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INVESTIGATING KNOWLEDGE SEARCHES IN AEROSPACE DESIGN

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Abstract

This research was undertaken to develop empirical understanding on how information searches are carried out in the aerospace industry. Ethnographical participation was used in conjunction with observations involving shadowing and diary-study methods. Ethnographical methods were adopted to characterise aspects of the social and organisational behaviour of engineers in an aerospace company and to generate insights into information searches undertaken in a real working environment. A group of fourteen engineers was instructed to fill out real-time design diaries for five weeks. This paper presents a preliminary model of the types of searches carried out, based upon the analysis of the diaries completed by five designers.

Keywords: Diary study; empirical research; knowledge acquisition; aerospace design

1 Introduction

Previous research indicates that engineering information searches are essential steps in the design process and engineering designers daily need to undertake searches to proceed with their tasks [1]. However, the requirements that engineering designers make on this information are not fully understood and further research in this area is required. Our research interest is in developing a detailed investigation into the sequence of steps that lead design engineers from the identification of an information requirement to the search, recognition and subsequent reuse of information and knowledge. This work extends the research into design management in an industrial context by Hales [2] and continues research into knowledge searches and the use of experience by Marsh [3]. The research was conducted within a major aerospace company and is part of a larger research project currently in progress.

2 Information searches: current understanding

The aim of this research is to contribute to research in design knowledge capture by investigating what information designers spontaneously require throughout the design process. Many of the studies that have contributed to developing an understanding of information requirements have focused on how designs are created, rather than on the precise information that is required [4]. Moreover, many studies have attempted to establish designers' requirements by understanding how and where designers access information and what information they use. Very few studies have focused on understanding what triggers designers to undertake knowledge and information searches. Consequently several detailed accounts of sources and media used by designers, together with time spent on information seeking practices, have been produced, whereas few studies have been undertaken on understanding why designers need knowledge and information. In addition to this, all these studies differ in their nature, data collection methods, environment where the study was conducted, number of subjects, and type of design. It is therefore very difficult to relate the findings. Some observations from previous research relevant for this study are:

- Designers were observed to spend a quarter of their time engaged in information seeking activities. During these activities, approximately one third of the design queries observed related to process-based requirements and one quarter reflected product-based requirements [3];
- Designers are interested in design information other than that found in design standards documentation. Information about the operation and purpose of a design object is often sought [5];
- Designers do not carry out designs with a pre-determined set of information requirements. They raise requirements as new information is needed. Exposure to information accessed triggers new requirements as well as reflection on information received in answer to previous requirements. The type of requirements also depends on the form in which the information is available to designers [6].

There is still insufficient detailed understanding about why designers raise specific information requirements. This understanding could provide the basis to identify how the way information is made available to designers might be improved.

3 Research approach

3.1 Research methodology

Research into why engineering designers in the aerospace industry seek knowledge and information required a methodology capable of studying the interplay between people-laden contexts and expert cognition. When seeking the most appropriate methodology, we were influenced by the concept of cognitive ethnography [7], which argues for a limited use of ethnographic methods for human factors research. The use of ethnographic methods can be distinguished from pure ethnography in terms of purposiveness, verifiability and observational specificity. However, in our study we have extended the concept of cognitive ethnography by supporting it with very specific data collection methods, such as diary studies and observations with shadowing. We believe that the use of this approach has enabled us to investigate knowledge and information searches by putting sufficient emphasis on the design aspect as well as the situational and social factors. For more details about the methodological approach see [8].

3.2 Data collection

Three different data collection methods were employed: (1) participant observation; (2) diary study including post-diary study interviews; and (3) observations with shadowing. In this paper only the methods employed for the first two approaches are described. These are summarised below.

During participant observation, the researcher carried out design work for nine weeks as member of a design department within the collaborating aerospace company. Before starting as the participant observer, a number of meetings were held with managers from the selected design department. The researcher was assigned a design task and a supervisor. He was given a desk in the open-plan design office of the department. The researcher was frequently involved in design discussions and throughout the period took daily notes addressing issues related to how information searches were undertaken by himself and by the designers in the group where he was working.

