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BARRIERS TO CREATIVITY IN THE CONCEPTUAL PHASE OF ENGINEERING DESIGN: PERCEPTIONS OF DESIGNERS AT ROLLS-ROYCE AEROSPACE (BRISTOL) IN NEW PROJECTS ENGINEERING

by

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Barriers to Creativity in the Conceptual Phase of Engineering Design: Perceptions of Designers at Rolls-Royce Aerospace (Bristol) in New Projects Engineering

Abstract

Anecdotal evidence from experienced engineers suggest that barriers to creativity are often due to the limitations of current technology, methods and support systems (Baird, Moore, & Jagodzinski, 2000). The aim of this research was to explore what the perceived barriers to creativity are and how they are circumvented by design engineers working in New Projects Engineering (NPE), Rolls-Royce Aerospace (Bristol).

Semi-structured interviews with four employees working in engineering design comprised a Scoping Study. This provided a general overview of the major issues perceived by the design engineers regarding barriers to creativity and resulted in six themes being identified. These themes were used as a framework for a Design Group Interviews Study that followed. Sixteen engineers comprising project managers, team leaders, experienced designers and new designers, graduate employees and trainees were interviewed using the same method. Using grounded theory to analyse the data, sixteen categories were drawn from the data. Confirmation of the findings was achieved through presentations and workshops with different groups from Rolls-Royce, and the development of an Interrelationship Digraph illustrating the relationships between the categories.

The second phase of the research focused on the phenomena under current working conditions. In the Tracking Study interview diaries recorded with thirteen design engineers over an eight week period highlighted the salient issues relating to their perceived barriers to creativity. Thirteen categories (some of which could be mapped onto the previous categories and some which were new) were drawn from the data. Validation of the categories was achieved through direct observations of two design engineers in the week long Shadowing Study and completed this phase of the research. Mapping and interpretation of the findings in relation to the literature obtained further verification. From these analyses it was becoming evident that perceived barriers to creativity were present at many different layers of the enterprise from a macro, organisational level to the micro-environment of the individual design engineer.

The final phase entailed the development of a conditional/consequential matrix model to illustrate the relationship between the macro and micro conditions, under which barriers to creativity were investigated, leading to the development of a theory. The final conclusions and suggestions for improvements demonstrate the relationship between high/low barriers and high/low creativity.

The research has shown the benefits of taking an interdisciplinary socio-technical approach and has highlighted the importance and relevance of the social dimension, as well as the technological, in the investigation of engineering design.

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Author's Declaration

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award other than those it was aware of namely:

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External Contacts:

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Signed: Rarkett

Dated: 16th December 2002

Chapter 1: Introduction to the Research Project

1.1 Introduction to the chapter

The purpose of this chapter is to describe the nature of the problem and the context within which it is researched and explored. A summary of the areas of literature reviewed is included with more specific reference to the literature relating to creativity. A general overview of creativity is presented, funnelling down to the problems and issues associated with the perceived barriers to creativity in terms of conceptual engineering design in the New Projects Engineering group at Rolls-Royce Aerospace (Bristol). A brief overview of the organisational setting where this research was conducted is described. The overall aims and objectives of the research project and an overview of the main phases of the research programme are described and outlined at the end of this chapter.

1.2 The problem

During the conceptual stage of design, engineer designers need to be creative. According to the literature (see chapter 3, section 3.6.3), creativity can be enhanced and facilitated in various ways, for example, advanced developments in Computer-Aided-Design systems (CADs), simulation (particularly interactive 3D graphics and virtual reality) as well as the establishment of appropriate cultures and organisational initiatives. However, most existing tools have arisen largely by a process of computerising the conventional drawing board. They exist to support the designer's traditional methods rather than to bring new affordances to illuminate the design space. A research project conducted at Rolls-Royce Aerospace, Derby and anecdotal evidence from experienced engineers suggest that barriers to creativity are often due to the limitations of current technology, methods and support systems (Baird, Moore, & Jagodzinski, 2000). There is a sense that better solutions elude them because such solutions lie beyond the limits of their own cognitive abilities and/or what technology currently has to offer. It is in the company's interest to ensure that creativity is encouraged and nurtured in order for it to continue to be a competitive force in the aero-engine industry. This research aims to investigate barriers to creativity as perceived and experienced by design engineers. It seeks to understand and describe what those barriers are, based on the perceptions of the design engineers and placed in the context of the wider company environment.

1.3 The context

1.3.1 Creativity

Before considering barriers to creativity, it is necessary to try and present a definition of creativity.

Donald MacKinnon during his address to a Nobel conference, on the subject of creativity, explained the difficulty in defining the term.

> "Many are the meanings of creativity. Perhaps for most it denotes the ability to bring something new into existence, while for others it is not an ability but the psychological processes by which new and valuable products are fashioned. For still others, creativity is not the process but the product [...] creativity probably carries all these meanings and many more besides."
>
> (MacKinnon, 1970, p.19)

There are those who would argue that for something to be creative, it not only has to be new and unexpected, but also be of value (Gero, 1996). Torrance (1988) argues that given its rare occurrence, the character of creative production and the variability of the forms of creativity would appear "to defy a definition". Others argue that creativity is commonplace and can be observed regularly perhaps in a child's drawing (Cropley, 1999).

When reviewing the literature, the subject of creativity is wide and varied having many facets depending on the particular discipline and perspective presented. Consequently there are many views and definitions of what creativity is and/or represents (e.g. Sternberg, 1988; Boden, 1992; Gero & Maher, 1993; Eder, 1995). Creativity can also be defined as a social phenomenon that can be facilitated by some social factors and inhibited by others (Heath, 1993). McLaughlin (1993) states that creativity can also be expressed in terms of a human process, or that which is invested in a product. These are described below and form the basis to the definitions of creativity adopted in this research.

1.3.1.1 Creativity considered from the perspective of it being an attribute of an individual where researchers are seeking to try and understand this ability.

Boden (1992) argues that creativity is not a single ability, but that it draws upon a number of psychological cognitive processes, e.g. noticing, remembering, recognition (of analogies in particular), perception, speaking, learning and understanding language. Heath (1993) proposes that creative people exhibit characteristics such as tolerance of ambiguity and uncertainty, strong inner-directed motivations, a broad knowledge and experience base.

1.3.1.2 Creativity investigated from the perspective of the process an individual is engaged in and how that may be enhanced enabling/increasing the opportunity for more creativity to be expressed.

A review of the literature regarding creative processes suggests a number of mental and cognitive processes are involved. Wallas (1970) identified four stages: preparation, incubation, illumination and verification. Others have linked creative thinking to the problem-solving process which seeks to define the problem, identify alternative solutions and then selecting the best alternatives (Dewey, 1933, as cited in Thompson & Lordan, 1999). Techniques can be employed to enhance the search for solutions such as brainstorming (Osborn, 1963).

However as the human mind is a highly complex computational system which allows for many routes to be explored, heuristics and tools can be employed to reduce the search space (Newell & Simon, 1972). Sometimes this action may inhibit creativity. For example an expert may preclude a solution because of applying certain heuristics whereas a novice with little or no prior knowledge may find a solution in the search space.

1.3.1.3 Creativity in terms of the actual product/outcome an individual has produced where judgements are made as to how innovative and novel the outcome was.

Amabile (1983) provides a consensual definition based on the creative product:

> "A product or response is creative to the extent that appropriate observers independently agree it is creative. Appropriate observers are those familiar with the domain in which the product was created or the response articulated."
>
> (Amabile, 1983, p.31)

Thus such evaluation of the creativity of a product is subjective unless set criteria to measure it against are in place. Gero (1996) suggests that for a product to be deemed creative it not only should be novel and original, but unexpected, valuable and fit for a purpose.

Ford and Gioia's (1995) definition attempts to encompass these three aspects of creativity (sections 1.3.1.1—1.3.1.3).

> "Creativity is a context specific, subjective judgement of the novelty and value of an outcome of an individual's or a collective's behaviour."
>
> (Ford & Gioia, 1995, p.17)

It would appear then that creativity is a multidimensional construct that cannot satisfactorily be comprehended from a single standpoint. As Isaksen (1987) says,

> "It is probably most productive to view creativity as a multi-faceted phenomenon rather than as a single unitary construct capable of precise definition."
>
> (Isaksen, 1987, p.8)

A discussion reviewing in more detail the literature on aspects of creativity can be found in chapter 3, section 3.6.

1.3.2 Barriers to creativity

The focus of the research is to investigate the barriers to creativity as perceived by the design engineers at Rolls-Royce Aerospace (Bristol). An outline of some of the barriers to creativity found in the literature is discussed below. This discussion is developed further in chapter 3, section 3.6.5.

Research has shown that obstacles to creativity can be manifested as blocks to creative thought. Haim (1998) suggests individuals fail to be creative due to "nine bad habits". Discarding these habits and adopting new ones will, he argues, enhance creative activity. For example, questioning and being more inquisitive, recording of ideas so they are not lost, revisiting previous ideas, articulating ideas, thinking in new ways, desiring some new invention to make life easier, trying to be creative, not giving up and encouraging creative behaviour. There are many other authors in this field who suggest similar activities to enhance creativity within individuals. For example De Bono (1984) refers to creativity as "lateral thinking" and has developed a number of tools and techniques to enhance this skill.

Looking at the wider picture, there are various factors which surround an individual which will influence and inhibit their level of creativity. Raudsepp (1982) has investigated organisational barriers to creativity and suggests things like "personal security" and an unwillingness to consider new ideas as being such factors. Organisations often have set rules and regulations which can involve excessive routine which he argues stifles creativity. Also employees are often expected to be passive and be directed by others and may feel reluctant to propose a creative idea for fear of being criticised. Barriers to creativity may have to be circumvented whilst others may be able to be removed. This will make the task of enhancing an organisation's creative climate easier.

Majaro (1992) suggests lack of organisational slack, bureaucracy, restructuring, poor lateral communication, the "imported talent" syndrome and "bean-counting" are barriers to creativity and innovation in companies. Similarly West (1997) suggests that organisational structure, communication, culture, technology, work design, human resource management and encouraging a learning organisation are important factors to consider in order to make an organisation innovative.

De Alencar and Bruono-Faria (1997) studied the characteristics of a Brazilian organisation to identify the factors that which affect creativity. From the transcripts of their interviews they identified 11 characteristics which they argue inhibit creativity. They are as follows:

1. Boss characteristics.
2. Lack of equipment and other materials resources.
3. Lack of training.
4. Organisation culture.
5. Organisation structure.
6. Personal relationships.
7. Physical environment.
8. Political and administrative influences.
9. Salaries and benefits.
10. Task characteristics.
11. Volume of tasks.

Thus it would appear there are a number of types of barriers to creativity including individual, cultural and environmental factors. Viewing it from an individual's perspective these can be manifested as psychological blocks which, some argue, can be reduced by employing a number of conscious tactics. Other barriers can be in the wider environment which the individual may have little control over and yet it could be argued that an element of creativity has to be asserted to operate within such constraints. Others may be in the local environment and amenable to solutions.

This research focused on the creative activities of individual design engineers involved in conceptual design. Evidence of the processes and the barriers which inhibited that creativity were observed. The nature and role of tools and techniques for enhancing creativity are poorly understood and were also considered in this research. The social and cultural influences upon creativity were also considered. These are less well documented in the literature.

The research was completed in association with Rolls-Royce Aerospace, Bristol and comprised three phases (see chapter 2, figures 2.2 & 2.5).

1.4 Aims and objectives

The first aim of the project was to broadly identify and describe the nature of the design process conducted by mechanical engineering designers in the conceptual design phase of aero-engines. Secondly, to identify what the perceived barriers to creative design may be and analyse users' experience for overcoming them. Thirdly, to define design engineers' requirements for an environment to support the conceptual stage of design. For example, the improvements in the creativity of designers may be achievable by means of changes to their tools, techniques and support systems.

The objectives of the three phases, which this research comprises, were as follows:

<u>Phase 1:</u>

Objectives of the Scoping Study:

- To attain a broad overview of the working environment in which conceptual design is taking place at this particular site
- To begin to explore with individual engineers the nature and sources of their own creativity in design and the perceived barriers they encountered to develop a structure for detailed studies

Objectives of the Design Group Interviews (DGI) Study:

- To describe the structure and infrastructure of the conceptual design process within New Projects Engineering (NPE)
- To investigate what different perspectives and experiences of creative activity were taking place in the conceptual design phase of aero-engines
- To identify what the perceived barriers to creativity were and how they were circumvented

Phase 2:

Objectives of the Tracking Study:

- To record instances of barriers to creativity and how they were circumvented
- To characterise the frequency and salience of the barriers experienced by engineers over an eight week period

Objectives of the Shadowing Study:

- To observe and record instances of barriers to creativity and how they were circumvented
- To characterise the frequency and salience of the barriers previously reported by the engineers in the Tracking Study

Phase 3:

Objectives of the final phase:

- To provide a model of the perceived barriers to creative conceptual design under macro and micro conditions
- To outline a theory of perceived barriers to creativity within NPE
- To recommend how improvements in the creative activities of designers may be achievable by means of changes to tools, technologies, systems etc.
- To critically reflect on the research method and analysis

1.5 The research questions

The research concludes with recommendations for improvements for an environment to support the conceptual design phase and the creative activities that were inherent in it. In order to achieve this, the following questions needed to be addressed and answered:

1. What are the perceived barriers to creative design at NPE Rolls-Royce, Bristol?
2. Why are there barriers?
3. Do these barriers have a systemic nature which can be generalised?
4. Can this be modelled?
5. What remedies might exist for overcoming the barriers?
6. Can these remedies be seen to be merely local or systemic and generic?

1.6 Summary of the areas of literature

The research covers a wide spectrum of topics and therefore several areas of literature have been drawn upon. These have been reviewed (see chapter 3) to present an overview of the areas relevant to answering the research questions. As the focus of the research is much more at the individual level, the global wider contextual issues in the literature are not reviewed. A brief summary of the areas of literature is presented below.

The topics related to the research reviewed in chapter 3 are mainly from the literatures of Psychology and Engineering Design. To begin with, the literature review focuses on design looking in detail at design methodology, and in particular, making comparisons between the two distinct approaches of rational problem solving (Newell & Simon, 1972) and reflection-in-action (Schön, 1983) (see section 3.2.1).

A number of models of design spanning the last four decades are presented and discussed in terms of the evolution of such models from the traditional, more systematic process based models, to newer models, which attempt to capture the iterativeness of contemporary views of design. Design models from the field of software engineering are also reviewed in section 3.2.2. Chapter 3, section 3.2.3 looks at the different types of design (e.g. Culverhouse, 1993).

In section 3.2.4, a variety of individual models of design are discussed. Some suggest a staged process as an individual progresses through a design task whilst others interpret the activities involved in terms of cognitive processes. A brief discussion highlighting the various approaches to design is also presented.

Cross and Cross (1995) argue that earlier models of design tended to focus on the technical aspects and cognitive processes involved in design activities. Social aspects have failed to be addressed despite most design taking place in a team/group environment and not in isolation. Section 3.3 therefore considers some studies which have identified some of the social processes involved in design activities and the factors to consider when designing tools to support collaborative teamwork.

Literature pertaining to external representations, for example sketching and drawing (e.g. Fish & Scrivener, 1990), cognitive artefacts (e.g. Norman, 1992), tools and technology (e.g. Cockburn & Jones, 1995) discusses the importance of using a range of media forms to enhance understanding and communication in design (e.g. Fussell & Benimoff, 1995; Lave & Wenger, 1995). These are presented in chapter 3, section 3.4.1.

Section 3.4.2 provides an overview of the tools and technologies available to support engineering design. The advantages and disadvantages of using such tools to aid conceptual design is discussed (e.g. Allwood & Kalen, 1994).

A number of psychological issues involved in design activities such as learning processes, visual perception and visualisation are discussed in section 3.5.

Another main focus of the literature review is creativity. This phenomenon is discussed in terms of the processes assumed to be involved (Poincaré, 1952; Wallas, 1970) and the Geneplore model in relation to creative design developed by Finke, Ward and Smith (1992). An adaptation of this model relating to engineering design specifically is discussed (Jarvis, 1997). Literature relating to suggested characteristics and attributes of 'creative' people and how to facilitate the creative process by employing various tools and techniques are presented. The recent advances in technology as ways of stimulating creativity in design are also discussed. Suggestions for how creative climates and environments can be enhanced and the barriers that can prevent this from happening complete the literature review. Finally a model representing the interplay of these literatures is presented and explained.

1.7 Setting and context

For the purposes of this research project, the focus was on the preliminary conceptual definition phase (see figure 1.1) of engineering design of military aircraft being undertaken at Rolls-Royce Aerospace, Bristol. This area of design was chosen after consultation with Rolls-Royce managers because it was expected that most creativity would be observed in this early phase of the design process.

1.7.1 Background to Rolls-Royce

"Rolls-Royce is a major power systems company supplying a wide range of power systems to a global market," (Baird, et al 2000). The company comprises different groups, the largest of which is the Aerospace Group. This group designs, manufactures and supports a range of aero-engines, that is civil, military and helicopter engines and is located on two sites, Derby and Bristol respectively.

The aerospace industry is a highly competitive one where the competitive edge was until recently focused on "improving efficiency and reliability." However, more recently the emphasis has moved towards achieving a competitive advantage to a market demand for a "quality project, which meets the customer's requirements at the lowest cost and is the first product in a new market," (Baird et al, 2000, p.334). To respond to these demands and to remain globally competitive, Rolls-Royce Aerospace has become involved with other international aerospace companies. Whilst this means design teams are globally distributed, the costs and risks associated with developing new engines are shared. In addition to this, Rolls-Royce has introduced business process engineering into the company, incorporated new information technology and working practices which mirror the new processes (Moore, 1997). One such major process is the Propulsion System Definition Process, namely Project Derwent, which covers all the activities from the generation of the initial product concepts through to entry into service.

Project Derwent has been implemented to improve the company's business performance and reduce time-to-market in this highly competitive aero-engine market. It comprises four major processes of which *New Project Planning* is the first and represents the context of this research. This process relates to Stage 1 where "new technical concepts are matched to new market opportunities" (Moore, 1997).

New Project Planning comprises 3 sub-processes as shown in figure 1.1. To begin with the market is analysed to identify any new products Rolls-Royce may want to pursue further. This process is called *Identifying the Need.* Once a particular potential market opportunity has been recognised, business plans are developed and this activity is called the *Business Concept Development* process. The process involves defining the possible business scenarios and establishing their associated business cases. "What if?" studies are then performed to develop the optimum business scenario. Finally the *Preliminary Concept Definition* process is initiated which is the development of a technical concept and associated plan to support the business scenario.

