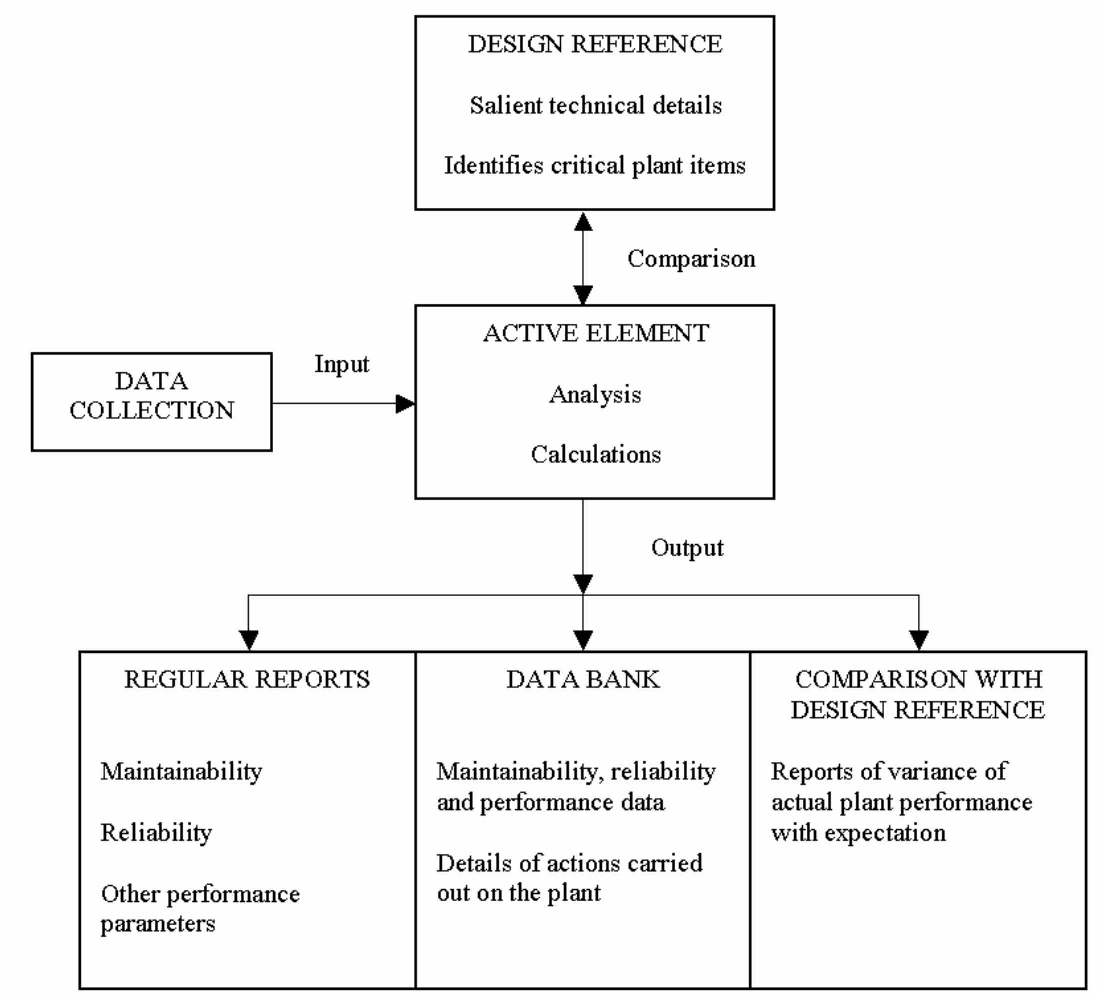

Figure 1. Feedback system model [Thompson, 1999]

Sandtorv *et al.* [16] have presented the results and knowledge gained from a project called OREDA (Offshore REliability DAta). The application of the OREDA data was in the risk and availability studies in the early concept and engineering phases of an offshore development and also in maintenance optimization. In order to organise the data, they have created three related database files for given equipment category: an Inventory part, a Failure part and a Maintenance part. The Inventory part contains a technical data such as capacity, size and some operating and environmental data such as operating mode, vibrations of each equipment unit such as a pump. The inventory description is stored in one Inventory record in the database. Information about all failure events experienced by an equipment unit during the time of surveillance along with one failure record for each failure event are stored in the Failure part. The information related to the preventive and corrective maintenance carried out, e.g., maintenance action and manhours, is stored in the Maintenance part of the database.