Diary studies are widely used in social psychology, but engineering design research has not made as much use of this technique compared to other real-time methods for data collection. To account for the high variety of information and knowledge searches undertaken throughout the design process, this research employed diaries. These provide a means of gaining information from participants in great detail over an extended period of time [9]. The study was conducted for five weeks and twelve design engineers agreed to complete real-time design diaries. They were asked to ensure that they took their diaries with them every time they left their desks. The sampling process was negotiated first and then agreed with managers from the collaborating design department. The diary form itself was developed through an iterative process with three design engineers selected to test it. The final design of the form to be filled in was strongly influenced by the need to minimise the burden on designers. A diary consisted of a number of A4 bound forms, each containing a table with the following *classes*:

- GOAL: the ultimate aim of the design task/activity performed by the designer
- REQUIRED INFORMATION: statement or question representing the information needed by the designer at the time
- SOURCE: where the design information can be obtained from
- MEDIA: means by which information is communicated or stored
- START TIME: time when the search was started
- OUTCOME: result of the information search
- END TIME & DATE: time & date when the search was concluded
- COMMENTS: any additional issues that the designer wanted to point out.

At the time of starting the study, training was provided to all participants by supplying basic instructions together with instances of how the forms should be filled out. Halfway through the first week, further training was offered to each of the participants in the form of short discussions to review how the diaries where being maintained. At the end of each week, feedback was provided by means of pre-scheduled meetings. Attendance of these meetings varied a lot. To provide background information about the design tasks and to further investigate each of the knowledge searches undertaken from the subjects, 15-80 minutes semi-structured interviews with audio-recording were conducted at the end of each week for each of the participants. During these interviews, the design diaries were used as pointers for the designers to describe the knowledge searches that they had undertaken and to recall relevant episodes associated with them. Questions the designers were asked included: (1) how is this search related to the previous ones; (2) what triggered your need for this piece of information; (3) did you find the information you were looking for. Intensive retrospective protocols were generated out of these interviews and these were used in conjunction with the diaries for the analysis phase.

3.3 Data analysis – coding category identification

The diaries and the transcripts from the interviews were analysed simultaneously. The unit of analysis was each information-seeking episode captured by a designer. The research has been data driven and it is still in progress.

In the process of data analysis, five coding categories required to be generated, one for each of the *classes* in the diary. The coding procedures are as follows:

- Developing coding categories for search: goals;
- Developing coding categories for search: required information;
- Developing coding categories for search: source;
- Developing coding categories for search: media;
- Developing coding categories for search: outcome.

As the search goals, sources, media and outcome are not the focus of this paper, the discussion will be based around the development of the coding categories for *required information*.

The *required information* represents the designer's information need at the time a search episode was undertaken. The needs were formulated either as short statements describing the requirements or as questions raised in the designer's mind. The heading *required information* was assigned to this diary-class during the pilot-study. At that point this seemed to be the best way to capture all designers' general needs. A number of categories for the search required information were developed based on the diary-study episodes and supplemented with the post diary-study interviews. The answers to the interviewer's question 'what triggered your need for this piece of information?' enabled the reasons for a designer undertaking a search to be captured. These were subsequently identified and analysed together with the related diary-study episode. The categories were developed by making comparisons among the analysed searches. *Required information* was divided in into three categories: (1) exact search; (2) exact search to understand; and (3) search for understanding. An *exact search* was undertaken to confirm, identify, obtain and define information and data of different nature, see Table 1. An *exact search to understand* was undertaken to obtain an exact piece of information that would lead to improved understanding on a particular issue. An *understanding search* was undertaken to gain understanding directly. The term *understanding* is used here to mean procedural and declarative understanding in a number of domains. See Table 1 for an overview of the domains identified in this study. For instance, in the material domain, declarative understanding was used to indicate understanding on how a material behaves and it is used. Procedural understanding was used to indicate attempts to gain understanding on how to proceed with a design task, e.g. what need to be considered to carry out an activity.