Propulsion System Definition Process

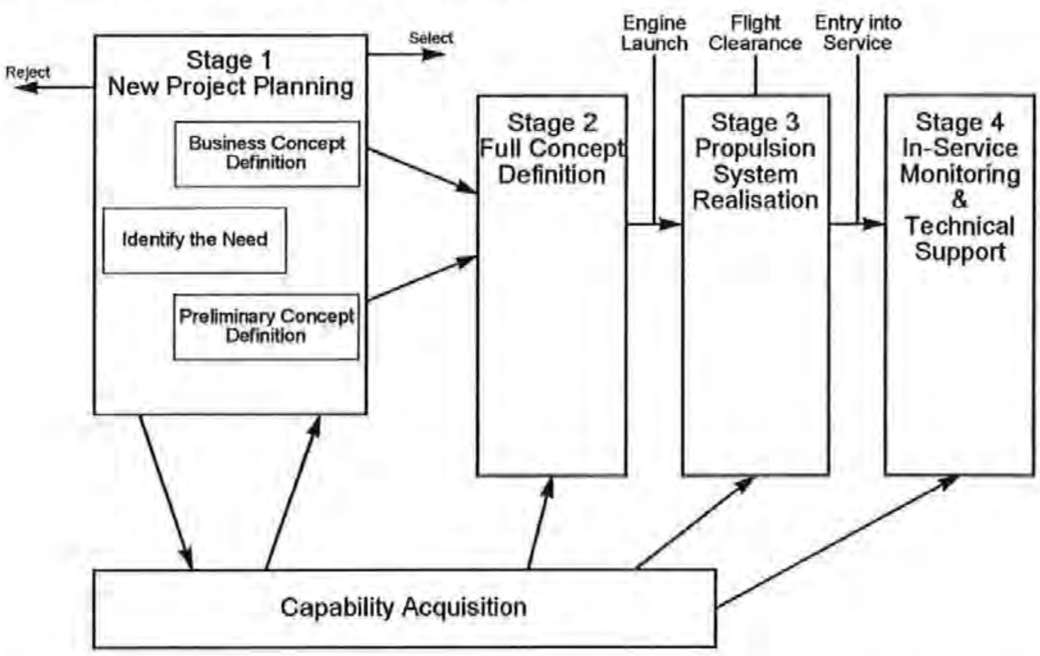

Figure 1.1: Propulsion system definition lifecycle (taken from Design Studies 2000, 21 (4), p.336).

This Propulsion System Definition Process continues with further sub-processes which are shown in figure 1.1 and briefly outlined below.

(a) *Capability Acquisition* is a core function which is performed in all stages. It ensures all resources are met to meet the company business needs.

(b) *Full Concept Definition* is where detailed plans are prepared to ensure all aspects are covered for the new concept. For example, process, working practices, technical tools, management systems and hardware. This is referred to as Stage 2.

(c) *Propulsion System Realisation* in Stage 3 is where "plans are implemented including the detailing of the designs, the manufacture of prototypes, verification and certification" (Moore, 1997, p.52)

(d) Stage 4 relates to post sales support when the engine is in service.

The stages are marked by Exit Review Gates where senior engineers and designers of Rolls-Royce meet and review the proposed designs presented by the designers and decide whether they can exit and pass onto the next stage. The number of people involved at a time is dependant on the particular stage of production. This research was undertaken in Stage 1 of the Project Derwent lifecycle (see figure 1.1).

Concurrent engineering is taking place within the company and is described below as:

> "A systematic approach to the integrated, concurrent design of products and their relative processes, including manufacture and support. Essentially it pulls together experience and knowledge from many disciplines and incorporates them early in the product development process. Evaluation of the completed projects shows that, though very little money is spent during the early phases, the decisions made during this period commit the vast majority of the project's life cycle funding."
>
> (Simms, 1993)

This change in practice has led to a disbanding of discipline based groups. Examples of these groups are stress, design, thermodynamics, aerodynamics and performance. So instead of all the designers working together in a design hall as they had done previously, they, like other discipline specific groups, work as part of a multidisciplinary team on particular projects. This could be as a co-located group working together on the same site or as a displaced group working on different sites and/or collaboratively with other companies on projects.

When involved in design, experts are called into the discussions and meetings as and when they are required, that is, when a particular problem needs solving. Otherwise the designer works on his own initiative. At Stage 2 in the Derwent Process there may be a more thorough integration of project team members, but this is outside this research.

It is important that Rolls-Royce keeps abreast of any new technologies, whether they decide to go through with the full development themselves or not. There should be enough accessible technical knowledge to make the designs work, but if not then there is a need to initiate a new capability acquisition in order to develop new components. Therefore retaining capability is an important role to keep ahead of competitors. If a 'new' or 'advanced' material is required, Rolls-Royce will seek to develop existing materials to new limits. Timescales can dictate whether there is a necessity to acquire knowledge "off the shelf" or whether it can be developed.

Military projects have time scales that are generally longer than the civil engine developments. They are also funded differently with contracts designated for specific parts of the engine. Projects are collaborative and therefore only part of the engine may be dealt with on site. Ultimately the engine has to be validated and certificated for airworthiness before it can be put into production.

1.7.2 Background to New Projects Engineering (NPE)

New Projects Engineering is a department at the Bristol site where engineers are involved in the conceptual stages of design with regard to Military aircraft planning for future medium and long term strategic innovations. They work on a number of concepts at any one time; be it the structural side of things (e.g. the most efficient structure for thrust) or how to achieve the optimum performance for the engine (e.g. maximum weight thrust ratio). Many of the projects undertaken in this department are short feasibility studies and as a consequence, NPE interfaces with other groups within Rolls-Royce such as Components or Business Development. These are referred to as Operating Business Units (OBUs). There are other major projects which are currently running in this department including Whole Engine development, Key Systems, Combat, Trainer and Transport.

NPE interfaces with all the individual departments internally and various other establishments externally. For example, partner companies, airframers, government agencies and industrial and academic institutions.

1.7.3 How the department operates

The department comprises an overall manager and a further 30 employees of varying levels of experience and status. The manager has authority to decide who stays and who leaves the department and, to some extent, what projects are taken on. However in the latter case, the Business Development team make the decision on whether a project is financially worthwhile or not to Rolls-Royce. As with any department, there are a number of set procedures for carrying out various tasks, some of which will be highlighted in the analysis of this research.

Of the 30 members of the department, there are project managers/team leaders, performance engineers (operational and technical designers) experienced designers and new designers, who have recently been, or who are in the process of being trained. Over the duration of the research there were inevitably some staffing changes which are noted at the appropriate points in the thesis.

The department brings together a multidisciplinary team of designers that include specialists and generalists. This is necessary as the projects are multitask and therefore require a broad spectrum of skills and knowledge. For example, the understanding of aerodynamics, performance analysis, the designing and stressing of components and engine development costs.

One of the major responsibilities of NPE is to carry out conceptual studies for propulsion systems for all future military aircraft and missile systems. Their objective is to produce competitive designs offering the best balance of return on investment for the customer and Rolls Royce. These designs must combine performance, weight, development costs and maintenance. The designers in NPE also work with airframers to ensure that the propulsion systems can be installed successfully taking account of all requirements.

Some of the projects require several designers to be involved whereas others are the sole responsibility of a particular designer. However, this arrangement is very fluid so designers and the system have to be flexible enough to accommodate changes in the required human resources and expertise as projects progress through development phases and other projects are phased in and out.

The project, which was drawing most human resources at the time of the research, was the Full Offensive Air Systems (FOAS) project.

1.7.4 Background to the FOAS project

The FOAS (Full Offensive Air Systems) project is an alliance between several major international aerospace companies with an overall aim to meet the aircraft needs of the MOD looking at the year 2015. A number of possibilities have been proposed including manned and unmanned aircraft. The MOD has set five criteria against which to some extent proposed designs are measured. These are referred to as the ALFAS:

- Affordability
- Lethality
- Flexibility
- Availability
- Survivability

At the time of the research Rolls-Royce were working in close collaboration with a second lead European company who had a permanent team working on FOAS, headed by a structure of Integrated Product Team Leaders.

In the initial report written for the MOD, changes in working practices were highlighted as necessary if the companies were going to be able to work together efficiently and effectively. For example, reference to "...new ways of working; removing perceived barriers and unnecessary traditional barriers; working together agreeing and applying common tools and processes which will help a seamless transition into other phases; a break with traditional culture leading onto an optimum level of operation."

Rolls-Royce have based the FOAS project within NPE with a number of core team members. Others assist as and when necessary. FOAS requires multidisciplinary teams, with a mixture of specialists and generalists, to work on different elements of the project. One part of the project is known as Weapons System Concept Engineering (WSCEII).

The structure of the team working on the WSCE II project is shown in Figure 1.2.

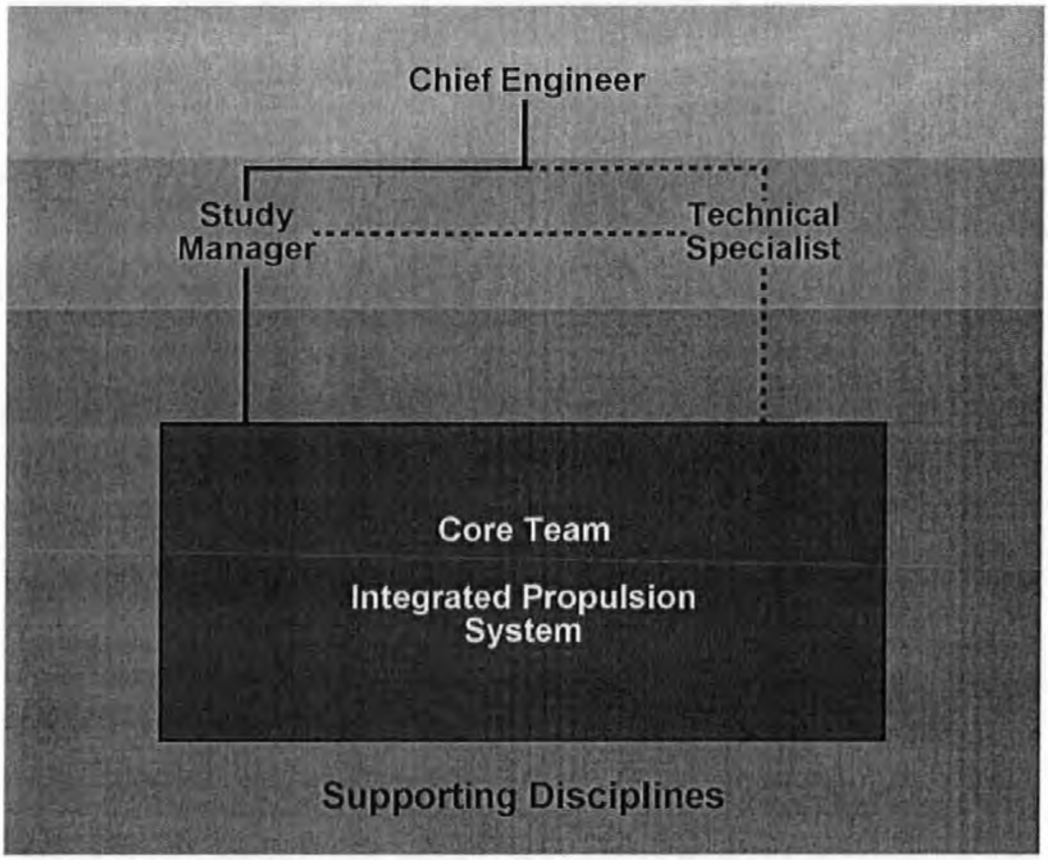

Figure 1.2: Engineering Team Organisation for FOAS, (WSCE II).

Each person has certain responsibilities and spends different amounts of time on the project. When not involved with FOAS they contribute to the other projects that are currently being undertaken in NPE.

There are a number of other functions and skills which support NPE to enable them to deliver what is required of them in this particular phase. For example, manufacturing, advanced engineering and installation engineering.

WSCE Phase II involves several different companies and departments, but the main two players are the European partner (mentioned above) and Rolls-Royce. About 30% of Rolls-Royce's input is in the development of the integrated propulsion system. Other areas that Rolls-Royce are involved with include: Support and Training (about 5%), Structures and Assembly (about 5%), Flight Controls (about 5%), Vehicle Systems (about 5%).

To date there have been 4 main proposals in relation to WSCE Phase II.

1. Engine derivative with slight changes.
2. Engine derivative with major changes.
3. New Build 1 (NB 1) with full mission capability.
4. New Build 2 (NB 2) with reduced mission capability at a reduced cost.

A number of milestones, maturity gates and deliverables have been agreed to ensure steady progress. New media are being considered to present the different staged deliverables which include; CD ROMs, video clips, animations, simulations, dialogue and interactive web pages.

Communication between companies is limited to the telephone, fax and visits between company sites. At the start of the research project Phase I-the *Concept Identification* phase-had already been completed. Rolls-Royce and others from the alliance were in the middle of Phase II-Concept Engineering.

1.7.5 The design work process

As described in section 1.7.1 Rolls-Royce follows Project Derwent to improve the company's business performance and reduce time-to-market. This research project took place within Stage 1 of the Derwent process. Subsequent stages were not undertaken in the timeframe of the research and were outside of the research boundaries.

It is feasible in Stage 1 to produce several design concepts for a design project. In practice resources are limited and it is unlikely that more than one would be considered at the Exit Review meeting. These meetings comprise presentations by designers of their chosen design which are reviewed by senior engineers and designers in the company who will decide whether the project can progress to the next stage. The stage following *New Project Planning* is *Full Concept Definition.* This involves implementing the creation of a plan based on the *Preliminary Concept Definition* and the knowledge of the company's capabilities to deliver to a customer specification (see figure 1.1). This is a much more detailed level of work so that the company can be confident it can achieve the contracted specification to cost and timescale. In practice this means that the whole engine design has been developed to the state where, for example, the part modules such as HP (high pressure) compressor, LP (low pressure) turbine and gearbox, and sub-system boundaries are unlikely to change beyond an agreed small amount of tolerance. Engineers who work in this stage are referred to as "detailers".

In broad terms the types of activities which design engineers engage in both on a day-to-day level and longer are as follows:

Daily:

- Writing of reports
- Dealing with telephone enquires
- Networking
- Sketching
- Working with CADs
- Discussions with fellow engineers
- Meetings (low level and informal), e.g. with team members

Weekly:

- Visits to other companies
- Meetings (high level and formal), e.g. with collaborators,

Longer term:

- Review meetings (high level and formal), e.g. with Senior Engineers
- Training

Evidence of these types of activities were observed and documented throughout the phases of the research.

1.7.6 Creativity within Rolls-Royce

Definitions of creativity vary widely as discussed in section 1.3 depending on the domains of the definers and the domains of the creative practitioners. The participants in the research were observed to be creative in all three ways described in section 1.3. For the purposes of the research it was left to the engineers to state when they were being creative. This has been accepted as such and supports the suggestion by Hori (1997) that routine design activity is always in some sense creative, as original and new formulations will be created to meet the desired design outcomes. The focus of the research relates to what the participants perceive the barriers to their creative activities are and how they are being obstructed and/or compromised.

Three categories of employees have been interviewed:

- Experienced designers who undertake primary idea generation activities. This research focuses on their design process, specifically where designers are having their thought/design processes interrupted and inhibited due to perceived barriers such as organisational constraints, technology, communication and co-operative activities with other designers.
- Project managers/team leaders, from whose perspective barriers to creativity have similarities to those mentioned above. However, their primary goals within the department are the scheduling of projects, resourcing and fostering a creative working environment.
- New designers and trainees who are still at the stage where they are building upon their experiences and developing the necessary skills such as problem-solving thus allowing them to develop more sophisticated solutions to creative designing.

1.8 Overview of the thesis

The research project is divided into three phases with the end of each phase providing a platform for the initiation of the next phase.

Chapter 1 outlines the whole of the thesis beginning with the aims and objectives of the research and the questions which it intends to answer. An overview of the literatures reviewed in chapter 3 is included. The context of the research in terms of the problem and the background of the company where it was undertaken are presented.

Chapter 2 describes the research paradigm and methodology adopted and the methods and research techniques used to complete the study. It also describes in detail how the data were analysed using grounded theory.

Chapter 3 reviews the literature of design methodology, models of design, types of designing and individual models of designing. Following these sections are the areas of social aspects of design, cognitive artefacts (tools and technology) and the psychological areas of learning, visual perception and visualisation. Finally aspects of individual and organisational creativity, and ways of enhancing and inhibiting creativity are discussed. A model to help explain the interrelationship between these literatures is presented at the end of the chapter.

Phase 1 of the research

Chapter 4 describes the Scoping Study and presents examples from the interviews to support the six major themes which were drawn from the data.

Chapter 5 describes the Design Group Interviews Study and presents examples from the interviews to support the definitions of the sixteen categories which were drawn from the data. This chapter also considers the initial confirmation of the categories and data through presentations and a workshop.

Chapter 6 reviews the findings from the studies in Phase 1 and interprets and discusses them in terms of the literature presented in chapter 3.

Phase 2 of the research

Chapter 7 describes the eight week Tracking Study and maps the emergent thirteen categories onto the sixteen categories from the Design Group Interviews Study. Examples from the interview data are presented and discussed to support the categories.

Chapter 8 describes the week long Shadowing Study and discusses to what extent the thirteen categories have been confirmed from the observation fieldnotes.

Chapter 9 reviews and interprets the findings from Phases 1 and 2 and discusses them in terms of the literature presented in chapter 3.

Phase 3 of the research

Chapter 10 presents a model of barriers to creativity and the developing theory. It also presents the conclusions and recommendations and looks at directions for further research.

Chapter 2: Research Methods

2.1 Introduction

This chapter presents an overview of the various methods and methodologies employed whilst undertaking the present research. This qualitative piece of research is presented and discussed within the context of the quantitative versus qualitative debate. The rationale for taking a qualitative approach is argued in terms of the constructivist paradigm and the appropriate ontology and epistemology associated with it. Due to the industrially situated nature of the research, an ethnographic approach was taken which allowed for a variety of research techniques to be used, such as interviews, direct observations, interview diaries and shadowing. These naturalistic techniques were chosen as they enabled a rich picture of the phenomenon under investigation to be described, articulated and demonstrated from the designers' perspectives. A brief rationale and description of the methods employed is given. Alternatives to the ethnographic approach are considered, discussed and compared in section 2.6. The data collection produced a large amount of material for analysis. The advantages and disadvantages of using a data reduction method for analysis are discussed and a justification for choosing grounded theory presented. Brassard's (1989) Interrelationship Digraph management tool, short reports and presentations provided interim validation and verification of the developing models and theory. Issues relating to reliability and validity are discussed and four types of triangulation are presented relating to aspects of the study. This provides confirmation of the findings.

2.2 The nature of qualitative research

Denzin and Lincoln (1994) describe how qualitative research has been practised over the last century by dividing that period into what they term as five different moments. That is the traditional (1900-1950), the modernist or golden age (1950-1970), blurred genres (1970-1986), the crisis of representation (1986-1990) and the postmodern or present moments (1990-present). Different epistemological theorising spread across these five moments. Also, according to Denzin and Lincoln, qualitative research means different things during each of these moments. However they offer a generic definition which is:

> "Qualitative research is multimethod in focus, involving an interpretative, naturalistic approach to its subject matter. This means that qualitative researchers study things in their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them. Qualitative research involves the studied use and collection of a variety of empirical materials—case study, personal experience, introspective, life story, interview, observational, historical, interactional, and visual texts—that describe routine and problematic moments and meanings in individuals' lives."
>
> (Denzin & Lincoln, 1994, p.2)

A variety of empirical materials such as case study, interview, observational and personal experience can be employed to research and describe what is going on in a particular context. Sometimes it is necessary to employ a wide range of interconnected methods to be able to understand what is going on. That is certainly the case in this research project (see section 2.4.4).