Houshyar *et al.* [17] developed a software program that enables operators to enter data which can be used by the design engineers and reliability engineers. The software program makes use of data on performance of the equipment. It generates statistics on the reliability and maintainability of the machinery. The data collected was related to manufacturing machinery and equipment.

Reliability data banks can be based on the service experience. Cooke *et al.* [18] highlight the users of the reliability data banks as: the maintenance engineer; the component designer; and the risk/reliability analyst. Lannoy *et al.* [19] state that for creating a database from operation feedback it is necessary to identify the needs of its potential users. The data regarding reliability, maintenance, operations, service, market, management focus, etc. facilitate to improve the product. The data has to be stored in systems that make it easy to retrieve, analyze, and draw conclusions [20]. Identification of end users and their requirements facilitate the design of the information system.

2.4 Summary of literature review

According to the reviewed literature, the in-service information useful in the design stage of the products covers: cost of spares, in-service life of components, types of failures in the field, the causes behind the failures, the data regarding reliability, etc. The in-service information is useful in: evaluating the reliability of the product in the field; predicting the reliability and availability of products; maintenance optimization; improving the reliability of the next generation of products, etc.

There is minimal literature on in-service information in general, and about aero engines in particular. The paucity of the literature on field feedback has been highlighted by Petkova [15]. The reviewed literature suggests the importance of identification of the potential users' needs in developing an in-service information system, but the literature does not explain in detail the requirements of these potential users, including designers. Also, the literature does not explain in detail the in-service information sources, and tools to manage this information.

3 RESEARCH METHOD

An exploratory study has been carried out at the collaborating aerospace company to answer the following research questions.

1. What are the in-service information requirements of designers?
2. What are the in-service information sources available to designers?
   - 2.1 What is their content?
   - 2.2 Is the information contained in these sources sufficient to answer the designers' in-service information requirements?

Different data collection methods contributed to answer these research questions (see Table 1). In particular, this paper focuses on question 2, above. In order to address this question, it was necessary to understand the information flows to the design department from the department concerned with the operation of existing products. In large scale engineering companies, information is exchanged through various channels. It was required to collect the data while satisfying the constraints imposed by the company such as unavailability of company employees, confidentiality requirements, and proper utilization of valuable time of the company experts. Under these circumstances, several research methods were used for the collection of data. In addition, the multiple data collection methods allowed us in updating our understanding, cross-checking the findings and clarifying various questions which emerged, leading to an improved understanding of the research questions.

Table 1. Different research methods and the research questions

Sr. No.	Research Methods	Participants	Sample size	Duration	Research Questions	
					Question 1	Question 2
1	Meetings	Designers, DfS, after market team members	12	2 to 5 Hrs each		
2	Documents analysis	Not applicable	25 different types	NA		
3	Focus group	Experts from DfS and after market team (4 members each team)	1	1 Day		
4	Interviews	Designers	3	60 to 90 Minutes each		
5	Questionnaire	Designers	3	30 Minutes each		
6	Interviews	Service engineers	3	60 to 90 Minutes each		
7	Observation (Module review meeting)	8 Designers, 8 DfS team members	1	3 Hrs		

Figure 1 shows an overview of the periods over which the different data collection methods were used; for example, meetings took place over the entire 18 months duration.