When analysing the required information episodes, two elements emerged as key parameters characterising different aspects of the searches: (1) possession; and (2) search context. These two elements together with the three categories generated for the *required information* have been used to characterise four main *search types* and a total of twelve *search sub-types*, see Table 2. An overview of these elements is now presented:

- *Possession* was identified as an important element in modelling the searches because it enabled the partial characterisation of the conditions prior to the start of a search. The search episodes were distinguished depending whether the likely outcome of the search was known or not-known prior to the start of the search. Knowledge of the outcome was inferred either because the designer stated it or because the search was previously undertaken with a successful conclusion.

- *Context* was used to characterise the searches collected throughout this study depending on whether the topic was *static*, i.e. not associated to the project, *current*, i.e. associated to the current project, or *past*, i.e. associated to past projects.

Table 1. Nature of exact searches and understanding domains

SEARCH	NATURE OF EXACT SEARCHES & UNDERSTANDING DOMAINS
Exact	Material, geometry, weight, pressure, temperature, stress, feature, configuration, manufacture, timescale, cost, administration, terminology, notation, document, contact, etc.
Understanding	Procedural and declarative understanding was sought in the following domains: engine, manufacturing processes, materials, etc.

4 Findings: search types

The results presented in the following sections are based on the analysis of 215 search episodes collected by five designers during five weeks of design work. Although designers frequently work on different projects and each at a different stage of the design process, they clearly use common approaches to information seeking. As shown in Table 2, four main *search types* and a total of twelve *search sub-types* emerged. Each *search sub-type* has been assigned a code that will be used throughout this paper to refer to it, e.g. 1S.

Table 2. Search types and sub-types

	POSSESSION	SEARCH		CONTEXT
1	Outcome is known	Exact search	1S	Static
			1C	Current
			1P	Past
2	Outcome is not known	Exact search	2S	Static
			2C	Current
			2P	Past
3	Outcome is not known	Exact search to understand	3S	Static
			3C	Current
			3P	Past
4	Outcome is not known	Understanding search	4S	Static
			4C	Current
			4P	Past

Table 2 shows that it was only possible to identify whether the outcome was known or not known in the case of exact searches. This implies that search sub-types 1S and 1C were undertaken to confirm, whereas search sub-types 2S, 2C and 2P where undertaken to identify, obtain and define. However, search sub-type 1P needs a special note. When considering this search sub-type, knowledge of an outcome assumes a different meaning. The designers in fact did not undertake these searches to confirm past design information but rather to compare information available on the current project with information associated with past projects. Therefore in these searches the designers were found to know only information on the current project. This information has some degree of similarity with that being sought either because associated to a similar feature/component or because pertaining to similar environmental conditions. Knowledge of the likely search outcome prior to the start of the search was not observed when designers undertook exact searches to understand, sub-types 3S, 3C and 3P and understanding searches, sub-types 4S, 4C and 4P. Whether processes of confirmation for these searches sub-types exist or not is still unclear. Further research is required to better understand them.

Definitions for each *search sub-type* are now given together with some examples from the search episodes collected from the diaries kept by the designers, along with a significant fragment of the transcript from a post diary-study interview.

Definition 1S: exact search to confirm information not associated with the project.

Table 3. Example of search sub-type 1S

GOAL	REQUIRED INFO	SOURCE	MEDIA	OUTCOME	COMMENTS	TRANSCRIPT
Can we make the Trent 500 IGB sump from Jethete	Is weldability of crown max c & Jethete as good as material database suggest?	P.D.	Telephone	Not at phone	Will try another material contact	...I wanted to check this with somebody from Materials.

The search episode in Table 3 shows how a designer unsuccessfully attempts to contact via phone a colleague to confirm material properties. The designer had already obtained these material properties during a previous investigation into a material database. This can be inferred both by the way in which the required information was formulated and by the designer's statement, recorded during the post diary-study interview, see *transcript cell*.