Denzin and Lincoln describe the use of multiple methodologies as a *bricolage* and the researcher as a *bricoleur*. According to Lévi-Strauss (1966, as cited in Denzin & Lincoln, 1994) a *bricoleur* is a "Jack-of-all-trades or a kind of professional do-it-yourself person" who ultimately produces a *bricolage*.

The *bricoleur* employs a number of different strategies, methods or empirical materials sometimes piecing them together or even inventing new ones. Hence the choice of tools is not planned in advance but chosen in view of the questions relating to the research and the context of that research.

The multi-method approach to the research thus provides an in depth understanding of the phenomenon whilst adding rigour to the investigation as well. Often the *bricoleur* works with overlapping perspectives and paradigms. The *bricolage* then emerges as a "complex, dense, reflexive, collage like creation that represents the researcher's images, understandings, and the interpretations of the world or phenomenon under analysis" (Denzin & Lincoln, 1994).

One advantage of qualitative research for its practitioners is that they have the choice of several paradigms to utilise and they find value in its mutlimethod approach. The advantage of employing qualitative research methods enables the researcher to develop a close relationship with the phenomenon being studied within the situational constraints which will influence and shape that enquiry. Qualitative research provides rich descriptions of the world from an idiographic case-based perspective. However, research does not take place in a vacuum and the researcher will have a particular standpoint from which the research is undertaken and analysed.

2.3 Paradigm

The choice of a paradigm for this research entails a review of the quantitative/qualitative debate which has continued for several years and revolves around the nature and practice of science and the generation and authentication of knowledge (Pidgeon & Henwood, 1996). Often the quantitative and qualitative approaches are viewed as distinctive and even incommensurable research paradigms. The quantitative approach seeks to establish objective knowledge of the universal laws of cause and effect using specific hypotheses to 'test' phenomena proposing that theoretical concepts are observable, manipulable and measurable. This hypothetical-deductive approach requires therefore, the specification of variables and statements of research hypotheses before data collection begins (Patton, 1987).

However, the qualitative paradigm seeks to explain meaning, understanding or *verstehen* rather than abstract universal laws. Qualitative methods are orientated towards exploration, discovery, interpretation and inductive logic seeking to build towards general patterns and develop theory. Thus theories are grounded in real-world patterns (Glaser & Strauss, 1967).

Alternative quantitatively based paradigms could have been used such as positivism, postpostivism and critical theory. However, it was felt that these paradigms were not appropriate because of the limitations mentioned previously. For example, positivism employs methods that are experimental and manipulative with the testing of hypotheses. There are advantages to using such an approach, as control and reliability are easier to achieve. However, there could be problems with the validity of the findings by using such methods, as experiments tend to be artificial and generalisations from the laboratory could be hard to substantiate in other more realistic contexts (Thomas & Carroll, 1979).

Studies that have sought to quantify aspects of the design process and creativity can provide some additional knowledge in these areas. For example, Savage, Miles, Moore and Miles (1998) investigated the interaction of time and cost constraints on the design process using an experimental 4 x 3 mixed design. Subjects completed 3 tasks in one of four conditions (either a control condition, a time constrained condition, a cost constrained condition or a time and cost constrained condition). The task was to design and build structures using mainly sheets of A4 paper. Results indicated that the constraints of time and cost produced an effect on the design process both independently and together. Savage et al's study draws some interesting conclusions, proposing that optimal solutions are not necessarily reached when the external constraints are removed and that to enhance creative design, cost and inherent constraints should be kept to a minimum. However, the study does not use real designers nor a real design workplace in the experiment. This poses questions as to the validity of the study and it would seem risky to make generalisations relating to design activity based on these results.

Designers, especially experienced ones, bring a wealth of history and knowledge to the design activity (Baird et al, 2000). Design activity is situated and social (Baird et al, 2000) and aspects of this activity will be affected by numerous real world constraints and factors. An experimental design could not take into account all those variables nor detect the attributes, characteristics and behaviours associated with real design activities. Thus experimental approaches are inadequate for researching the complex process of design and the factors which affect and influence it in industrial contexts.

In order to address the research question of the present project, a richer picture needs to be comprehended, within a constructivist framework. Constructivism asserts that humans do not discover knowledge, but construct it. Concepts, models and schemes are invented to make sense of experience. We then continually test and modify these constructions in light of new experience. Thus constructivism produces reconstructed understandings which are 'checked' in terms of trustworthiness and authenticity (Denzin & Lincoln, 1994).

The constructivist paradigm assumes a relativist ontology (section 2.3.1) (where there are multiple relatives) and a subjective or transactional epistemology (section 2.3.2) (where the knower and the subject create understanding) using a naturalistic set of methodological procedures which are hermeneutic and dialectical (Guba & Lincoln, 1994; 1998). Knowledge can be generated within networks of social activities and systems of socially constructed meanings. The researcher has to be free to explore and be sensitive to the multiple interpretations and meanings which are recorded within the context under investigation. There are a number of criteria set for this paradigm, namely of trustworthiness, transferability, dependability and confirmability (Denzin & Lincoln, 1994). The aim of the present enquiry is one of understanding and reconstruction.

In order to describe the constructivist paradigm, three elements need to be considered: ontology (what is reality?), epistemology (how do we know the world?) and methodology (how do we gain knowledge about the world?), and these are discussed in the following sections.

2.3.1 Ontology: relativist

Reality is understood in terms of models and mental constructions which are socially and experientially based. They can be individual and specific and yet there may be elements that are shared collectively across individuals or even cultures. Individual's constructs will differ in elaboration and by their very nature can be modified as can their associated realities (Guba & Lincoln, 1994; 1998). Thus the nature of the knowledge is that of individual multiple reconstructions coalescing around consensus. More knowledge is accumulated by the construction of more informed and sophisticated reconstructions and vicarious experience.

2.3.2 Epistemology: subjectivist and transactional

Qualitative interpretations are constructed and created between the researcher and the subject as they are "assumed to be interactively linked" (Guba & Lincoln, 1994; 1998).

2.3.3 Methodology: hermeneutic and dialectic

Using a hermeneutical and dialectical methodology means that both the researcher and the subjects can elicit, interpret meaning and refine the constructions until a consensus is reached and a reformed, more sophisticated construction than before emerges.

The next section provides a rationale for the methodology use in this research.

2.4 Methodology

2.4.1 Ethnographic approach

As mentioned in the introduction to this chapter, this research project has taken an ethnographic approach to the data collection.

According to Button (2000), traditionally studies involving ethnography were theoretically, methodologically and politically motivated. Historically anthropologists and sociologists have used the ethnographic method to study different cultures in fine detail (Vidich & Lyman, 1998). Used in the field or research situation, without any preconceived idea of what will be found, an understanding of the complexities of the particular culture under investigation emerges. It is a naturalistic method which seeks to understand how the social actions and day-to-day activities happen within a particular context. It is characterised by a number of distinctive elements, such as the researcher being fully immersed in that culture for an extended period of time and collecting data using a variety of qualitative methods. This is deemed to be "pure" or traditional ethnography (Ball & Ormerod, 2000).

More recent studies, which have looked at particular areas of work (e.g. looking at aspects of technology in the workplace), have more practical goals and are often conducted under the banner of ethnography (Button, 2000). He goes on to argue that increasingly psychologists and those working in other fields, such as computer science conduct these types of studies. Button also proposes that many of these studies are informed by ethnomethodology and not by ethnographic tradition and therefore care should be taken in referring to them as ethnographic studies. Button argues that these types of studies are used "as a proxy for fieldwork". He agrees that true ethnographic studies involve fieldwork, but unlike ethnography they do not involve the "analytic mentality" which ethnography does. According to Button, the outcome of some fieldwork studies results in a description and overview of the situation and those working in it (what he describes as "scenic fieldwork"). It is not interpreted in terms of a chosen sociological theory nor does it address the "interactional what" of their involvement of those observed in activities. In other words, he argues that rather than describing what people do in organisations, further analysis should be undertaken to explicate what he refers to as the "member's knowledge". This approach would result in a greater understanding of what people need to know to have to work and would make contribution to knowledge in that area.

Suchman (1987) proposes that actions can only be interpreted in the social and physical environment in which they take place. She states, "However planned, purposeful actions are inevitably *situated actions.*" Thus it is an interaction of the intent of the individual, their behaviours, the resources and constraints within the environment they are working that can allow their actions to be interpreted. Several studies have been conducted in various workplaces which seek to explore how people operate and interact within complex technological environments (e.g. Hughes, Randall & Shapiro, 1993a; Heath & Luff, 2000).

However, it has been recognised for sometime that those studies, which employ variations of the pure ethnographic method, are acceptable in certain contexts. For example, Hughes, King, Rodden and Anderson (1994) present four different types of ethnography which they have used to provide insight into the social nature of the work under investigation in various settings. They argue that the scale of the problem and the length of time available to undertake the study are factors which have influenced the emergence of the ethnographic derivatives. Thus one of the main characteristics, where such approaches differ to that of pure ethnography, is one of time and another being the focus of the study.

One such derivative is that of "quick and dirty" ethnography described by Hughes et al (1994) as being "where brief ethnographic studies are undertaken to provide a general, but informed sense of the setting" (p.5). The use of this type of ethnography allows the researcher to seek information which is relevant to the investigation whilst accepting that a complete and comprehensive understanding of the setting would be an impossibility. Studies that use "quick and dirty" approaches are conducted over a greatly reduced amount of time compared to that of "pure" ethnographic studies, but can however, produce a large of amount of data (Hughes et al, 1994). Figure 2.1 illustrates an example of how "quick and dirty" ethnography can be employed.

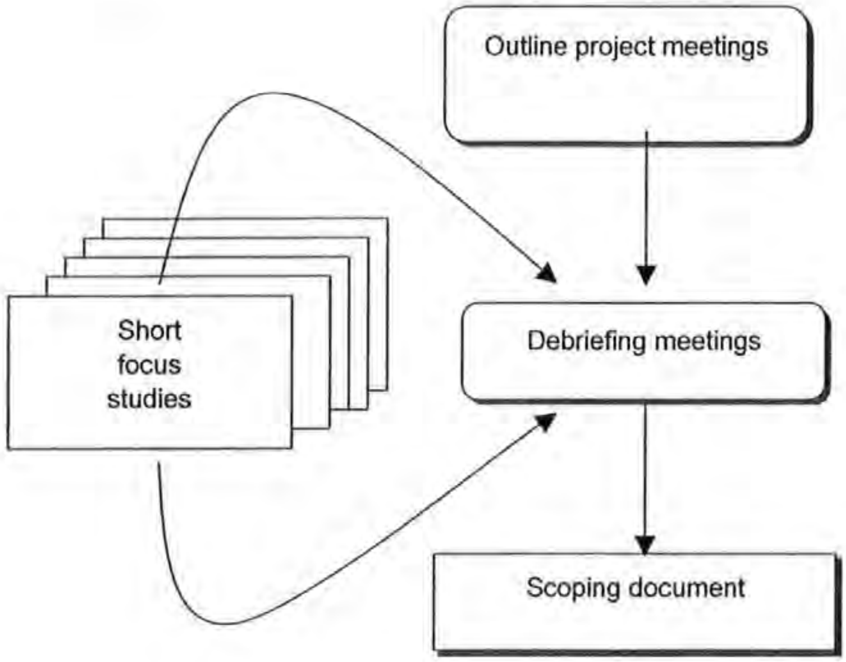

Figure 2.1: Quick and dirty ethnography (taken from Hughes, King, Rodden, & Anderson, 1994, p.7).

It could be argued that this research used the "quick and dirty" approach where, referring to figure 2.1, the "outline project meetings" relate to the initial meetings with Rolls-Royce setting out the projects aims and objectives and how the research was to be conducted within the company. The "short focus studies" relate to the Scoping Study, the Design Group Interview Study, and the Tracking (interview diaries) and Shadowing Studies where data were validated and confirmed through a workshop, seminar and presentations ("debriefing meetings"). Finally the "Scoping document" relates to the theses.

Lloyd (2000) conducted a study in what he describes as "in the spirit of ethnography" where he acknowledges that two weeks is not long enough to become fully aware of the complexities of the organisation under investigation and therefore cannot call his approach true ethnography. Indeed, it is more likely that most commercially motivated projects would conduct fairly short investigations, particularly if they involve organisations, due to logistical constraints and cost-effectiveness regarding the research.

Ball and Ormerod, (2000) observe that ethnographic methods, in design research specifically, have increased over the years and agree that there is a disparity in the use of ethnographic methods. They state that many studies claim to use ethnographic techniques, but they violate many of what he refers to as the characteristics of a prototypical case of ethnography. These characteristics, according to Ball and Ormerod, include "situdatedness, richness, participant autonomy, openness, personalisation, reflexivity, self-reflection, intensity, independence and historicism" (p.150). The violation occurs, they suggest, (or imply) because of the *purposes* for which the ethnographic methods are employed. That is, purer methods of ethnography are used to unearth the complexities of unknown cultures and social practices and thus exhibit all aforementioned characteristics, whereas other versions can be employed when the aims of the research are more applied. For example, seeking to understand certain phenomena in an organisation which undermine the productivity or creativity (as in the case of this research) of designers.

However, such a version of ethnography which Ball and Ormerod refer to as "applied" ethnography will inevitably violate characteristics such as intensity (in order to be cost–effective), independence (where the study may be theory driven) and personalisation (where verifiability is a major necessity for applied research). Ball and Ormerod (2000) also argue that some of the key features of ethnography are retained using this approach, but there are fundamental differences mainly in the length of time of the study and its *purposiveness*. However, they acknowledge that using such a method provides insights into working practices in applied settings which would not necessarily be uncovered using the more conventional methods of traditional protocol analytic methods. In view of their argument, they propose that "ethnography can be understood as a *radial category* which exhibits *prototype effects*" (p.405).

Therefore, it appears that ethnography, or at least versions of it, have been accepted by some as an appropriate method to use to study the culture and different organisational processes of various organisations (Bucciarelli, 1984, 1988; Sommerville, Rodden, Sawyer & Bently, 1992; Hughes et al, 1994; Lloyd & Deasley, 1996; Lloyd, 2000; Jagodzinski, Reid, Culverhouse, Parsons & Phillips, 2000; Baird et al, 2000; Ball & Ormerod, 2000, & others).

The overarching aim of this research is to establish what perceived barriers exist to creativity within an engineering design context. The research employs a number of qualitative research tools taking an ethnographic approach not from a purist theoretical stance, but with a pragmatic approach due to the constraints which are imposed upon the research project. One of the main constraints is that the company, in which the research took place, operates in the highly competitive Aerospace Industry market. Therefore although access to the secure areas was arranged, there were limitations as to what could be recorded and noted and subsequently published[1]. Time was another factor whereby it was not possible to spend an extended period in the company at any one time. Access to personnel identified, as a primary source of information, was not always possible due to their particular work commitments. As a result of this, the data collection exercise had to be flexible and compromises have had to be made and as others have, it is within this context of *purposiveness* that this research is then best described.

2.4.2 Alternative approaches

Other theoretical approaches were also considered. For example activity theory and action research.

Activity theory seeks to explain the interactions between everyday activities, material artefacts, social systems and cultures in co-operative work settings where a collective object-orientated activity system is the prime unit of analysis (Hasu & Engestrom, 2000). Activity theory thus provides a framework to study co-operative work and it has often been used in studies relating to Human Computer Interaction (HCI) in organisations (e.g. Decortis, Noiralise & Saudelli, 2000). It was decided not to use this approach in the present research though, as the phenomenon under investigation was primarily 'perceived barriers to creativity' and not the co-operative activities of the designers in achieving a collective goal. Factors which inhibit or enhance creativity were considered within the framework of the conceptual design engineer's working environment which to some extent could be analysed in terms of activity theory. However, as the phenomenon in question was more abstract than a particular goal or object it was felt that the activity theory approach would not be adequate for this particular research.

Action research is participative and requires the researcher to define the problem initially and then to plan action in order to address it (McKernan, 1991). The research would be conducted in collaboration with stakeholders as it is very much research *with* participants

1 There are no transcripts or fieldnotes included as appendices as this could compromise the company's security.

rather than *on* participants (McNiff, 1988). The researcher sets out with a hypothesis to test by applying the action to the problem and then evaluating its effectiveness with a focus of improving practice. Whilst it is hoped recommendations for improved practice will be found, the research was initiated with an open mind with no preconceived ideas or assumptions. Therefore an action research approach would not be appropriate to use in this instance.

It could be argued that an appropriate framework for the study could have been based on socio-technical and systems theory. Checkland (1981) identified four system types, one of which includes Human Activity Systems described as a set of human activities carried out to fulfil a given purpose such as a process in an organisation. This particular system can be based on tacit knowledge with years of history and embedded experience which necessitate a naturalistic, qualitative method to articulate it (Jirotka, Gilbert, & Luff, 1992). The nature of human activity systems demands an approach that in the context of research includes the technology and how humans interact with it. Therefore it could be said that this research was conducted in the spirit of socio-technical theory with the underlying purpose of improving the socio-technical systems within which the designers work. This *purposiveness* determined the foci and interpretations and ultimately the conclusions drawn from the study.

2.4.3 Research cycle

Figure 2.2 illustrates how the various research techniques have been employed, what the analysis process was, what the outputs were at that point and where they can be found in the thesis. The black arrows indicate how those outputs were used as a platform to launch into the next data collection exercise which resulted in another analysis process being undertaken with further outputs. These in turn then became a platform for further data collection. This pattern continued through the three phases of the research and is described in more detail in the following section.