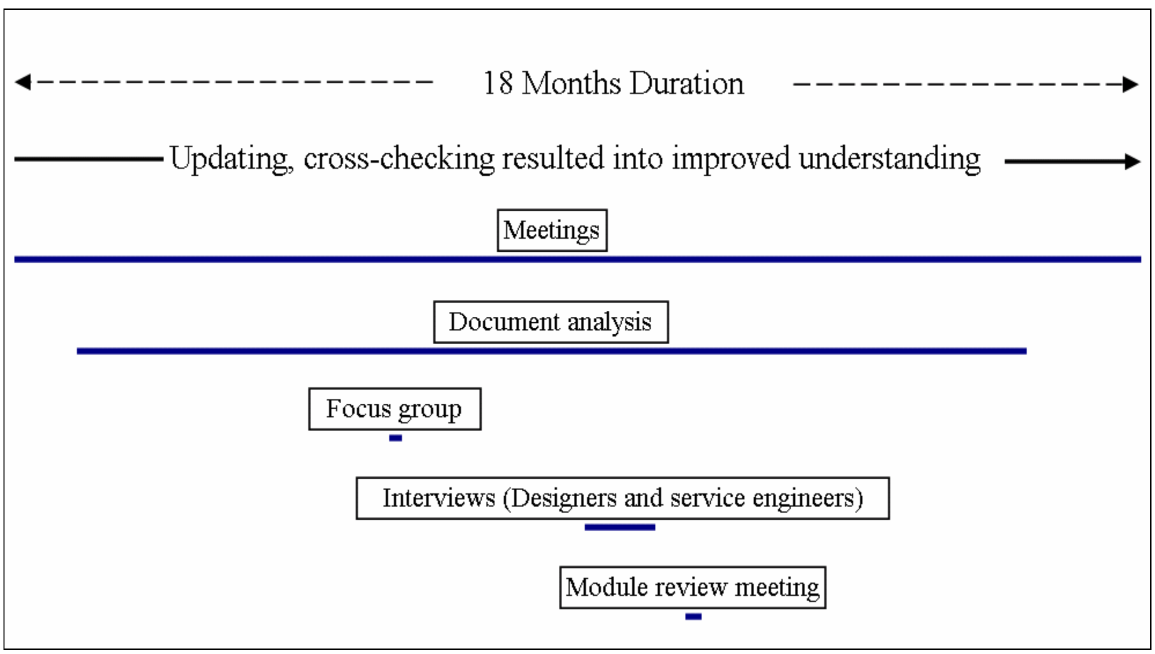

Figure 1. Distribution of data collection time for different methods (Figure is not to the scale)

The data collection methods are described below.

- Meetings:

The research started by arranging meetings with the members of the aftermarket team and DfS team and designers. The description of the aftermarket team and the DfS team is presented in the section 4.1.1. In total, 12 such meetings were arranged. In each of these meetings, at least one designer, one member of the DfS team, and one member of the aftermarket team were present. Collectively, these meetings allowed us to interact with 8 designers, 7 members of the DfS team, and 4 members of the after market team. These experts have different range of years of experience, and are involved in different tasks. The notes taken during the meetings allowed us to document the information for further analysis.

- Focus group:

The collaborating company arranged a one day course to provide an overview of:

1. the different activities of the company regarding in-service information capture, storage and sharing;
2. the various personnel and their roles regarding this in-service information transfer to designers.

In this focus group, the members of the various teams related to the in-service information explained their activities. In addition, the focus group involved discussion between researchers and company experts. The focus group was audio recorded and transcribed by the company; and the transcripts were provided to the researchers.

- Module review meeting:

A module review meeting was observed. This meeting is between the aftermarket team members and the designers. The members of the aftermarket team present information related to service issues of various components of a module (e.g. high-pressure and intermediate-pressure compressor). The objective of the meeting is to share information. Generally, one meeting covers one module. The systems, components covered in the module depend on their contribution to events, repair/replacement cost etc. Designers ask questions to the members of the aftermarket team.

The meeting was attended by 8 members of the aftermarket team and 8 designers. The duration of the meeting was 3 hours. The observed module review meeting covered major components from the HP and IP compressor. Audio recording of this meeting was not allowed because of the commercially sensitive nature of the shared information. The notes taken during the meetings allowed us to collect information for further analysis.

- Documents analysis:

Various in-service information documents were collected and analysed to understand their content. The details of these documents are presented in the subsequent sections.

- Interviews:

Semi-structured interviews with 3 designers and 3 service engineers (SE) allowed collecting some of the information. All interviews were audio-recorded. The notes taken during the interviews allowed documenting the information for further analysis. These notes were updated after listening to the audio recordings. The time of each interview was 60 to 90 minutes. After the interview, designers were requested to comment on a list of 39 questions regarding in-service information, indicating how frequently they might ask each question when designing a new component or system [7].

4 FINDINGS

The data collected through the different data collection methods was heterogeneous, and the analysis was qualitative. The findings described below are based on the analysis of data collected through the various methods described in section 3.