Definition 1C: exact search to confirm information associated to the current project, e.g. search for material specification.

Definition 1P: exact search to compare information associated to a past project with that associated to the current project, e.g. search for weight, pressure and temperature in a past engine design.

Definition 2S: exact search for information not associated with the project, e.g. search for standard part dimensions, availability and material.

Definition 2C: exact search for information associated to the current project.

Table 4. Example of search sub-type 2C

GOAL	REQUIRED INFO	SOURCE	MEDIA	OUTCOME	COMMENTS	TRANSCRIPT
Establish critical date for ordering stubshaft forging material	Representative material & machining lead times	J. P. (Has completed similar exercise)	Face to face	Have lead times for material & m/c	Lead times seem high - wish to confirm numbers with manufacturing	I'd like to put it into a plan which shows what we need to do and when we need to do it

The search episode in Table 4 shows how a designer searches for representative material and machining lead-times by asking another designer in a face-to-face conversation. As shown by the transcript from the post diary-study interview, see *transcript cell*, the information is sought to put together an action plan. It is noteworthy that in the *comments cell* the designer indicates his intention to confirm this piece of information. This episode anticipates in fact a search sub-type 1C.

Definition 2P: exact search for information associated to a past project, e.g. search for classifications given to shaft forgings in past projects.

Definition 3S: exact search for information not associated to the project to gain understanding, e.g. search for material data to understand a part's deflections might be.

Definition 3C: exact search for information associated with a current project to gain understanding, e.g. search for pressure values to understand issues associated with diameter variation.

Definition 3P: exact search for information associated to a past project to gain understanding.

Table 5. Example of search sub-type 3P

GOAL	REQUIRED INFO	SOURCE	MEDIA	OUTCOME	COMMENTS	TRANSCRIPT
Design the interface between the static and the rotating seal parts	What are max stress predictions on Trent 500 part?	EKES stress plots	Paper plots	Max & min stress values for various flight cycles	Will compare to material properties on Commit database	I wanted to understand the history behind the Trent 500 part

The search episode in Table 5 illustrates how a designer is searching for max/min stress values on a past project part to gain understanding of its history. The specific aim of the designer in this case is to investigate opportunities to use the same material as was specified on the past project part.

Definition 4S: search for understanding not associated to the project, e.g. search for understanding on how to pre-release a drawing.

Definition 4C: search for understanding associated with the current project, e.g. search for understanding on effects of a damaged flange on mating parts.

Definition 4P: search for understanding associated to a past project.

Table 6. Example of search sub-type 4P

GOAL	REQUIRED INFO	SOURCE	MEDIA	OUTCOME	COMMENTS	TRANSCRIPT
Define HP turbine bearing	Reason for specifying gravity condition during oil interuption	P.J. - author of specifica-tion	Face to face conversa-tion	Specification understood		…reading through the report on the previous diary entry I found a specification for the HP turbine bearing which is of interest to read as I have one of these in my assembly.

The search episode in Table 6 presents an example of a requirement that was triggered by exposure to a report being browsed to satisfy a previous information requirement, see *transcript cell*. It is noteworthy that although this requirement was raised halfway through the previous search, a first attempt to satisfy it was only started when the preceding search was terminated. The designer expressed an interest in understanding a specification for a past project part, the Trent 500 HP turbine bearing, as he was looking at a similar part for a new engine application. To understand this requirement, the designer engaged the author of the specification into a face to face conversation, which had a successful conclusion.

5 Findings: frequency of search types

Frequency of occurrence of the identified search types is shown in Figure 1. It is interesting, initially, to consider this chart independently from the search types and focus on the search context. An even split between searches for information directly associated to the current project and searches for project independent static information can be observed. Searches within these two contexts accounted for 77 searches (36%) out of a total of 215 searches. Searches to revisit past projects accounted for 61 searches (28%). As more than one quarter of the searches revisit past projects, the reuse from past experience is clearly significant in the aerospace industry.