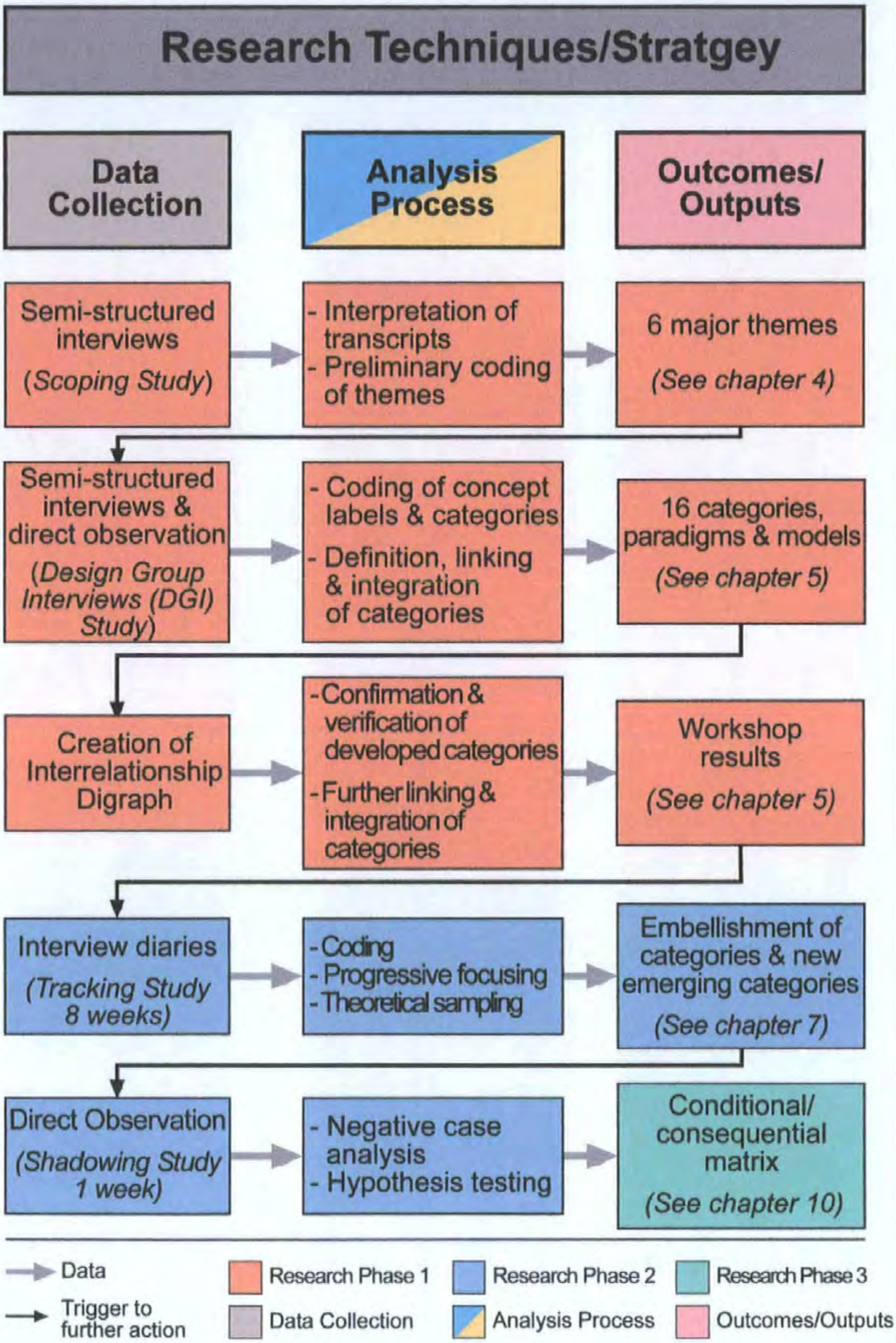

Figure 2.2: Schematic diagram of the research process.

2.4.4 Research techniques/strategies used

2.4.4.1 Interviews

Interviews provide an economical method of obtaining information which can be focused on particular sets of issues. Face-to-face interviews afford a flexible approach to data collection allowing the researcher to modify the line of enquiry and pursue alternative interesting topics which may arise (Robson, 1993). In conducting semi-structured interviews, a set of items, probes and prompts are prepared in advance culminating in an interview schedule. This can be modified as the interview develops with each individual interviewee thus allowing the researcher to follow lines of enquiry which would not be feasible if a questionnaire had been used. This method can produce rich and highly illuminating material reflecting the priorities of the subjects (Robson, 1993). However, interviewing can be time consuming and the lack of standardisation implies there may be concerns about reliability. Bias can also be an issue which needs to be addressed.

Throughout the first two phases of the research project, semi-structured interviews were undertaken to elicit the information in the data collection exercise.

The preliminary interviews with targeted designers in the initial phase comprised some structured questions followed by open questions. The questions included the career history of the individual, experiential history in design, personal instances of creativity, constraints they were working under and other perspectives on related issues (see appendix C). The use of such questions was to identify salient elements and ideas for detailed studies at a later stage. The preliminary interviews were much less structured than subsequent interviews in the Design Group Interviews Study and were what Holstein and Gubrium (1997) refer to as "active interviews". That is rather than a benign and innocuous interview taking place, both respondent and interviewer are active in constructing the hows and whats of the meaning making process of the interview. The interviewer 'actively' encourages the respondent to expand their dialogue by allowing them to draw upon personal experiences and narrative positions and bring that to bear on the topics under discussion. Thus alternative perspectives and knowledge bases can be tapped into.

Normal practice for collecting data from interviews would be to tape and then have the discourse transcribed. This was the case for the Scoping Study, but as the interviews of the Design Group Interviews Study took place in a secure area where tape recorders were not permitted by the company, recording did not take place. Therefore hand written notes were taken in those interviews. All data were treated anonymously and confidentiality was upheld at all times.

2.4.4.2 Direct observation

Direct observation, where the researcher was an observer-participant, was used sparingly. As an observer the researcher does not become involved in the participant's activities although they are aware of the researcher's presence (Martella, Nelson & Marchand-Martella, 1999). This method was employed when the participants of the study invited the researcher into meetings where the topic was of interest and relevance to the investigation. Field notes were taken in these instances which attempted to record the interactions within the meetings between the people present.

This method is the appropriate technique for getting at 'real life' in the 'real world' (Yin, 1994). In the context of the present study, the use of this method allowed observations of meetings which to a certain extent could add to and inform the data collected via other methods. Direct observation in such settings as meetings provided a view of another dimension of the designers working environment. However, one of the disadvantages of this method is the extent to which the observer affects the situation under observation (Robson, 1993). For example, the researcher does not know how much of his/her presence has effected the behaviours and interactions of those being observed. In addition the researcher, to some degree, is always selective in what they choose to observe and this element of subjectivity cannot be ignored.

At this point in the research cycle of data collection, analysis began using grounded theory. A core feature to this methodology is that the theory evolves during the research process as a result of the "continuous interplay between data collection and analysis" (Strauss & Corbin, 1994). Evidence of this sequential process is described in the following sections.

2.4.4.3 *Grounded theory*

In classical ethnography, the data would be written in the form of 'stories' articulating the views and perspectives of those from whom the data were collected and presenting an authentic view of the situation. However, to make sense of such a volume of data and interpret it in terms of the purpose of this research, reducing it to a more manageable scale has its advantages. There is a need for an element of analysis to facilitate the drawing out of general issues and conclusions. The use of grounded theory to systematically build theory from the data distinguishes the study from an ethnomethodogical approach (Strauss & Corbin, 1998). Analysis requires the coding and categorising of the data to facilitate its interpretation, and those processes take it to a higher level of abstraction and generality than individual stories. It is important that the categories produced do provide a true representation of the data whilst leading to conceptual understandings and links to theoretical interpretations (Pidgeon & Henwood, 1996).

However, there are problems with taking the data reduction approach of assigning categories and employing coding techniques in that the researcher is imposing an element of interpretation onto the raw data. As a result, the authenticity and meaning will be lost to some extent and a certain amount of interpretative bias introduced (Strauss & Corbin, 1998). This was thought to be acceptable in view of the advantages that data reducing methods offer and it was felt that the concern over the authenticity could be addressed through the appropriate application of triangulation and confirmation with the participants.

Grounded theory is a methodology which can accommodate an atheoretic stance, the emergence of themes and ultimately the development of a theory grounded in the data which has been systematically collected and analysed (Glaser & Strauss, 1967; Strauss & Corbin, 1998). The approach was used because it allowed the significance of the findings to be drawn from the data through an iterative process, rather than attempting to impose pre-determined models, hypotheses or categories. Thus it could be described as solely inductive. However, as the analysis using grounded theory develops so inferences can be drawn, hypotheses stated and subsequently tested. Therefore grounded theory represents an approach to research which is both inductive and deductive (Hammersley, 1996).

Grounded theory also accommodates a number of data collection techniques such as interview, participant observation and open-ended-conversational style techniques. Therefore, this methodology served to complement the ethnographic line of enquiry taken in this project.

The research activities involved in grounded theory are the development of a basic taxonomy, focused conceptual development and cycles of interpretation which are expanded upon below (Pidgeon & Henwood, 1996).

The approach of grounded theory is suitable for use with any large corpus of unstructured material such as audio interview transcripts, observational data and notes from interviews of participant's accounts, all of which were collected in this project. The researcher becomes immersed in the data and employs a number of analytical tools for handling the data systematically and creatively. Inspection and analysis of the data allows the identification, development and relationship of concepts which enable the theory to be drawn from the data by the process of induction initially. As the data are collected, interpretations are sought for understanding the actions of the individual or collective actors being studied. Early analyses prompt further data collection by theoretical sampling. This may involve returning to participants to explore aspects of the emerging interpretations (Pidgeon & Henwood, 1996). Researchers also interpret what is observed or read. Hence this methodology suits the constructivist paradigm. Grounded theory ultimately provides conceptual density and richness in an interrelated, coherent manner (Strauss & Corbin, 1998).

There are several steps in conducting grounded theory with qualitative data. Those proposed by Pidgeon and Henwood (1997, p.257) are illustrated on the left of the figure 2.3.

Pidgeon and Henwood present four major elements of this grounded theory approach to data analysis namely "data preparation", "initial analysis", "core analysis" and "outcomes". Strauss and Corbin (1998) tend to follow similar steps but refer to the "initial analysis" as *open coding*, "core analysis" as *axial coding* and *selective coding* and "outcomes" tend to be described in terms of '*paradigms*' and *models*.

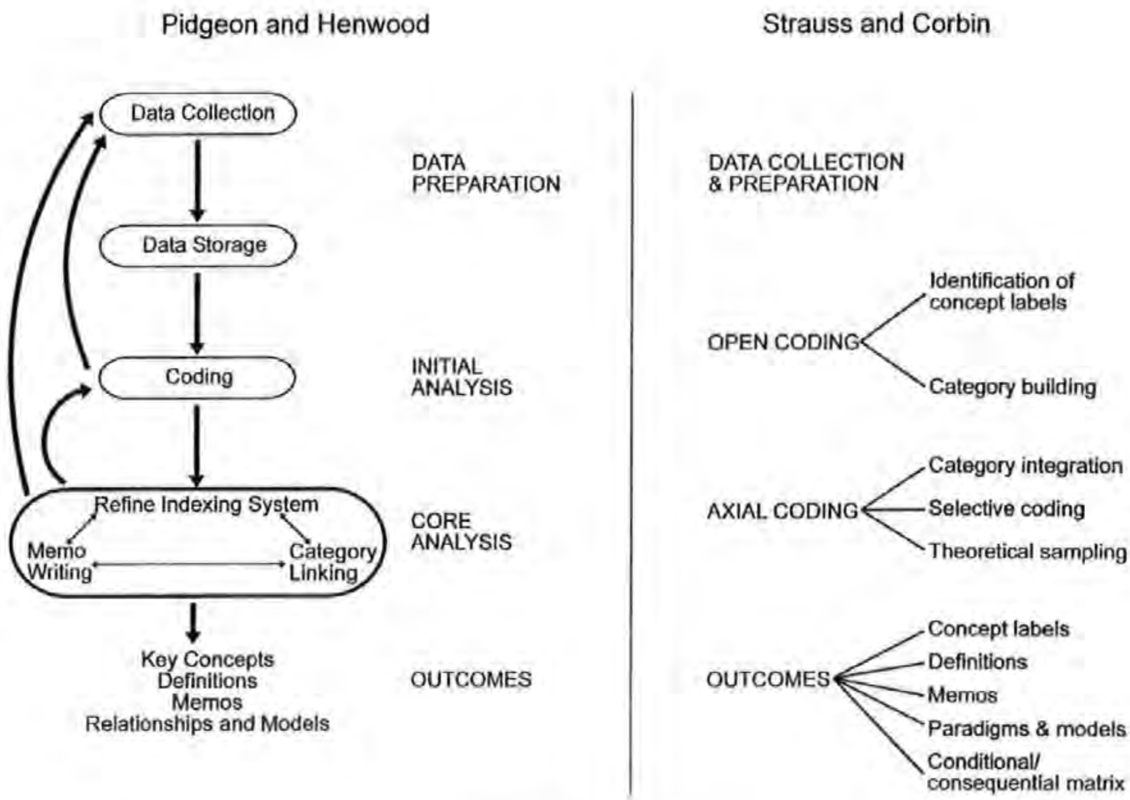

Figure 2.3: A comparison of the processes involved in the grounded theory approach.

Figure 2.3 illustrates the similarities and the differences between the steps presented by Pidgeon and Henwood and Strauss and Corbin when undertaking the grounded theory methodology.

Below are the three coding procedures as described by Strauss and Corbin (1998). Coding enables the researcher to make sense of the data; to begin to sort it and categorise it in terms of the concepts elicited.

Open coding:

Open coding is a process by which, conceptual labels are assigned to the unit of analysis, which in this case tended to be by sentence and/or paragraph of interview transcripts. Concept labels are terms that the researcher believes best represent items of text (Strauss & Corbin, 1998). During this coding process, the researcher is constantly comparing each unit of analysis with another to establish the appropriate conceptual label. They conceptualise abstract events, discrete incidents, ideas, and so on, from the data. When assigning a conceptual label, there is some degree of interpretation of meaning derived from the context. However, naming or giving of labels does not always explain what is going on. Further analysis needs to be conducted by grouping the concepts into categories, yet another data reduction exercise, to make the data easier to work with.

Categories represent groupings of similar conceptual labels and thus a funnelling of findings. Categories are defined in terms of their meaning, and where appropriate, their properties and dimensions. Properties are characteristics of a category and dimensions represent the degree of that property along a continuum. Saturation of a category occurs when no further information emerges from the data which would add to its dimensions and properties. It is at this point that categories are fully defined.

Axial coding:

Further development of categories and the development of 'paradigm'/models takes place in the second stage of coding. Axial coding is the tool which reassembles the data which was fractured during the open coding process, finding out where the relationships lie between the categories and sub-categories at the level of properties and dimensions (Strauss & Corbin, 1998). For example, which categories overlap and integrate with other categories, establishing links between categories and where related concepts are made. Pidgeon and Henwood (1996) see this as part of the "core analysis" stage. The researcher needs to ask the questions of why or how come, where, when, how and what are the results/outcomes of such interactions. This uncovers the relationships between the categories. Answers to these questions then help contextualise the phenomena thus placing them within a conditional structure (Strauss & Corbin, 1998). The structure sets the stage, that is the particular circumstances under which problems/issues or events relating to the phenomenon arise. Whereas the process refers to actions/interactions of people, organisations etc. in response to the problems and issues. The combination of the structure and process helps determine and explain the complexity of the phenomenon.

Selective coding:

The process of selective coding involves integrating and refining the theory. Integration happens throughout the analysis and often continues until the final writing according to Strauss and Corbin. By using a number of techniques, such as diagrams and writing the storyline, major categories are related to each other through explanatory statements of relationships. At this point the theory can be refined, poorly developed categories are identified and addressed by further theoretical sampling and any irrelevant data is discarded. At this point it is necessary to begin to validate the findings by presenting it to the respondents.

Paradigms, models and outcomes:

Linkages between categories can be very subtle and implicit so it helps to have a scheme to sort and organise the emerging connections. Such an organisational scheme is referred to in grounded theory by Strauss and Corbin as a 'paradigm'/model which allows the ordering of the data in such a way that structure and process are integrated. An example of how categories may 'fit' together in a 'paradigm'/model is shown in figure 2.4.

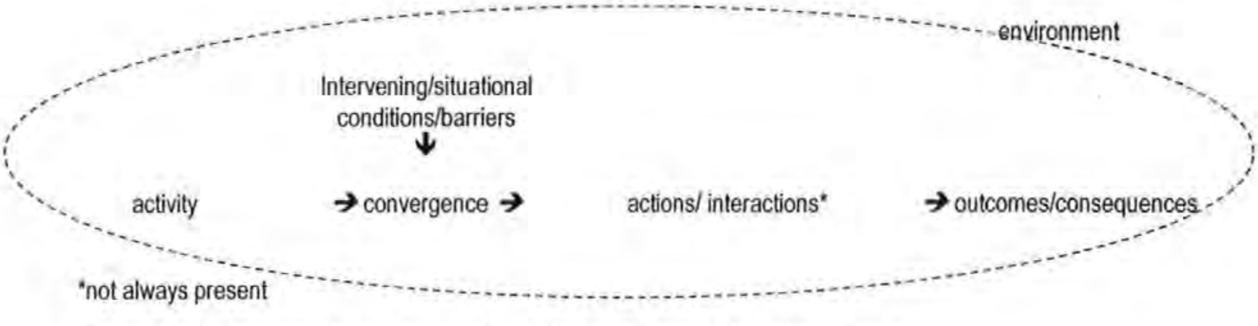

Figure 2.4: 'Paradigm'/model representing the occurrence of the phenomenon.

To help explain the model in figure 2.4, *intervening conditions/barriers* are the precursors which create the event or situation taking place. These help to explain why people respond in certain ways when engaged in an *activity. Intervening/situational conditions/barriers* can arise out of various things such as time, place, culture, rules, regulations, beliefs, economics, power, gender factors, social worlds, organisations and institutions. Properties may effect this directly or indirectly and can be micro[2] or macro[3], causal, intervening or contextual. Therefore conditions which converge to a 'problem' which is responded to through some form of *action/interaction* with some *outcome/consequence* needs to be identified. Changes in the original situation as a result of action/interaction also need to be identified.

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2 Micro conditions/consequences are those which are narrow in scope and possible impact.

3 Macro conditions/consequences are those which are broad in scope and possible impact.

Actions/interactions may be rules regulations, policies or procedures which may or may not be taken to resolve a problem. It may also include a strategy developed to overcome a problem. *Outcomes/consequences* have inherent properties, can be singular or many, be immediate or cumulative, reversible or not, foreseen or unforeseen, narrow or widespread.

The building of 'paradigm'/models and diagrams helps to explain what is happening and ultimately represent the phenomenon in question, that is where related patterns of happenings/events, the conditions/barriers and the possible actions/interactions carried out in response and the outcomes of those actions. Matrices and flowcharts are other ways of representing how the categories and concepts relate and link to each other (Pigeon & Henwood, 1996).

As the analysis progresses, the different coding procedures are not always followed sequentially, but often simultaneously with the analysis, allowing for a deeper understanding of the complexity of the data. Inferences can be made and hypotheses tested of the data. For example, when *x* happens, it will always result in *y*. This can not only help to validate the data, but also identify where there are any contradictions found in the data. Pidgeon and Henwood (1997) refer to this as "negative case analysis". Applying this approach systematically and open-mindedly eventually leads to a theory emerging from the data which can identify the meanings and significance of the observations.

Memos and matrices:

The fieldnotes made during the interviews and the observations from the time spent at Rolls-Royce were subjected to the analysis by open, axial and selective coding (Strauss & Corbin, 1998). A rigorous recording of the coding exercises took place throughout this quite complex and long drawn out process. All units of analysis were cross referenced and identifiable yet anonymous. Indexing of categories was used to identify similarities and differences in the conceptual labels. Definitions of categories were written once the categories were saturated. Throughout the grounded theory analysis memos were written. Memos in this context were an ongoing dialogue with oneself, in a sense, where anything of relevance was noted and annotated. For example, it included ideas and insights about the data, plans as to what to do next, reflection on how the coding was going and notes about the coding process *per se* (see appendix A for an example).