4.1 Current information sources and their content

The principal information sources used by designers at present are the aftermarket team, and various service documents.

4.1.1 Aftermarket team

The aftermarket team is comprised of service engineers, service representatives, and technical services and operations (TS & O) team. The service representatives act as a medium of interaction between the collaborating company and airlines. They need to interact with the various departments of airlines such as: commercial department (e.g. commercial and marketing aspects of the business); supply department (e.g. procurement of spare parts); and maintenance control area and power plant department (e.g. the maintenance of engines). Mostly, their interaction is through e-mails, phone calls, and face-to-face discussions with the airlines and the collaborating company’s employees. Service engineers are located at repair and overhaul (RO) centres, and provide expert support in identifying and solving emerging problems. The service representatives and service engineers are responsible for populating the document repository with maintenance reports and other similar documents. The TS&O

team is concerned about the in-service operation and management of existing fleet engines and technical publications. They can use the collected in-service information to monitor trends that develop over a fleet of engines.

Designers do not generally have time to make detailed searches through the in-service information in detail. The present flow of in-service information to designers is schematically shown in the Figure 2. The aftermarket team provides the relevant information to the DfS team in summarised format. The role of DfS team is to: analyse the in-service information in order to identify emerging patterns; provide this information or patterns to designers; answer queries of the designers regarding this information. The aftermarket team is principally concerned with the predictability of service, and with reducing in the cost of repair and overhaul. Based on this summarised information about a particular module, DfS team arranges module review meetings with the designers concerned with that module.

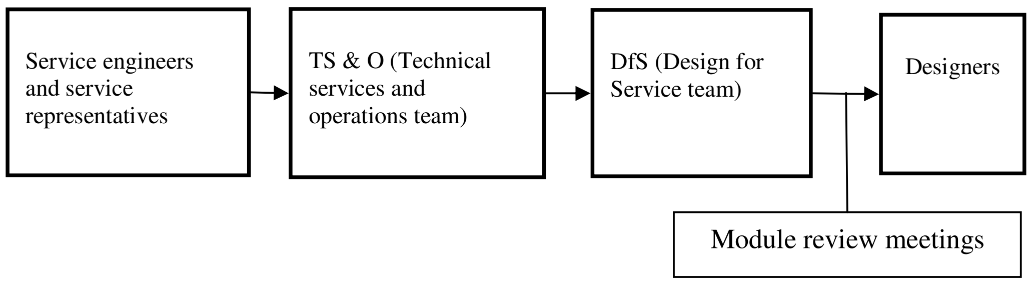

Figure 2 In-service information flows to designers

4.1.2 Service documents

In total, there are 25 different types of in-service information documents. Out of these 25 documents, 19 were collected and analysed; while the content of the remaining 6 documents was explained by the company experts during interviews, meetings, and focus group. These 6 documents were not provided to the researchers because of their content's commercially sensitive nature. The content of these 25 documents is classified in the following categories:

- events: provide information about minor failures, the corresponding components involved, etc.;
- safety events: describe major events such as crash, loss of life, actions taken to close them, etc.;
- causes: explain the root causes behind the failures;
- failure mechanisms: provide information at the component level, e.g. the level and details of failure mechanisms such as oxidation, erosion, wear, etc.;
- redesign: informs the design changes to a component of an existing engine;
- design requirements: provide the requirements related to the in-service issues to be satisfied by a components of a new engine;
- statistical analysis: related to the reliability analysis;
- RO centre findings: provide pictures, summary of parts that are replaced, repaired, accepted; reasons for the rejection of a component, etc.
- information to customers, RO centres: make customers, RO centres aware of any changes (e.g. changes in engine design, maintenance instructions, etc.) made to an engine or its spare parts, the likely effects on engine manual, aircraft maintenance manual, etc. These documents provide information about the cost of each component and its service life under specified conditions, etc.
- engine health monitoring: provide analysis of the data collected by monitoring the health of the engine in situ to identify any potential problems.

Table 4 shows the information content category and the associated number of sources. The information content of some of the documents is associated with more than one of these categories.

Table 4. Information content category and the number of sources

Sr. No.	Information content category	Number of sources
1	Events	4
2	Safety events	4
3	Causes	4
4	Failure mechanisms	2
5	Redesign	3
6	Design requirements	4
7	Statistical analysis	1
8	RO centre findings	1
9	Information to customers	3
10	Engine Health Monitoring	1

Out of the 25 different types of documents, designers refer to 10 types either frequently or occasionally.