Statistics for each search type are now discussed. As shown in Figure 1, the results for *search type 1* (1S+1C+1P) indicate that 36 (17%) out of the 215 searches studied were undertaken to confirm static or current information, and to compare current and past project information. It is however important to note that 10% of the total consists solely of searches undertaken to compare information on a current project with that on a past project, search sub-type 1P. As previously reported it was found that in these searches designers look for similarities of design and environment conditions.

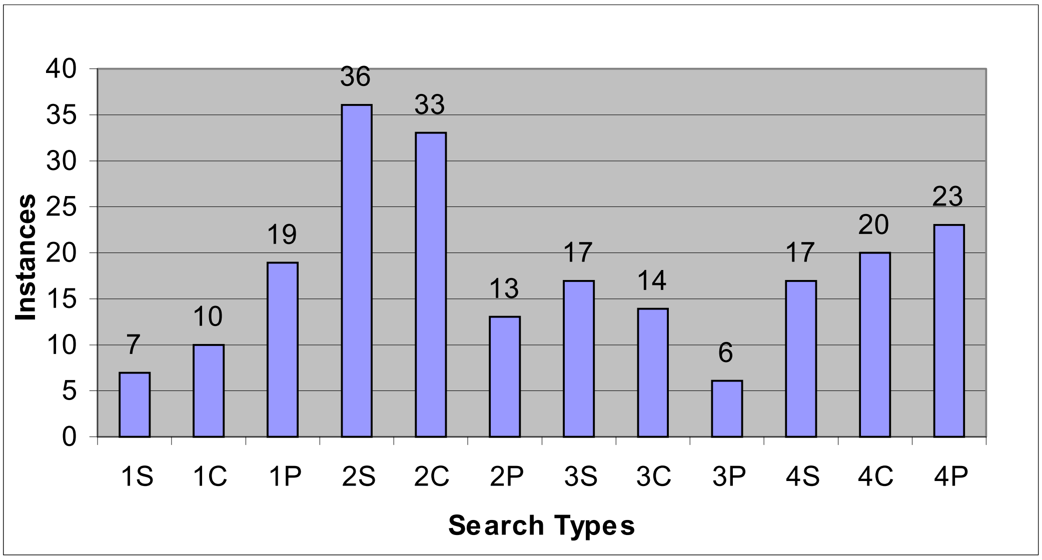

Figure 1. Frequency of the Search types

Search type 2 (2S+2C+2P) is the most frequently undertaken. Overall 82 exact searches were carried out independently of the search context. In this type, searches for static and current information far exceed those for past design information. Exact searches to understand, *search type 3* (3S+3C+3P), occurred almost as often as exact searches, type 1. A total of 37 instances were counted. These are searches generally aimed at obtaining information that would help to understand a design. *Search type 4* (4S+4C+4P) is the second most frequently undertaken. In total 60 searches for understanding were reported.

This analysis revealed that searches for understanding, whether direct or through intermediate information searches represent a total of 97 searches. This indicates that these two classes are nearly half of the total amount of searches undertaken by designers.

6 Conclusions

This research has been undertaken in an industrial context using ethnographical methods in conjunction with more traditional methods for engineering design research. The combination of ethnographical participation and diary-study methods has enabled us to identify various types of design searches in a way that differs from contributions gained in previous studies. A preliminary categorisation and analysis of how searches are undertaken in the aerospace industry has been completed. A number of search types and the differences between them have been identified. Around 45% of searches undertaken by designers are aimed at gaining understanding rather than confirming and answering specific queries. However, data analysis has also raised a number of issues that needs to be further investigated. Further work is required: (1) to understand to what extent conditions prior to the start of a search can be characterised; (2) to investigate features of the understanding sought by designers; and (3) to identify where designers attempt to gain understanding from, and whether or not they are successful in it. Understanding gained from this first preliminary study will be used to improve subsequent data collection stages.

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