Eventually a diagrammatic representation, "conditional/consequential matrix", illustrating the interplay between the macro and micro conditions where the phenomenon under investigation occurred was developed (Strauss & Corbin, 1998). The macro conditions referred to in this research were the more general and broader concerns relating to issues such as departmental culture, values and relationships with other departments and companies. Phenomena found under micro conditions referred more to the specific day-to-day instances of perceived barriers to creativity. The emergent model/matrix demonstrated the relationships between the categories which had developed from the data collected and was used as a tool for explaining what was going on the NPE in terms of perceived barriers to creativity (see chapter, 10 figures 10.1a & 10.1b).

Having analysed the interviews and direct observations in Phase 1 of this study using grounded theory, the themes, categories, 'paradigm'/models, which had emerged from the data, needed to be validated by the participants involved in the study. This would also present an opportunity to explore the aspects of the emerging interpretations which Pidgeon and Henwood (1996) recommend as part of the procedure. Part of this procedure involved employing the Interrelationship Digraph management tool (Brassard, 1989).

2.4.4.4 Interrelationship Digraph (ID) management tool

The Interrelationship Digraph (ID) is one of a set of 7 "management tools" used by, for example, managers, decision makers and team leaders. The tools are used in group situations to help elicit and structure thoughts, ideas, conceptions etc., with regard to a particular problem, of those involved. The ID often utilises data produced by another management tool, for example the Affinity Diagram. This stage provides a pool of ideas, issues, opinions etc. generated in response to a complex problem where a solution and/or greater understanding is necessary. Alternatively the source of data for the ID, in response to an issue/problem statement, can be generated by brainstorming ideas, thoughts etc. Ultimately the ID should identify the root causes of the problem statement. The ID was chosen to validate the findings of the grounded theory analysis at this stage. Strauss and Corbin (1998) suggest that verbal presentations to participants are usually necessary throughout research to feedback preliminary findings and provide some initial verification and confirmation of the data. Three such presentations to Rolls-Royce designers took place at Plymouth, Bristol and Derby (see chapter 5, section 5.4). The ID was used as part of the feedback and confirmation process to enable designers to participate in the identification of perceived barriers to creativity.

For the purposes of the workshop with Rolls-Royce participants, a modified version of the ID was developed by them. Due to constraints of time, it was not feasible to use the Affinity Diagram tool. Instead, the participants were invited to brainstorm issues which they felt contributed to the phenomenon 'perceived barriers to creativity' in terms of the categories which the researcher had identified from the data collected in Phase 1 (see chapter 5, section 5.4.2.2 for more detail).

Ultimately the Interrelationship Digraph is developed by mapping out logical and sequential links between interrelated items (previously generated data) in relation to a central idea or, in this case, phenomenon. Single-headed arrows depict the origin of the problem and through the processes of articulation and discussion, a representation of a number of key sources and links are constructed.

The ID was generated in relation to the phenomenon 'perceived barriers to creativity'. It appeared to identify relationships which began to confirm the initial models proposed by the researcher developed through the axial coding process.

However during the course of constructing the ID, it became apparent that the categories the participants were working with were at too high a level. As they created the links, they were debating and discussing and reaching a consensus by referring to specific, micro conditions where examples of 'perceived barriers to creativity' were occurring on a day to day basis in their working environment. It was at this point when the outcomes of the workshop were being fully evaluated (see chapter 5, section 5.4.2.2) that it was decided a further phase of data collection was necessary in order to explore the low level details of the issues.

This decision led to what is called theoretical sampling in grounded theory where the data gathered is driven by the concepts which have been developed from the emerging theory. In carrying out this activity using interview diaries, the aim was to gather more detailed material from the designers on a regular basis to try and identify the salience of the 'perceived barriers to creativity' and to compare the properties and dimensions of the different categories under different conditions. This helped to consolidate categories, differentiate amongst them and demonstrate their variability.

2.4.4.5 *Diaries and interview diaries*

Diary methods entail reports of thoughts, feelings, actions, and accounts of physical or social context (Breakwell, Hammond & Fife-Schaw, 1995). Diarists need to be told what is required of them and be given careful instructions. Unstructured diaries mean that the respondent would be free to add whatever she/he felt was relevant. Diaries which are structured with a specific set of questions asking about particular behaviours are more focused. However this can produce bias towards the researcher's hopes and expectations. The advantage of using diaries is that they are a cost-effective way of the sampling of information. It allows the sequencing and historicity of data and can provide an intimate and spontaneous insight to a daily/weekly routine.

There are a number of disadvantages regarding spontaneously generated diaries though. The researcher has no real control over the information put into the diaries as the diarist self selects the material. The dropout rate can also be a problem as can reactance and veracity (Robson, 1993). Often a diary will include a number of structured questions to help formulate the respondent's answers. However, this is not always advantageous as constraining the flow of the written diary could result in important information being omitted.

It was not feasible to ask the designers to complete a diary every day due to the workload they were experiencing. Therefore a combined research method of using semi-structured interview diaries was employed when visiting the designers on a weekly basis and asking them a series of questions about the previous week. An oral report was much easier for them to engage with the researcher. This standardised protocol tracking over the eight week period, resulted in data that were similar in nature to that of a diary. That is, it provided data collected on a regular basis which could then be compared over the weeks and between respondents as to the types of problems and issues the designers were experiencing. However, there was a problem inasmuch this method relied upon the memory of the individual being interviewed as they reported retrospectively. This combined method appeared to be the best solution due to the limitations of pure diary methods. These type of interviews had some similarities with the ethnographic interview method described by Spradley (1979) whereby interviews are more like a series of friendly conversations interspersed with ethnographic type questions which aim to elicit the data.

This method of interview diaries was shown to be effective in a study with an electronics company which investigated how project leaders support collaboration between design engineers. It looked at how, when confronted with management problems, they resolved these and what impact that had ultimately on the design process (Reid, Culverhouse, Jagodzinski, Parsons & Burningham, 2000). Weekly interviews conducted in a consistent format invited the engineers to reflect on the week, focusing on the design activities and the implications of them in relation to the project overall. Whilst this method generated a lot of data, it elicited the information required for the research project in a way that was acceptable to the company.

In the present research data collected during this phase (Phase 2) were analysed using grounded theory which led to the embellishment and consolidation of the categories developed in the previous phase and the opportunity for theoretical sampling. Phase 2 also allowed for a further incremental step to be taken in the analysis and a greater depth of understanding of the phenomenon under investigation to develop. In order to confirm and validate the data collected using the retrospective interview diaries over the 8 week period (the Tracking Study presented in chapter 7), one week's direct observation took place (see the Shadowing Study presented in chapter 8).

2.4.4.6 Shadowing

The shadowing of designers enabled a picture of how the working environment both on an intra-individual and inter-individual level operated within the company. This method, similar to participant observation (Yin, 1994), allowed the researcher to interact with the designers enabling informal data and personal viewpoints to be elicited as and when necessary. Access to archival data such as internal documents was beneficial to supplement this particular technique.

Also shadowing allowed the researcher to identify problems with the designers' supporting technology and how the designers overcome any barriers that they may experience during their creative activities.

By shadowing the designers it was intended that evidence of what they do and who they talk to would be revealed. Questions asked by the researcher of the designers would also allow an elaboration of what was happening and an opportunity to find out why they tackle problems the way they do.

2.4.5 Alternative research techniques/strategies

Reductionist methods of enquiry were considered, but they were thought not particularly useful in disclosing the tacit and socially enabled aspects of what might be going on in an organisation which qualitative methods can tap into (Jagodzinski, Reid & Culverhouse, 2000). The emphasis was on exploring the nature of these particular social phenomena rather than setting out to test hypotheses about it.

Verbal reports and protocols could have been employed to elicit from the designers the barriers they encounter when they are being creative. This method was used by Ullman, Dietterich and Stauffer (1988) to collect evidence from five mechanical designers in an attempt to develop a model of the mechanical design process. However, for this particular study whilst this method may have elicited some evidence for the phenomenon, it would have done so in isolation of the context in which it happened. Designers work under a number of constraints, for example, organisational, time, workload, technology etc. and these need to be included in the equation if the research questions are to be answered adequately.

Lloyd, Lawson and Scott (1995) have concluded from a series of experiments that using protocol analysis can impair the designer in the tasks they are carrying out and it is inadequate in eliciting aspects of the design process such as perception and insight. They suggest it is better used when a specific question needs to be addressed.

Some studies have used observational techniques such as video recordings to establish and help analyse design activity (e.g. Cross & Cross, 1996). Whilst this technique would have complemented the other methods and techniques used, it was not possible due to security restrictions in force in the area where the research was undertaken.

2.5 Validity and reliability

Issues of validity and reliability are major concerns for research. Hammersley (1992) considers a number of criteria proposed by different researchers over time (Lofland, 1974; Guba & Lincoln, 1982; Athens, 1984) to tackle these issues. However, Hammersley argues that the purpose of research is "to provide information that is both true and relevant to some legitimate public concern" (p.85). Hence he suggests that there are two basic criteria on which research findings should be judged. That is truth (validity) and relevance.

In terms of validity, are the accounts true? A true account will represent the features of the phenomenon, which is under investigation, accurately. Hammersley (1992) suggests that there are three important considerations:

1. Sufficient evidence needs to be supplied to make sure audiences are convinced beyond reasonable doubt that the account is true and accurate. They have to be credible.
2. The claims which are central to the investigation have to be substantiated with more evidence than those which are marginal claims.
3. The types of claims made in ethnographic research have to be distinguished and evidenced separately. For example, in the case of descriptions evidence which accurately describe events and locations would be acceptable. Evidence for theories however, would be found in the relationships between the phenomena and where such instances occur.

Therefore to satisfy the issue of validity, the main claims of the study are backed up by the appropriate evidence which is compared and judged by the company at various points in the research to judge its plausibility and credibility. Such evidence is found in the chapters 5, 7 and 8.

According to Hammersley, the issue of relevance relates to two important aspects. He suggests that the audience, this could be fellow researchers and practitioners who read the research, can judge the importance of the topic within a particular field. He also suggests that the research should make a contribution to literature and knowledge.

It is within this framework that the findings of the research are confirmed. At various points, the audience, the practitioners (participants in this case), were invited to confirm and validate the findings. Since they were the participants, they would be able to judge whether the evidence really can substantiate the conclusions drawn. Thus they will play a key part in determining the authenticity of the research undertaken.

Furthermore issues of reliability and validity are addressed by grounded theory through multiple sources of evidence. Patton (1990) suggests there are four basic kinds of triangulation that contribute towards the verification and validation of qualitative analysis. The following briefly describes what these are and how they were employed in this research:

1. *Methods triangulation:* Using a variety of different methods to check consistency in the data collection exercise. In this research various research methods and techniques were used (see section 2.4.4), namely interviews, direct observation, Interrelationship Digraph, interview diaries and shadowing.

2. *Triangulation of sources:* Checking different data sources using the same method. Data were collected from a number of different people throughout the research exercise, and this enabled comparisons and commonalities to be established.

3. *Analyst triangulation:* Use of multiple analysts. Patton (1990) proposes that another approach to this type of triangulation is to have the participants in the study review the findings. This has been used throughout the study specifically with the workshop (see section 2.4.4.4 & chapter 5, section 5.4.2.2) where brainstorming techniques led to the development of models which formed recognisable representations of their views. Seminars, presentations and detailed reports for their examination were other techniques used to obtain confirmation from the participants of the issues.

4. *Theory/perspective triangulation:* Using multiple perspectives to interpret the theory. This was achieved by collecting data from project managers/team leaders, experienced designers and novice designers from within the organisation.

The researcher's immersion in the data raises the issue of subjectivity and the possibility of misinterpretations and distortion of meaning taking place (Strauss & Corbin, 1998). However, to reduce this problem, the researcher must continually compare one piece of data with another in order to validate the findings. The writing of memos throughout the application of grounded theory provides not only an audit trail of how the research took place, but also provides a source of reliability with which to measure the outcomes. Ultimately, the participants themselves should verify the theory developed from the data as representing a credible picture of what they believe is going on.

In terms of the generalisability of ethnography, Hammersley (1992) suggests that findings can be generalised, but there is a need to reflect, be clear about populations and time periods to which generalisations can be made. Another possibility is the use of aggregate data and data which already exists generated by survey research and carry out systematic co-ordinated similar studies to sample populations across time. An ethnographic study conducted at Rolls-Royce, Derby had taken place prior to this research and some generalisations and comparisons are made throughout the research in view of those findings. In chapter 10 section 10.6 the validation and the generalisation of the research findings are discussed.

2.6 Overview of the phases

The figure below (figure 2.5) illustrates how the study comprised three phases. This model differs from figure 2.2 as it demonstrates both the iterative and sequential, yet overall systematic, nature of grounded theory as used in this research. The associated colour codes facilitate the links that can be made between these two diagrams.

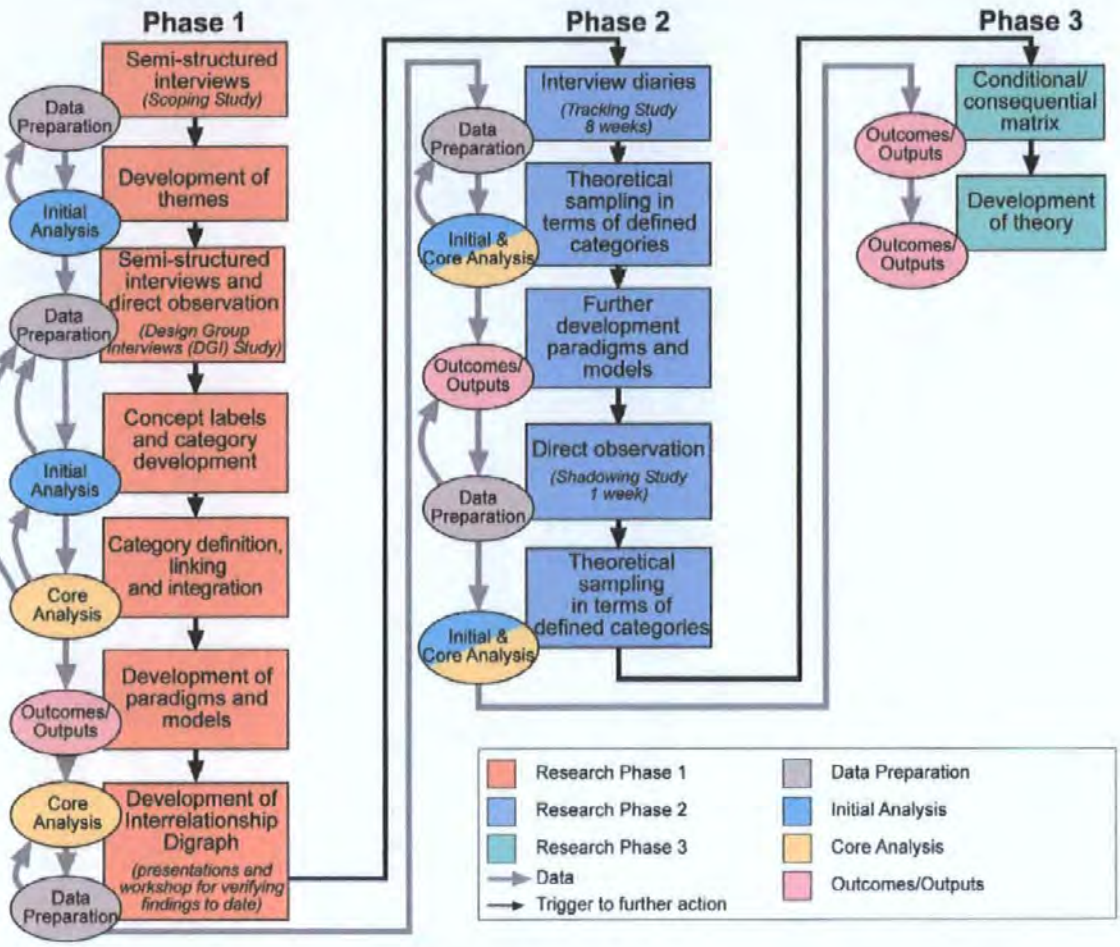

Figure 2.5: Schematic diagram of the three phases of the research.

For each phase it can be seen how the process reflects the model of Pidgeon and Henwood (1997) shown in figure 2.3. For example, data preparation encompasses both data collection and data storage (see figure 2.3) and that it occurred at various stages throughout Phases 1 and 2. The grey arrows which feed backwards again are reflected in Pidgeon and Henwood's model and indicate the iterativeness and continual comparing of new data with previously coded data. Through this process, categories developed, sub-divided and re-emerged as the analysis progressed. Ultimately relationships and models were drawn out which sought to present the theory of the phenomenon derived from the data.

The studies employing the research techniques and strategy presented and discussed in this chapter are reported in chapters 4, 5, 7, and 8. A reflection on the research process and the appropriateness of the techniques used can be found in chapter 10, section 10.7. The next chapter contains a review of the literatures which were used as a basis for the research findings.

Chapter 3: Literature Review

3.1 Introduction to the chapter

Design and creativity are subject to much research and this has generated many themes within the literatures. A number of these themes have relevance for the research undertaken in this project. The function of this chapter is to characterise different aspects of design, as found in the literature, and then to locate and link them to the research described in later chapters 6, 9 and 10. Thus a framework is presented to provide a literature overview of research and theory in the area of conceptual design. This literature is considered under a number of headings relevant to this research and then drawn together to identify the 'fit' and overlap between the topics in the conclusions. There is a necessity for a broad review of the literature. The 'acid test' for inclusion is whether that particular issue was drawn out from in the findings and therefore can be related back to the literature.

3.2 Design

According to Gero (1994) design is a most "complex and intellectual human activity" and that it is not yet well understood. A number of techniques have been employed by researchers to provide formal structures and frameworks to better understand the design process. In the following sections some of these formal structures and frameworks are discussed and their adequacy in representing the design process assessed. It is not surprising that there should be such an array of design perspectives because research into this area has come from many different disciplines, such as engineering (e.g. Pahl & Beitz, 1984; French, 1985, 1999), architecture (e.g. Oxman & Oxman, 1992), psychology (e.g. Thomas & Carroll, 1979), computer science (e.g. Boehm, 1988) and industrial design (e.g. Pugh, 1993, 1996). A number of different interests can be identified in this work which are presented in section 3.2.1 to 3.2.4.

3.2.1 Design methodology

In the 1960's theories from a positivist background saw design as a rational and rationalisable process (Dorst & Dijkhuis, 1995). Newell and Simon (1972) also provided a paradigm based on problem solving theories where design was seen as a means-end analysis or rational problem solving process. From this rational viewpoint, design focuses "on the rigour of the analysis of the design processes, objective observation and direct generalisation of findings" (Dorst & Dijkhuis, 1995). This approach interprets design as a very logical search process where clear steps are taken to find a solution. This approach is limited by the information processing capacity of the subject. This type of paradigm for explaining design activity is reflected in the sequential linear models developed to represent the design process (section 3.2.2). This may be acceptable for well-defined problems that have a clear goal with often one correct answer and rules or known ways of proceeding that will generate an answer. However, for ill-defined problems, which have no definitive formulation of the problem and no defined solution path to the problem, this particular approach may not be viable.