Some of these documents are created at several sites around the world, in the collaborating company or RO centres that are not owned by the collaborating company, or at airports. This has resulted in a large variety of formats, as many report types are unstructured.

4.2 Designers' in-service information requirements and availability of in-service information

As mentioned in Section 2, semi-structured interviews and questionnaire with three designers allowed us to understand the in-service information sources and the in-service information requirements of designers [5]. The questionnaire and the interviews showed that designers were interested in the in-service information related to the following categories:

- maintainability (e.g. accessibility, facility to detect and isolate failure);
- reliability (e.g. Weibull analysis of reliability);
- failure mechanisms (e.g. failure mechanism, failure mode, causes, consequences, how identified, etc.);
- service instructions (e.g. inspection/repair/replacement recommendations, service standards/regulations, etc.);
- operating data (e.g. variation of different performance parameters with engine type, operator, etc.);
- component cost (e.g. component cost of ownership management strategy, repair cost, replacement cost, etc.);
- design information (technical diagrams, the materials used for different components, information related to redesign aspects of an existing component, etc.).
- component life (e.g. longest/shortest life of a component, component's average life, change in component life with the change in inspections/overhauls intervals, etc.)

The steps to identify the availability of in-service information to answer designers' questions are as follows:

1. understanding the information stored in the various in-service information documents by analysing the sample copies of these documents;
2. selecting one question at a time from the list of 39 questions [5], and examining which of the documents can answer that question;
3. confirming the output of step 2 by discussing with the members of the aftermarket team and DfS team.

The information required to answer the 39 questions [5] is available in these various documents. The information required by designers is buried within the documents, and it would be very time consuming for them to search through large number of documents. Figure 3 shows an illustration of the availability of information for answering designers' in-service information questions. For example, the pictures of the failed parts are stored in the information source 4.

		Service Informaion Sources																								
Sr. No.	Designers' Questions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	What are the common failure mechanisms associated with this part?																									
2	Can I see a picture showing a failed/damaged part?																									

Figure 3. Availability of information for answering designers' in-service information questions

4.3 Positive and negative aspects of the current in-service information system

Designers think that the positive aspect of the current system for gaining in-service information is the availability of contacts with the aftermarket and DfS team.

The designers think that the negative aspects of the current system to gain in-service information are:

- at present, it is difficult to gain a complete picture of the service information;
- not enough details about the cost of overhaul and repair are available;
- an information system which can pull information from the various sources and present it in a summarised format is not available;
- complete feedback on the design changes which are successful in service is not available.

5 DISCUSSION

The use of different data collection methods such as meetings, focus group, interviews, questionnaire and analysis of documents containing in-service information allowed us to explore the available in-service information and confirm the findings of the individual methods. The information required to answer the questions that designers would ask regarding in-service experience is available; but it is in distributed and heterogeneous format across different information sources.

Ahmed *et al.* [21] propose two stages to differentiate between data, information and knowledge: an awareness stage and an interpretation stage. In the first stage, if a person is aware of the context of the data, the data has meaning for that person and it becomes information. The second stage is interpretation. If a person is able to interpret the information, the information can become knowledge. Figure 4 illustrates these terms for structuring the in-service information for the designers.

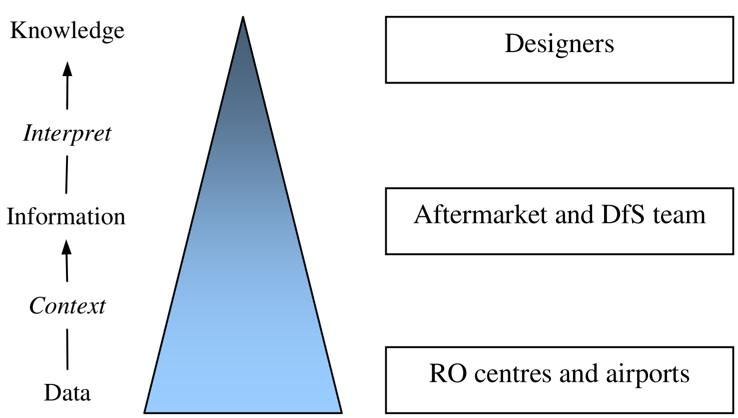

Figure 4 In-service data, information, and knowledge

At present, the in-service data is collected at RO centres and airports. The members of the aftermarket team and DfS team are aware of the context. The relationships/links between the various existing documents, databases, etc. that are known to these teams facilitate in gaining this context and obtaining in-service information. At present, in the collaborating company this information is presented to the designers through the module review meetings. This information is interpreted by the designers to obtain knowledge, and make appropriate decisions.