In the 1980's Schön (1983) suggested a radically different paradigm describing design as a process of "reflection-in-action". Schön's theory is based on a constructionist view of human perception and thought processes, seeing design as "a reflective conversation with the situation". This approach suggests that the designer frames the problem and attempts to change and improve the situation by taking certain actions whilst regularly evaluating and reflecting on their own actions in structuring and solving the problem. Such a paradigm reflects the iterative process designers have to adopt when engaging in conceptual design in particular. Evidence for this type of approach was found in NPE (e.g. see chapter 8, section 8.3.9.1).

	Rational Problem Solving	**Reflection-In-Action**
Designer	Information processor (in an objective reality)	person constructing their reality
Design problem	ill defined, unstructured	essentially unique
Design process	a rational search process	a reflective conversation
Design knowledge	knowledge of design procedures and 'scientific' laws	artistry of design: when to apply which procedure/piece of knowledge
Example/model	optimisation theory, the natural sciences	art/social sciences

Table 3.1: Two paradigms summarised to describe design methodology (taken from Dorst & Dijkhuis, 1995, p.263).

According to Dorst and Dijkhuis (1995) models of design methodology have failed to adequately address the realities of most design situations. It is important to take this into account, as design is not just a process but a 'situation' that is also experienced by the designer. Winograd and Flores (1986) describe the design situation using an analogy of chairing a meeting where one "cannot avoid acting, cannot step back and reflect on their actions, the effects of actions cannot be predicted, one does not have a stable representation of the situation, every representation is an interpretation, and language is action" (p.34-35).

Dorst and Dijkhuis (1995) employed both types of paradigm to describe a number of design activities and compared the outcomes. They concluded that the rational-problem solving approach to the study of design was adequate when dealing with well-defined problems where the designer could apply well known strategies and heuristics to solve them. However where the design activity was less formal, for example, in the conceptual phase, there was no evidence of a rational-solving approach. Whilst the rational approach can record certain design activities well, it says nothing about good or bad design practices.

On the other hand, the authors argue that Schön's approach involving the reflective conversation lacks the clarity achieved by the rational problem-solving paradigm. Schön's paradigm is closer to describing "the design-as-experienced" rather than seeing it just as a rational problem process and is especially useful in the conceptual phases of design where the search in the solution space is not necessarily governed by known strategies and heuristics.

Allwood and Kalen's (1994) review of the research conducted on design from a psychological perspective supports this finding. They suggest "formal" approaches to design such as described by Simon (1973) seeking to fully formalise the design process. However, the "empirical" approach to describing design by authors such as Schön accommodates the elements of design which are "inexplicable and unique". The authors suggest that both approaches are applicable, but with different emphasis required depending on the type of design being undertaken (see section 3.2.3). This was certainly evident from the studies undertaken in the present research which is focused on the creative conceptual design phase and in particular for ill-defined problems. The situation at Rolls-Royce Aerospace (Bristol) is discussed fully in chapter 6, section 6.4.4.

3.2.2 Models of design

Research by Lawson (1984) provides evidence of the way designers and scientists differ when solving a problem. Scientists appear to use a more systematic way of looking for a solution and problem-solve by way of analysis, whereas designers problem-solve by way of synthesis using solution-focused strategies when tackling ill-defined design problems. It could be argued that scientists favour a deductive approach whereas for certain design activity designers prefer an inductive approach.

In the early 1980's models of the design process were very linear in their representation. For example, French's (1985) model represents engineering design in the form of a flow chart where a number of activities beginning with the "analysis of the problem, conceptual design, embodiment of schemes and detailing" are presented. Whilst it incorporates an element of iteration, it also identifies and represents stages attained with their respective outputs. This descriptive model of the design process is argued as being heuristic and typical of conventional engineering based on a simple three-staged model of "generation → evaluation → communication" (Cross, 1989). These types of models describe design, but do not indicate how design is conducted (Dym, 1984).

Prescriptive models have been suggested as a way of improving the way designers design by encouraging them to follow a more "algorithmic and systematic" procedure (Cross, 1989). These models suggest an underlying structure of "analysis → synthesis → evaluation". In these types of model the emphasis is on making sure the design problem is fully understood and the solutions to the problem are fully investigated and evaluated resulting in a rational choice. Using such models as a basis, Archer (1984) developed a detailed prescriptive model which identified six types of activity. Archer, described his model of the design process as follows:

> "One of the special features of the process of designing is that the analytical phase with which it begins requires objective observation and inductive reasoning, while the creative phase at the heart of it requires involvement, subjective judgement, and deductive reasoning. Once the crucial decisions are made, the design process continues with the execution of working drawings, schedules, etc. again in an objective and descriptive mood. The design process is thus a creative sandwich. The bread of objective and systematic analysis may be thick or thin, but the creative act is always there in the middle."
>
> (Archer, 1984, p.64)

Hawkes and Abinett (1984) discuss the systematic approach to design and propose that by adopting such a method, design solutions evolve. Their representation of the design solution process vaguely describes the need for synthesis, which should result in a number of different proposals and solutions (minimum of 3) of which detailed comparisons can be made, and important features highlighted. A simple evaluation of the solutions is then conducted employing a rating method against a number of the design features. This description appears to follows a reductionist approach reducing the design process to a number of elements. It fails to adequately address all that the design process entails where perhaps the "whole is greater than the sum of its parts", especially in the early conceptual design stage. The authors attempt at a later stage to discuss the iterative design procedure with a flow diagram to represent the stages of re-design (feedback loops) in the system.

A more comprehensive design model than those previously described was developed by Pahl and Beitz (1984). This again has a number of stages:

- clarification of the task
- conceptual design
- embodiment of design
- detail design

Their model also involves a number of sequential activities each resulting in certain outcomes at the various stages of the process. These types of design models presented so far could be described as narrow and procedural.

Cross (1989) argues that the aim of trying to model the design process in such a systematic way is to enable it to be seen as a "transparent and rational" process. However, there have been some concerns raised with regard to these traditional models as they do not appear to be able to reflect contemporary practices mainly due to the increase in complexity of today's designs and design problems. Contemporary design tends to be more iterative (Pugh, 1993). This may result from the recent development of concurrent engineering practices and flexibility offered through information technology.

However Cross argues that systematic approaches to design are necessary to enable teams to work collaboratively together and to assist the designers in adapting to the new materials and technologies. Risk reduction and the need to reduce lead-times are other factors which make a systematic approach to design necessary (Cross, 1989). This is an important issue at Rolls-Royce Aerospace.

Ferguson (1993) argues that engineering is unpredictable and the final goal can never be deduced at the outset because of unforeseen circumstances that the designer will inevitably encounter during the design process. Therefore design cannot be adequately presented in a block diagram as a formal sequential process. As already stated, these type of diagrams imply a division of design into discrete segments each of which have to be 'processed' before progressing onto the next step. Although block diagrams employ 'feedback' paths, many of the steps in the design may well be going on at once.

In the realm of software systems design, the "waterfall" model is viewed as the classic traditional model of the software engineering cycle (Pressman, 1992). The basis of the model is that of a systematic, sequential approach where each step is finalised before going onto the next one. This would appear to be similar to the early models of engineering design. However, although this model has been the most widely used its applicability to all situations has been criticised for a number of reasons. For example, in many instances design projects do not happen in a series of sequential steps. Steps in the design process have to be visited and re-visited in an iterative fashion as progress is made. The "waterfall" model does not accommodate this type of process. However, Sommerville (1992) argues that whilst the waterfall model appears to be linear, it does involve a sequence of iterations throughout the different stages when implemented to develop software.

In comparison, towards the end of the 1980's and the 1990's, other models of software system design were developed, for example, prototyping (Pressman, 1992). This model involves the actual building of a model, a prototype which can be in a number of forms, that the designer has in mind. To begin with, the designer needs to gather all the relevant information pertaining to the product before constructing a 'quick design' and the prototype from which it is then built. Both developer and customer are involved at this stage to ensure that requirements are defined and met. Again, once the prototype has been made, it can be evaluated by the user and further refinements made. After a process of iterations, the final prototype is realised by both the designer and the customer/user. The problem with this type of model is that the customer may not realise the superficiality of the prototype. Also the designer may employ certain components at the start which were easily accessible and may end up actually using them in the final product although they may be less than ideal (Pressman, 1992).

Boehm (1988) developed the spiral model to incorporate the best features of the waterfall and prototyping models previously discussed (see figure 3.1).

The main sections of this model are planning; risk analysis; engineering and customer evaluation. The basis of this model is again iterative. By starting from the middle and working outwards, each section is re-visited as the designer aims towards a completed product. In other words, as they move continually through the spiral, so they begin to get a more complete model. For example, at the beginning of the design process, a prototype may be made to represent initial ideas. This in turn will be 'revisited' on subsequent circuits to be modified until the final product is completed.

Within each quadrant of the spiral, aspects of the other two models can be implemented. Thus the spiral model has the advantages of the stepped and systematic approach of the classic model whilst still maintaining the essential iterative process that is required in the design process.

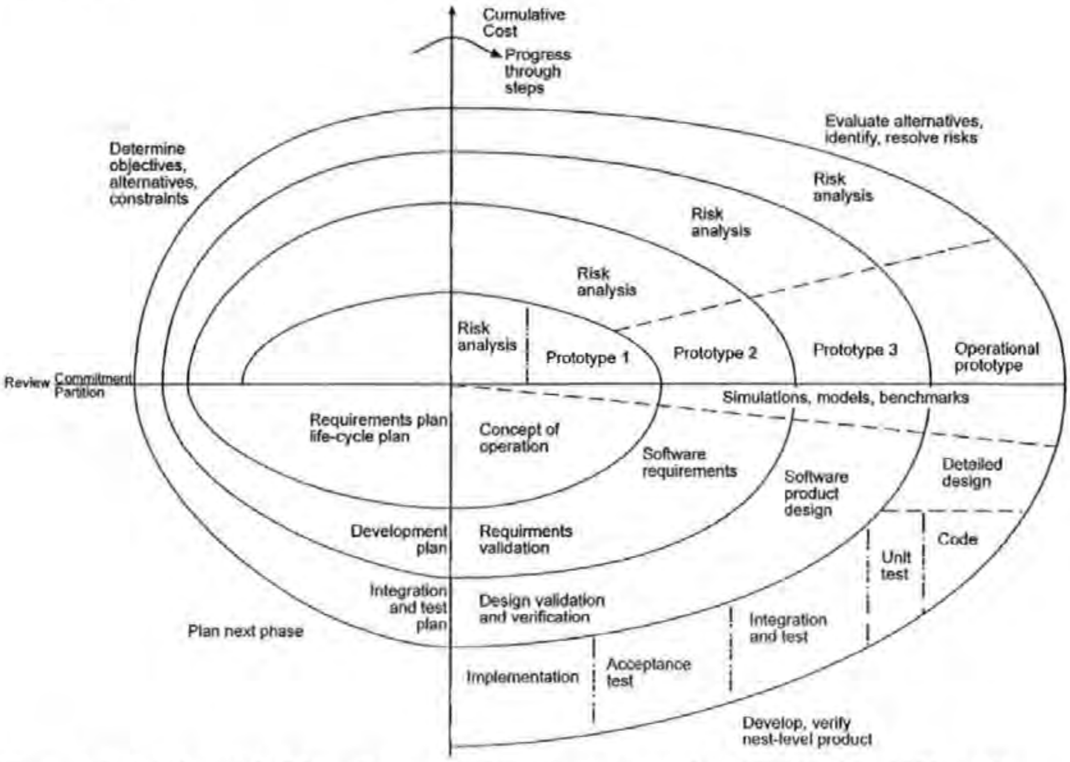

Figure 3.1: Spiral model of the software development process (taken from Boehm, 1988, p.64).

According to Pressman (1992), a few problems regarding the evolutionary approach of this model have been identified and there may be more as it is relatively new and has yet to be adequately evaluated.

It is suggested by Pressman (1992) that a design project in software engineering may benefit from a number of paradigms being combined and depending on the type of project, should dictate the kind of model(s) that is/are employed. To a certain extent this is achieved with the spiral model where the combination of the aforementioned paradigms are represented.

Rechtin (1997) refers to the spiral-to-circle process model which incorporates the attributes and the important features of both the waterfall and spiral models. In this version, the design process is tracked in an outward spiral. At certain points it reaches stages where a stable version of the design is attained with a review of progress before progressing to further development.

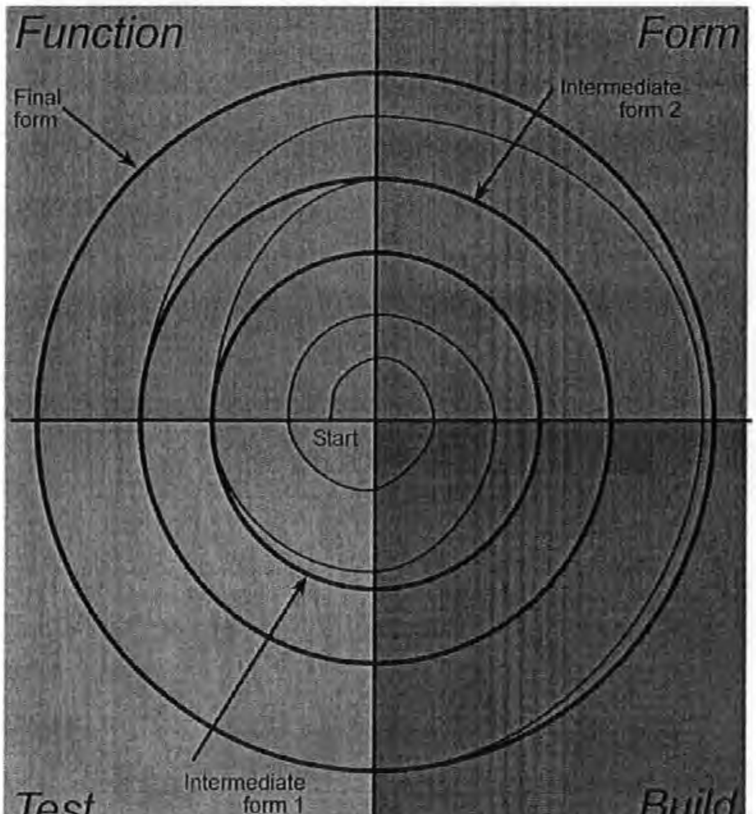

Figure 3.2: Spiral-to-circle model of the software development process (taken from Rechtin, 1997, p.55).

Recent advances in software development environments have made it much easier for software to be prototyped quickly, and this has encouraged iterative prototyping methods of design using rapid application development (RAD) techniques. However, it is less easy and more expensive to prototype in metal.

It would appear that in the disciplines of both engineering and software design, the design process had not been adequately represented by the original models, especially regarding the early stages of design, and adaptations and modification of the models have taken place as understanding has evolved.

Attempts have been made more recently by other authors who have also proposed models which describe a broader and wider perspective of engineering design. For example, Pugh (1993, 1996) proposes a model which is based on a number of central activities which he refers to as the "design core". These core activities are "Market → Specification → Concept Design → Detail Design → Manufacture → Sell". "Total Design" according to Pugh (1993, 1996) is described as "a broadly based business activity in which specialists collaborate in the investigation of market, the selection of a project, the conception and manufacture of a product, and the provision of various kinds of user support" (p.489). Iteration through these different stages is necessary although eventually the whole process will have been conducted in a sequential way. Whilst this would appear to be a relatively linear process, it has the important iterative elements within the model.

According to Pugh, a good product development specification (PDS) which is thorough and understandable is essential for the designer to follow as a design project progresses. The PDS has to be evolutionary and interaction between the different elements of the core design allows the PDS to evolve. Even in the conceptual stage of design it is beneficial to work to a PDS. This particular stage breaks down into two main components which are (i) the generation of solutions and (ii) the evaluation of the solution that is best matched to the PDS.

Pugh argues that design is a collective and interdisciplinary process which involves the essential element of human interaction. Compared to the prescriptive models described previously, his model has a much broader perspective and he acknowledges that in addition to the core design activities which are bounded by product design, there exists a personal design boundary and a business design boundary. The product design boundary relates to what is determined by the customer and the PDS. The personal design boundary relates to the constraints placed upon the total design activity such as the characteristics and skills of those engaged in the activity. The business design boundary relates to the many facets of a business, which interact with the design core in terms of information, resourcing and support to ensure the most effective outcome. Findings from this research are discussed in terms of these boundaries in chapter 6, section 6.4.4.

3.2.3 Types of design

In seeking to clarify and understand design problems and define better models, there have been efforts by various authors to identify different types of design. These are discussed in this section.

Pahl and Beitz (1984) define three different types of design. "Original" design, they propose, involves finding "an original solution principle"; "adaptive" design involves "adapting a known system (where the solution principle remains the same) to a changed task" and the "variant" design which involves "varying the size and/or arrangement of certain aspects of the chosen system".

Pugh and Smith (1976b) also propose that there are variations in the total design activity model and discuss the view of static and dynamic product concepts within a spectrum of conceptual design activity. At one end of the spectrum (referred to as boundary A) where innovative, dynamic concepts evolve, the order of the core design activities differ from the order required for more static and conventional designs found at boundary B (the other end of the spectrum).

Pugh (1993, 1996) argues that companies have to recognise that depending on whether the product is conceptually static or not will determine what mode they should operate in. Companies should always be aware that static elements of a design could and may need to be modified and an alternative concept developed. However, the authors acknowledge that resistance to such conceptual changes do occur.

Maher and Gero (1993) have also classified design into three types. "Routine" design is where all necessary knowledge is available and the output will not differ that much from previously produced designs. "Innovative" design is where the product, although similar, may be based on a particular set of values of variables which are outside the range usually used. Finally "creative" design is where, as a result of introducing new variables, a substantive difference in the product has resulted. These types of design are similar to those described by Pahl and Beitz (1994).

Culverhouse (1993) proposes that there are fundamentally four different models of design. He refers to them as "repeat order" design, "variant" design, "innovative" design and "strategic" design and has attempted to describe them in terms of percentage of new knowledge required in the design and production. Culverhouse suggests that for "repeat" design, little or no new knowledge is required to complete the product whereas at the other end of the spectrum, "strategic" design requires over 50% new knowledge being applied in order to resolve the design problems. Whilst these conclusions were drawn from studies conducted in the electronics industry, there are commonalities, in terms of types of design within mechanical engineering and others presented here.

It would appear that there is a need to consider what type of design is involved for a particular problem and then apply and adapt an appropriate design model to it that reflects the process the designer has to go through. Where projects are well-defined and fully specified, the classic approach with its sequential steps can be adopted. However, where the requirements are not fully realised or easily specified, the designer may have to adopt a different approach.

3.2.4 Individual models of/approaches to design

This section discusses the literature that describes how individual cognitive models of design may be articulated. Individual design models need to be understood so that appropriate tools and support mechanisms can be developed to support creative, intellectual and problem-solving activities carried out be designers.

Coyne (1990) suggests that connectionism may be an alternative way to classical cognitivism in understanding such design activities. Classical cognitivism focuses on the idea of symbols as the mental representation of design where the use of rules, hierarchies of types and the articulation of the design process are important. This approach has implications for the development of artificial intelligence in the area of design. However, connectionism is about knowledge representation and how to model human reasoning. Coyne argues that this particular approach provides a framework for considering the importance of observing and doing in learning to design. Emphasis is also on the building of a rich experiential base and recognising the importance of intuition and that certain design activities cannot be articulated. Another aspect of this approach is that creative solutions can emerge from simple ideas, although Coyne argues that for this to happen a thorough understanding of the fundamentals of the design problem is a prerequisite.

It has also been argued that connectionism and classical cognitivism can help understand the different aspects of design behaviour (Coyne, 1990). Liu (1996) supports this idea. Liu suggests that designing involves the combination of two searches to find solutions. During the conceptual phase, designers seek alternative ways to reinterpret the current design state and new emergent sub-structures are formed. Liu argues this is close to the connectionist processing model. Later in the design process when designers are searching for alternative rule applications to move the reinterpreted design state to one which is a closer match to the practical design requirements of the problem an approach closer to classical cognitivism is employed.

A study conducted by Spillers and Newcome (1993) attempted, through interviews, to elicit information on the practice of conceptual design from five designers. Their goal was to produce alternative solutions to successfully complete a design. They found that designers' design ideas were constrained by external requirements. Sketching was an important aspect of the design process to facilitate the thinking through of the design idea and for communication purposes. The number of design ideas generated varied with some just focusing on one idea whilst others reported that they considered several at the start. All participants in the study stated that design details came after the initial rough sketching and often after narrowing down the alternatives. What was interesting about this study was that not all the designers were engineers and yet their approach to the conceptual design activity was fundamentally the same.

Smith and Browne (1993) propose a conceptual framework whereby design thinking and practice can be understood in terms of five major concepts. The first, they argue, is that the designer begins with a set of goals when addressing the initial design problem. To solve the problem they will need to find solutions which will probably be realised by going through a number of alternatives. Constraints define the feasibility of the alternatives considered and finally representations in terms of various artefacts assist the designer in the problem solving process. Thus these five elements form the basis of an individual's approach to design.

At the Delft Workshops (Cross, Christiaans & Dorst, 1996), protocol analysis was used to elicit verbal accounts of participant's cognitive abilities as they solved a given design problem. Several teams undertook the same task and conclusions were drawn regarding the use of this particular technique. Generally it was decided that protocol analysis was acceptable for studying short-term processes such as solving a design problem, but other techniques were necessary for analysing more complex and realistic design tasks.

An experimental study by Reid and Reed (2000) found that cycles of speaking and turn taking occurred within engineering design teams who were observed whilst working on a design problem. The participants in the study were 3rd year engineering students. The discussions observed alternated between those of conceptual arguments and those based on figural arguments which involved the use of sketches. Whilst it is argued that the participants were given a realistic design problem to solve and were assigned company roles, they did have the luxury of fully concentrating on the design specification which may not be achievable in a real-world situation. However, it would appear that communication is an important aspect of the design process. Evidence to support this aspect of design is found in chapter 8, section 8.3.9.1 and discussed in chapter 6, section 6.4.2 and chapter 9, section 9.3.2.

There is a fundamental problem with some of these studies which promise to elicit the design processes that individuals go through in that they have taken place within a controlled setting. Real design takes place not in isolation, but within a social environment. Many additional factors therefore need to be taken into account if we are to fully articulate the individual's design processes.

Although a brief outline of the basic elements in a generic design process has been described, differences in the way that individual designers approach a design problem also need to be considered.

References to two different types of designer appear in the literature. For example, Roy (1993) compares the work of two inventors. Dyson, inventor of the "Cyclone" vacuum cleaner, used transfer of knowledge of one application to another. He preferred to be relatively uninformed in the early conceptual stage so as not to be constrained by previous solutions which led onto becoming an expert in a particular area of invention. This then led to physical models of his ideas being made.

Sanders, who invented a portable bike, however, immersed himself in the problem and existing solutions from the start and then began sketching profusely. He also sought to find analogies between the problem he was trying to solve and a product/component with similar functions.

According to Perez, Johnson and Emery (1995), the design process is approached differently by experts and novices due to the divergent design models they employ. They suggest that experts draw upon their knowledge of the domain and perform a "front-end-analysis" on the problem by attempting to understand it fully to begin with. This represents a breadth first approach to the problem which then continues in an iterative, reiterative and cyclical manner. Novices, however, begin with a depth first approach by looking in detail at the various design strategies. Evidence from this research of the different approaches to design regarding experts and novices is discussed in chapter 6, section 6.4.4.

Ramirez (1994) believes that the cognitive processes employed during creative design engineering are comparable to learning. The end product has materialised through a process of disassembling and reassembling of knowledge within the domain and this interaction and exploration is a critical stage in constructivist learning. Ramirez argues that a designer requires a basic ability of "semantic adaptivity" for creative design. "Semantic adaptivity" is an ability that enables them to perceive the important features and then build relevant meanings which fit the appropriate context.

Dreyfus (1997) proposes a five stage model of skill acquisition. Stage one starts with the "novice" who learns from instruction in non-situational contexts. In stage two the novice then progresses to the "advanced beginner" who can begin to use situational aspects and integrate this with the non-situational features learnt previously. In order to gain "competence" of a skill, the next stage, stage three, requires the learner to adopt a "hierarchical perspective" by seeking rules and reasoning procedures. Competency ultimately comes with experience and trial and error. The fourth stage is that of "proficiency" where intuitive behaviour replaces reasoned response developed gradually through the replacement of theory by "situational discriminations accompanied by associated responses". The fifth and final stage is that of "expertise" where the expert not only knows what needs to be achieved in a situation, but also knows how to achieve that goal.

Hubka (1995) states that experienced designers have a "feel for design" based on intuition. He argues that they instinctively know the appropriate characteristics and features, such as wall thickness, screw size, to solve a design problem without doing the necessary calculations. This "feel" is based on experience and conceptual knowledge and understanding. This was certainly found to be the case when observing experienced designers during the Shadowing Study (see chapter 8, section 8.3.9.1).

Two different cognitive styles in design are proposed by Oxman and Oxman (1992) namely "refinement" and "adaptation". They describe the former as being "associated with model-based generic design" and the latter with "case-based adaptive design".

In this section a number of different design models from several disciplines which aim to describe the main activities in the design process have been presented. Literature relating to the various types of design activities and individual designer's models has been discussed. The next section highlights the importance and relevance of social aspects of design that in the main are omitted from the traditional models of design.

3.3 Social aspects of design

Bucciarelli (1988) argues that design involves more than just the application of cognitive processes. From his ethnographic study of engineering design, he presents a description of design that encompasses a whole range of individual and collaborative tasks. The people involved will each have a different interpretation of design as a concept and process and he suggests, that in this sense, design is a "social construction". The problem with this approach is how to represent the range of individual models of design into a common/representative model which they can identify with. He argues that models of engineering design indicate a sequential flow of activities, but fail to address and capture all that is happening during the process of design. Bucciarelli (1988) also says that design involves many social processes and therefore models of design should accommodate group as well as individual perspectives. Pugh (1996) also acknowledges the social and organisational context as an essential part of his total design model. This view is clearly supported by the work of Baird et al (2000) in their paper on engineering design teams at Rolls-Royce Aerospace, Derby.

Research conducted by Baird et al (2000) focused on engineer design teams working through the team lifecycle from beginning to the attainment of their goals. One of the key findings was the importance of the social networks within the company. Baird et al refers to "social permissions" which are developed through close working relationships and 'permit' communication at various times with certain people.

Another important aspect found in Baird et al's research was the strong information networks between selected individuals. Wegner (1987) has described such mechanisms as transactive memory systems which are constructed when individuals acquire knowledge about other individuals' domain expertise. As a transactive memory system develops, it becomes more complex "involving the operation of the memory systems of the individuals and the processes of communication that occur within the group" (Wegner, 1987, p.191). A transactive memory system cannot be located within any individual nor elsewhere, as it becomes an inherent part of the group. Evidence of such systems were frequently recorded in this research (see chapter 7, section 7.4.12.1 & chapter 8, sections 8.3.8.2 & 8.3.11.1) and are discussed in chapter 6, section 6.4.1 & 6.4.4 and chapter 9, section 9.3.1 & 9.3.2.

As with Rolls-Royce Aerospace many companies now have to work collaboratively in teams which may be locally located and/or co-located. Working as a team presents many issues. Cross and Cross (1996) suggest they include communication with other members of the team, roles and relationships, planning and acting, information gathering and sharing, problem analysing and understanding, concept generating and adopting and conflict avoiding and resolving.

Many issues, for example communication, cultural, social and political issues which relate to the social aspects of design, do not appear to be adequately described in the mainstream literature of engineering design. These issues also include the socio-technical problems that exist within the organisation which it and an individual may face. Discussion of similar problems have been debated in detail in other areas of literature for example, computer-supported collaborative work (CSCW) and computer-mediated communication (CMC) and are not included in this thesis.

An example of the interplay between the technology and social aspects of design can be found in the construction and presentation of effective visual displays for providing information. This involves the consideration of many factors including cognitive and perceptual processing, ergonomic factors and cultural influences (Gribbons, 1991). Gribbons presents a communication model where the "sender" approaches the task with the desired intent, such as to inform, educate, train, etc. The appropriate "medium" has to be chosen to communicate the intent in an effective and efficient way. The "reader" then approaches the medium with certain preconceived needs, knowledge, skills, expectations and limitations. All three components have to agree in order for communication to take place. If it does not then a message may be ignored, lost or misinterpreted.

As described in section 3.2.4, the study by Reid and Reed (2000) found that communication is an important aspect of the design process. This was confirmed in this research by the designers at Rolls-Royce Aerospace (Bristol) who said that communication underpinned the whole design process and was seen as vital if projects and goals were to be achieved (see chapter 5, section 5.4.2.2).

Economic, technological and business factors are creating a need for new ways of allowing collaborative work to take place. As new technologies are developed, they must take into consideration the various psychological and social issues that are involved when designing in a shared workspace.

Research has been undertaken over the years to investigate and establish the issues which are involved and which need to be addressed if people are to work in groups. For example

Tang and Leifer (1988), studied small groups design sessions to find out what types of activities occur in the shared workspace. They found that gestures were used more actively to focus attention and communicate actions, interactive communication was very important and the opportunity to develop ideas with the group. They go onto suggest that if collaboration and working in groups is to be supported using different tools and technology, then facilities which allow these actions to be viewed need to be incorporated.

Ishii and Kobayashi (1992) have developed a "ClearBoard" which aims to provide a "seamless workspace" where "gaze awareness" and gestures can be integrated into the shared workspace in supporting real-time and remote collaboration.

Further research in the area of small engineering design groups has been conducted by Reid, Reed and Edworthy (1999). They video recorded the design process of small teams of final-year engineering design students in which three co-located teams were allocated a realistic design brief to solve. This observational study looked at how the teams used speech, freehand sketching and gestures whilst undertaking the design brief and seeking a solution to the problem. Analysis of the recordings indicated that the length of time spent in an event sequence depended upon what type of design reasoning the engineers were involved in (either visual or non-visual). That is, time spent in the visual sequence (defined by the authors as "one for which a visual action (sketching, pointing to a sketch, or figural gesturing) has a direct relationship to the design idea, and is necessary, or at least facilitatory, to the communication of this idea to other people". This was longer than time spent in non-visual sequences[1]. Also conversational grounding was initiated by different people: the speaker in the visual sequence and the listener in the non-visual sequences. Their findings of different interactional patterns of visual and non-visual sequences have implications for the development and design of "seamless" groupware media. Such findings need to be considered when designing new technology for collaborative workspaces.

In the past, early designs of groupware failed to take social factors in to account adequately (e.g. Grudin, 1994). Subsequently research into computer-supported co-operative work

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1 Non-visual sequences are defined by the authors as "utterance or action units directly related to the design brief that can be understood without recourse to a visual action".

(CSCW) has sought to include elements from the social sciences which investigate the factors involved in working as teams. Cockburn and Jones (1995) propose four principles of groupware design namely:

1. *Maximising personal acceptance* by actively encouraging and demonstrating the benefits to users.
2. *Minimising requirements* in order to reduce the disparity between the groupware's cost and benefits to the user to acceptable levels.
3. *Minimising constraints* regarding the use of groupware technology.
4. *External integration* ensures that the groupware is properly integrated with the whole working environment.

According to Fussell and Benimoff (1995) advances in interactive multimedia conferencing systems have been driven by what is currently technically feasible. In their paper they discuss and evaluate studies which have looked at interpersonal communication to provide a framework for the design and evaluation of features for advanced telecommunications technologies. They conclude that careful consideration of the end user needs to be taken into account and experiments involving end-users in real-life settings should be conducted in order to fully understand and support the dynamics of interpersonal communications whilst using such technologies. Easterbrook (1995) argues that interactive software is generally not designed to suit the user and by introducing it into a company it will change the user's requirements anyway. In his paper he describes how and why "co-ordination breakdowns" occur between collaborators and how these can be averted.

As discussed earlier in this chapter, sketching is an important activity which designers engage in. Sketching supports the designer in their visual imagination by creating an external artefact which can then be shared and communicated to others. Tools have been developed which have aimed to support designers who are geographically separated such as the ROCOCO (RemOte CO-operation and COmmunication) project which allows designers in different locations to share a computer-based "Distributed Share Drawing Surface" (Scrivener & Clark, 1994). In their study a number of different configurations involving the use of the sketchpad, a video tunnel and audio link, appeared to indicate that design could be supported at a distance in a natural and acceptable manner.

Conceptual design does not occur in a vacuum and therefore all aspects of the environment in which it takes place needs to be considered. It is necessary for models of design and creativity to incorporate these elements adequately if the design process is to be fully understood and explained especially at the conceptual stage. Cross and Cross (1996) acknowledge that for too long studies looking at the design process have focused on it from the technical perspective, where it has been described as a "sequence of activities based on a rationalised approach to a purely technical problem" or as a cognitive process. They suggest that "design methodology now has to address the design process as an integration of three elements: as a technical process, as a cognitive process and as a social process" (p.317). It is very much within that spirit that this research project was conducted.

3.4 Cognitive artefacts: tools and technology

In this section the various artefacts, tools and technology which support and facilitate designers' design activities are discussed.

3.4.1 External representations

External representations (ERs) and cognitive artefacts (CAs) are used to facilitate cognition and have been found to be both beneficial and necessary when trying to comprehend a variety of problems (e.g. fractural analysis, Fermats last theorem etc. (Norman, 1998)). There are numerous examples of where ERs have shown the advantages of externalising one's thoughts (Reisberg, 1987; Larkin & Simon, 1987; Mayer & Gallini, 1990). With respect to CAs certain design principles such as providing adequate feedback are recommended with regard to their use to ensure that they do in fact aid cognition and not hinder it (Norman, 1992).

CAs are found in many different media such as drawings, sketches, maps, etc. Pugh (1993) recommends a number of media should be employed by the designer to express his/her ideas for example, in a graphic, diagrammatic and/or model form. Sketching and drawing are exercises which play a critical role in design and serve several purposes. These include providing an external representation of what the designer has in his/her head thus allowing the communication of concepts to fellow designers and providing a visual stimulation of ideas (Ullman, Stauffer & Dietterich, 1987).

Schenk (1991) has investigated drawing and sketching as an aid to communication between graphic designers. Her study revealed that drawing was an integral part of the whole design process they were involved in, that is from the initial stages of the design to the communicating of their ideas to other designers.

A study by Ullman, Wood and Craig (1990) involving protocol analysis of five mechanical engineers engaged in a design problem concluded that drawing was the preferred method of external data representation and well exceeded that of text and calculations. They also found that sketching was an important form of graphical representation and a necessary extension of visual imagery. It also served as an extension of the designer's cognitive capability in enhancing mental stimulation. Evidence of this activity was observed at Rolls-Royce, NPE and is discussed in terms of the findings in chapter 6, section 6.4.4 and chapter 9, section 9.3.4.

Sketches tend to be unconstrained and ambiguous and may therefore allow for new ways of interpreting the sketch of an image to emerge (Purcell & Gero, 1998). This is supported by Schön and Wiggins (1992) who suggest that a visual display such as sketching can be perceived in different ways and reinterpreted. In their framework which they term the "moving and seeing paradigm", perceptual reinterpretations are referred to as "moves" while the outcomes and implications of those "moves" are referred to as the "seeing". Thus, they argue, it allows the designer to access other knowledge domains which are still relevant to the design, but were not accessed to begin with. This alternating between "moving and seeing" allows more and more knowledge domains to be drawn upon which facilitate the designer in handling complex and ill-defined design problems. Schön and Wiggins also suggest that the interconnections of the various facets of knowledge brought to the consciousness through this process of "moving and seeing" differentiates the experts from the novices. This explanation fits well with the connectionist processing model as discussed by Coyne (1990) in section 3.2.4.

As designers refine their sketches, more detail is added and unstructured sketches become more precise and explicit drawn representations (Goel, 1995). Goel suggests that lateral transformations tend to happen more in the conceptual design phase and are usually associated with the unstructured sketch. Vertical transformations, a possible solution transformed into more detail, generally occur later in the design process and are associated with more precise drawings.

Pugh (1993) suggests that sketches should also be enhanced with word descriptions so that others can understand them. This practice was observed in this research project (see chapter 8, section 8.3.9.1) and discussed in chapter 6, section 6.4.4 and chapter 9, section 9.3.4.

According to Ferguson (1993) three types of engineering drawings can be identified.

1. The "thinking" sketch which is used to guide non-verbal thinking.

2. The "prescriptive" sketch which is sometimes scaled and which is made by an engineer to direct a drafter in making a finished drawing.

3. The "talking" sketch where instead of just sitting down and talking, everybody draws and sketches to each other perhaps even taking the pencil away from the other designer in order to add some detail or clarify something.

These visual media are what Ferguson (1993) describes as the *lingua franca* of engineers in design and is of vital importance together with the hands-on-experience for feedback and continued reflection.

Fish and Scrivener (1990) argue that sketching using pencil and paper facilitates creativity by assisting the internal cognitive processes involved in design to be represented in a depictive form. Current technological advances in computer systems have enabled the recording and manipulation of visual images, but, according to Fish and Scrivener have so far failed to support the early stages of design where unconstrained sketching is so important. They argue creativity is constrained by using a computer at this point because the designer is compelled to provide information which is inappropriately precise and too early. They propose that both the internal and external processes involved in the creative design process need to be thoroughly investigated and understood. This then needs to be applied to the design of computer software to enable better support for designers and their visual cognition.

Computer tools to aid the sketching activity which takes place in the early stages of design require certain attributes according to Verstijnen and Hennessey (1998). From their studies which investigated sketching behaviours they found that two mental processes were essential in the creative process. These were "restructuring" and "combining" which in turn were influenced by the expertise in the sketching and the individual's creativity. They found that paper and pencil are used spontaneously by both experts and novices. They recommend that computer tools must be intuitive as working with pencil and paper and should be easily accessible and not require specialist knowledge. From their studies they found that combining elements using certain tasks could be easily performed using mental imagery whereas when a design task involved restructuring, they were more successful if they were allowed to sketch. One of the reasons for this is the sketch can then be scrutinised for emergent structures. Therefore a computer tool would have to be able to support unspecified forms as input and possibly switch between various structural descriptions of the input after it had been generated. However according to the authors neither component of the creative process, combining and restructuring can be adequately supported as yet in the conceptual phase of design.