As designers do not generally have time to make detailed searches through the various service information documents in detail, it would be helpful to support them with a tool or method which can pull information from the various sources and present it to them in a summarised format relevant to the design task. The existing in-service information that is available in the various sources needs to be structured to satisfy designers' in-service information requirements. Information extraction from text [22] can facilitate in populating a database with the information extracted from several sources (see Figure 5).

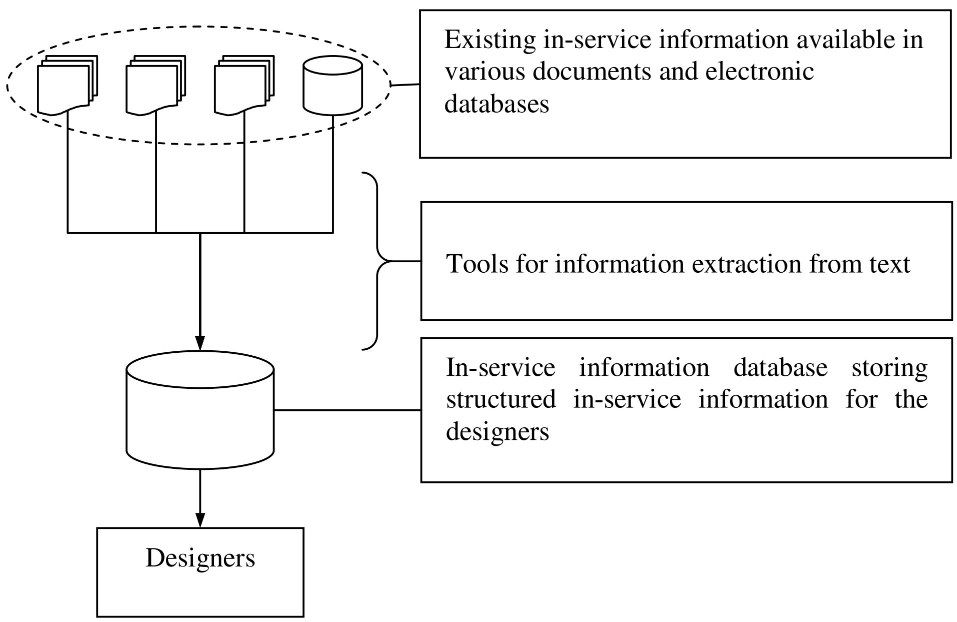

Figure 5 Structuring existing in-service information to satisfy designers' information requirements

At present, the various sources of in-service information such as documents, electronic databases, etc. are not designed for satisfying the designers' information requirements. The format of these sources has been primarily developed for managing the operation of existing engines in service. The new in-service information that will be captured in future can be captured in the information sources that are designed to satisfy requirements of all stakeholders including the designers. The in-service information database (see Figure 5) can be directly populated by the information stored in such structured sources without any need of sophisticated computer tools. The information stored in the in-service information database can be retrieved by the designers in a user-friendly way.

In addition to the in-service experience of the components/systems of the existing engines, it would be useful if the information regarding the expectations of the designers of the existing components/systems is presented to the designers of the new components/systems. This will allow the comparison between the actual in-service experience of the existing components/systems and their final specifications that determine the expectations of those components'/systems' designers. The results of this comparison can enable the designers of the new components/systems to understand the success/failure of the concerned component/system, and allow them to formulate appropriate requirements for the new component/system. Furthermore, the in-service experience would be useful in generating alternative solutions for the new components/system.

It would be useful to have meetings between designers and the members of the aftermarket and DfS team, as these meetings enable the transfer of knowledge from the aftermarket team and DfS team members, which is not otherwise available through in-service information database.

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