Pugh (1993, 1996) argues the design activity requires communication between a variety of people both internal and external to the company and recommends, in addition to these communications, a number of information sources and databases (both internal & external) will need to be accessed.

Communication can be achieved by a number of different media as suggested by Pugh (1993) and presented in table 3.2.

Mode	Media
Oral/verbal	face to face telephone
Written	pencil/pen/ink and paper
Written	fax
Graphically	by both forms of written media
Electronic mail	alpha/numeric - local/remote
Computer networking CAD	local/remote
Graphically/written	blackboards; electronic white boards; alpha/numeric - local/remote

Table 3.2: The comparison of communication modes and media used.

Added to this list could be other forms of communication such as normal mail and video conferencing. However the latter form has been shown to be more effective if preceded by face-to-face contact or by personal recommendation (Baird et al, 2000). Some may be favoured rather than others for their formal or informal approach when communicating with someone.

Electronic white boards have been found to be very useful at all stages of the design process (Pugh, 1993). They are useful to record data manipulation and for surveillance by design teams. The main attributes are:

- some have very large screens allowing for viewing by the whole team
- images can be erased and changed at will
- provide copies which can be given/circulated to other team members
- placed side by side they can provide a large display

Having such a single system allows for collective concentration rather than several individuals looking at several different screens and facilitates ideas for good design argues Pugh (1993). It can be very useful in the various stages of conceptual design especially.

Pugh (1993) also suggests that the ideal set-up for total design is to have a combination of electronic aids. The suggested system is as follows:

- "VDUs with access to internal and external data bases, software packages and helpful knowledge-based systems that have been well designed with the user in mind
- a projection screen to provide a unitary view from any one terminal
- an array of five electronic white boards
- a FAX machine
- a telephone etc."

Advancements in technology offers new possibilities for the way design activities are undertaken. A brief overview of how computers may be able to support design is presented in the following section.

3.4.2 Design and computers

3.4.2.1 Conventional CADs

According to Ertas and Jones (1996), the term engineering design has changed in concept significantly over the last three to four decades. They state that in the 1960's engineers viewed design as an exercise which meant spending many hours at a drawing board utilising many drafting tools in order to produce drawings. Technically, things have advanced from this time with the employment of Computer-Aided-Design systems (CADs). Wireframe CADs were introduced during the 1980s to offer a semi-automatic drafting-based design environment. Computers can be used to complete the more tedious and repetitious tasks at the detailing stage more efficiently and flexibly. They have advanced enough now to assist in the preparation of manufacturing instructions for the making of certain components. However, the advent of CADs has also tended to isolate designers because work is less visible to others (Baird et al, 2000). This was evident in the research undertaken and discussed in chapter 6, section 6.4.5 and chapter 9, section 9.3.5.

Several changes have been required by market pressures including a shorter development time and improved communications and co-ordination between design engineering and manufacture. This has resulted in a process called concurrent engineering where departments which were once operationally segregated have now become, for many firms, much more integrated in their activities and aims. The introduction of systems like CAD and Computer-Aided-Manufacture (CAM) into the early phases of design has also meant that processes formally conducted in a sequential way, such as design and production, are now done simultaneously.

Goumain and Sharit (1988) suggest that the design process should be seen as two separate stages which reflect the different tools employed. In the early stages, the designer uses drawings which are personal and need verbal additions to enable others to understand them. However, in the later stages, aspects of the design need to be made explicit and therefore a greater degree of precision is required. This idea is supported by evidence from a case study of creativity in innovative product development presented by Roy (1993). The study compares and contrasts the different approaches undertaken by two inventors. One of these inventors was Sanders, who invented a folding bike. He immersed himself in the problem by sketching extensively to clarify what was going on in his head and how that might fit in with the design. He argued that CADs is a useful tool which helped him rapidly explore, refine and present design ideas. However, it is most useful after the conceptual stage of design.

According to Ertas and Jones (1996) there are a number of advantages for using CADs/CAMs including the reduction in engineering costs. For example, they argue that the length of the design cycle is reduced and a substantial added advantage is the analytical capability it has to offer, that is, Finite Element Analysis (FEA). This is an important tool used to evaluate the structural dynamics and stress analysis of a design. Further advances in the technology have introduced the technique of solid three-dimensional modelling using a number of geometric shapes to generate designs. Therefore not only is it possible to view designs in 2D, 2½ D or wireframe models, but also as full 3D representations. This added facility simplifies the numerically controlled programming task and therefore enhances the integration of design and manufacture.

According to Pugh (1993, 1996), many companies have invested a lot of funds by purchasing CADs. CADs are best used where an existing concept needs to be re-engineered to meet a new specification (i.e. where designers are working at boundary B see section 3.2.3). Here a minimum of synthesis in terms of design procedures etc. would be required. As CADs presupposes an existing system, it is best utilised in this context where the designer can explore different options albeit within certain limitations.

However at boundary A (see section 3.2.3), the blank paper end where maximum synthesis is required, computer programs are of little help, according to Pugh (1993, 1996). The designer may have little idea as to the nature of the final design. Pugh presents a number of examples, which support the use of computer programs, but they are only beneficial after the initial creative thought.

Allwood and Kalen's (1994) review paper of the research conducted on design and CADs discusses various issues from a psychological perspective. They present a number of authors which highlight the difficulty of using complex CADs (e.g. Waern 1988; Luczak, Beitz, Springer & Langner, 1991; Robertson, Ulrich & Filerman, 1991) and some of the shortfalls of the systems program (Bill, 1995). Waern (1988) suggests that CADs can inhibit creativity because designers learn to use set strategies and methods which they then apply to other designs. Further evidence suggests that CADs fail to adequately support the conceptual design stage (e.g. Allwood & Kalen, 1994; van Dijk, 1995; Baird et al, 2000). The advantages and disadvantages of using technologies such as CADs as experienced by NPE design engineers are presented in chapter 6, section 6.4.5 and chapter 9, section 9.3.5.

The use of computers in the conceptual stage of design is still fairly limited although developments are under way (French, 1999). Programs have been developed which help designers with the calculations needed to assess stress levels in components. However, many groups are developing software packages which can aid the conceptual design process by enhancing creative design. Computer-Aided Conceptual Design (CACD) tools such as those discussed and explained in section 3.6.4 are intended to provide such support. According to French (1999), such tools will be commonly found in industry in the not too distant future.

3.4.2.2 Recent technologies

Further advances in technology have produced software such as Pro/ENGINEER™ (Pro/E), which have attempted to provide a more user friendly package for designers. Some companies use this tool to implement concurrent engineering into the mechanical design process (Bill, 1995). The system is based on a parametric-based solid modelling technique where the models are dimension driven, easy to change and have some intelligence. It would appear that this particular piece of software offers optimal features to enable integrated product development. These include a fully associative design/drawing database; a design database that is complete, unambiguous, and directly accessible for all engineering, analysis and manufacturing operations; a full range of engineering analysis capability, including geometric (weight, centre of gravity), finite element model and tolerance (Bill, 1995).

Another technological advancement is rapid prototyping. This is a technique which is used to produce a physical model of the designed part supplied by data from the CADs. Stereolithography is one such technique which enhances the visualisation of a newly designed product which may not be so easily understood from a drawing or computer image. There are however, a few limitations with this method such as the type of materials that can be used and hence the number and variety of test conditions that can be submitted to the prototype.

Virtual reality is another technology which, although not used extensively in design in industries at present, may have the potential to enhance the design process (Wilson, D'Cruz, Cobb & Eastgate, 1996). The simulations produced by this method could potentially reduce costs and provide more diverse and wide ranging tests than those conducted in a laboratory. Problems can be highlighted and design modifications made and evaluated relatively easily.

Hollan and Stornetta (1992) argue that what is required is the development of tools, which by their very merit are preferred over conventional methods of communication. In other words instead of providing the tools which try to emulate any communication as if "being there", they feel the focus of development should be from a different perspective which they have coined as "beyond being there". The authors suggest that by focusing on the affordances of the types of communication that are desired, and then ensuring that the particular medium conforms to those requirements, its use will subsequently be preferred. For example, email may be preferred to using the telephone because it is quick and asynchronous.

This present research attempts to identify what the obstacles and barriers to creativity are experienced by design engineers when using current technology. What is it current technology cannot do that they would like it to do? What features may enhance their creativity? Reference to the tools used in Rolls-Royce Aerospace (Bristol) and how they inhibit or enhance creativity are discussed in chapter 6, section 6.4.5 and chapter 9, section 9.3.5.

3.5 Psychological issues

A foundation of knowledge based on the fundamental areas of psychology thought to be involved in design and in identifying perceived barriers to creativity are outlined in this section.

3.5.1 Processes of learning

There are many conflicting and alternative theories regarding knowledge acquisition and learning. Curry (1983) has produced a framework, the Onion model, to view the main learning theories. The outer layer of this model relates to "instructional preference" which considers factors such as the learning environment, preferred choice of how to learn (e.g. in groups, lectures), teacher and learner expectations and other external features which can affect learning. The middle layer is about the information processing style of an individual and how they assimilate information. Theories such as Kolb (1984) and his focus on experiential learning and Honey and Mumford (1992) and their examination of preferred learning styles fall into this layer. Finally the inner layer considers theories relating to "cognitive personality style" and the approach individuals use to accommodate and absorb information.

Kolb's (1984) experiential learning cycle suggests that individuals build their knowledge by encountering "concrete experience" then conducting a "reflective observation" from which they make an "abstract conceptualisation" and then participate in "active experimentation". There is no starting point; it can be entered at any point. Similarities are found in the process described by Schön (1983) in his reflective "learning" paradigm. Schön argues that if the individual reflects on prior understandings and knowledge which were implicit in their recent behaviour it will enable a new understanding of the phenomena they have experienced. This will result in a change in the situation. For example, engineers can make judgements of quality without being able to state adequate criteria, rules or procedure. They may ask themselves what is it about this thing that they recognise, but be unable to articulate it (Polanyi, 1967). This implies "tacit knowing" or implicit knowledge (Berry & Dienes, 1993).

Apprenticeships in the traditional sense of the word allow for another learning process to take place by employing methods of observation, coaching and practice (Lave & Wenger, 1995). Lave and Wenger (1995) refer to this as "situated learning". These methods appear to suggest that tacit knowledge can be acquired by experience. In addition, it may not only be practical domain-specific knowledge, but issues relating to the social context and culture in which the learning takes place. Baird et al (2000) describe the elaborate social mechanisms which enable the exchange of design information by engineers. Cognitive apprenticeship focuses on the learning and understanding of conceptual and factual knowledge. By then applying the knowledge gained to a variety of different contexts a deeper understanding and problem-solving approach is facilitated (Collins, Brown & Newman, 1989). Learning issues relating to perceived barriers to creativity and the experience of designers are discussed in chapter 6, section 6.4.4 and chapter 9, section 9.3.4.

3.5.2 Visual perception

Marr's (1982) theory of visual perception is based on a computational approach to vision postulating that interpretation of what we see is conducted in the brain. Contrary to this theory is Gibson's (1950) which suggests that stimulation in the world is sufficiently rich in information due to ecological optics and affordances which allow for direct perception. Consequently, there is no need for extensive interpretation within the brain and central nervous system to make it meaningful as our sensory systems have been developed to pick up the information in the environment around us. Furthermore, the light which falls on the retina, Gibson (1950) argues, is highly organised by its reflections from the surface and objects in the environment therefore requiring little interpretation by the brain.

To explain further, according to Gibson the visual field changes in very predictable ways as we move through the world. Some features will remain unchanged (called invariant features) in the visual array whilst others will change at different points in time as we travel through space (referred to as optical flow patterns). For example, one aspect of the visual array which does not change is the "centre of expansion" or the point toward where you are heading. In the case of a pilot coming into land, as they approach the runway so objects in their visual field will rush past them with the runway stretching away before them towards the horizon. The closer the plane gets to the runway, the slower this rate of the runway stretching appears to be. Such emergent information should allow the pilot to gauge his/her speed and angle of descent when landing. Gibson refers to this as optical flow patterns. This particular theory of Gibson's fits with Norman's (1988) view that cognition not only occurs in the head, but in the world also. In addition, Norman's argument that objects should offer affordances is related to Gibson's (1979) theory of direct perception. People thus experience the world directly as meaningful and functional due to the affordances objects offer. Smets and Overbeeke (1994) suggest that Gibson's theory should be considered and applied when designing CADs for use by designers.

According to von der Marlsburg (1990) visual perception is dependent upon stimuli from the environment, which are used as signals to create an internal "representation" of the world we see. However an individual's memory, knowledge and experience mediate this view of the world.

3.5.3 Visualisation

Visualisation as a means of representation and communication has been prevalent for thousands of years if we are to include the earliest markings which cave dwellers made around 3000 BC (Lansdown, 1994). Olsen (1991) suggests that until the 17th century, visual expression was crucial in providing meaning to their world, for example, in the external form of intricate illustrations and other artefacts. This was disseminated to a wider audience with the introduction of new technology, that is the printing press.

However, this perspective changed with the advent of the scientific revolution. A number of 17th century philosophers believed, at that time, that in order to understand the world it was necessary to quantify it by number and mathematics arguing that visualisation was a lower order of cognition and of little use (Olsen, 1991).

Olsen (1991) and Carr and England (1995) postulate that science in the twentieth century would appear to be returning to an emphasis on visual representation once again across many disciplines. Evidence for the use of visualisation as a cognitive strategy for solving everyday problems is discussed by Rieber (1995). A variety of problems are presented which appear to be more easily solved when employing this strategy and constructing a visual representation of it instead of trying to solve it mentally. In addition to the more common place problems examined, Rieber, and indeed Olsen (1991) consider how important visualisation, together with imagination, have been seen as methods of facilitating scientific inspiration, illumination, creativity and discovery. For example, Einstein was known for conducting "thought experiments" which allowed him to 'see' or visualise what it might be like to ride a beam of light. Another famous chemist August Kekulé reported how he "saw atoms dance before his very eyes" when he gazed into a fire and went onto to discover the ring-like molecular structure of benzene.

A final example is Watson's (1968) conception of the double-helix shape of DNA where again visualisation played a crucial part in its discovery. However, in the latter example before the double-helix shape was fully understood, a number of simpler perspectives were required, for example, a section of DNA was analysed through x-ray diffraction studies.

Olsen (1991) also argues how, before the onset of the printed word, visual representation was an important method of communicating ideas and concepts and current technological developments are leading culture back to this. The utilisation of such methods allow designers to experience open communication of their ideas both for themselves and others (Ferguson, 1993) (see 3.4.1). Visualisation is particularly important in mechanical engineering design where form and function are inseparable.

Mental imagery and the role of visualisation is important in the early creative phases of design problem solving (Athavankar, 1997). Athavankar ran an experiment where an experienced designer was given a design brief and then blindfolded once he had familiarised himself with it. He was denied access to sketching and the feedback this provides, but was encouraged to verbalise and gesture as he went through the design activities. Thus he had to rely on his mental images to propose a solution to the design brief he had been given. These activities were video recorded. At the end of the experiment he was invited to sketch the design he had developed as a mental image. A few features were changed as he sketched compared to this mental image and some were omitted that he had referred to whilst undergoing the experiment. However, on the whole the image he had constructed in his mind had most of the details. It was reported that during the experiment he had appeared at ease and easily manipulated the image and evaluated alternative modifications and other features through a process of reflection. The author also reported that the mental image evolved as the thinking process progressed and suggested that this is a powerful activity which should be considered and researched in the future in light of the developments in using computers to aid design. The ability to visualise was also demonstrated and seen to be a vital part to the design process of the designers (see chapter 6, section 6.4.4 & chapter 9, section 9.3.5).

It would appear that throughout history there is a wealth of evidence to suggest the use of visualisation is a useful and sometimes necessary mechanism in order to enhance the generation and crystallisation of ideas and hypotheses.

3.6 Creativity

3.6.1 Models of creativity

As discussed in chapter 1, section 1.3.1 there are many interpretations and definitions of the concept of creativity. However, there is a general agreement that there are four key concepts of creativity (MacCrimmon & Wagner, 1994). The first relates to output and it is argued that for the product to be creative, it should be judged by others as being original and having appropriate value and use[2]. The second relates to the process to generate creative thought and action which comprises a number of phases and techniques. The third concept is that of the individual and here their characteristics come into play including demographics, knowledge and personality traits that underlie their creative ideas. The final concept is that of environment which includes both social and physical factors. Thus MacCrimmon and Wagner suggest an imaginative individual engaged in a process

2 It is not the intent of this thesis to discuss and evaluate whether the product of the design by engineers at Rolls-Royce Aerospace is creative or not.

conducive to creativity, working in a supportive environment can produce a creative output.

There have been several attempts at describing what the creative process involves. Poincaré (1952) and Wallas (1970) suggest and discuss the four stages of creativity:

1. *Preparation*: Where conscious attempts are made to solve the problem by explicitly adapting familiar methods. During this stage the methods applied can often appear to be of little use, frustrating and unproductive.
2. *Incubation*: This may last a few minutes or a few months. It is when unconscious processes result in productive mental work.
3. *Illumination*: Often referred to a "flash of insight", it is the manifestation of long unconscious prior work into more apparent solutions.
4. *Verification*: The final stage involves the evaluation of the new conceptual insights which are itemised and tested.

Boden (1992) argues the above sequence is more suited to mathematical and scientific creativity where there is a goal in mind. Koestler (1964) also criticises Poincaré's view that incubation is automatic and rejects his explanation as being too mechanistic. However, Lawson (1997) proposes a similar model to the one described above that he argues designers use. He includes an initial step of identifying a problem and then determining how to tackle it. Lawson suggests though that whilst this linear model is useful in identifying under what circumstances creativity occurs, in reality it is more complicated than that. Other cognitive processes will be involved such as, searching, looking for new combinations, associations and synthesising ideas.

Koestler (1964) argues that the bisociation of two normally non-associated contexts or planes of thought can explain creativity. They might not even be thought to be compatible, but the combination of the two results in creativity.

Perkins (1981) agrees with Koestler in that creativity is grounded in everyone in shared psychological capacities. It is expertise and motivation which makes one person more creative than another. Polanyi (1967) who argues that all skills and intuitive insights are grounded in tacit knowledge also highlighted this.

Ebert (1995) presents a model which suggests that creative thinking comprises elements of cognitive processing and learning. Rather than a cyclical model, five components of "perceptual thought, creative thought, inventive thought, meta-cognitive thought, and performance thought" (p.285) form a spiral continuum. He argues that the spiral demonstrates how the processing of information has an effect on the knowledge base of the individual. These concepts support more recent theories as described below.

De Bono (1994) prefers to refer to creativity as "lateral thinking" and has identified four factors associated with this activity. These are: (1) "recognise dominant ideas that polarise perception of a problem, (2) searching for different ways of looking at things, (3) relaxation of ridged control thinking, and (4) use of chance to encourage other ideas". He has developed a number of tools and techniques based on these factors which if implemented can facilitate and enhance this skill he argues. De Bono also argues that intelligence is innate, but thinking is a skill which can be learnt and improved with practice just like any other skill.

Finke, Ward and Smith's (1992) investigations into creativity have employed formal experimental methods to identify the cognitive processes involved. In addition, they have sought to establish general cognitive principles which can be applied across domains thus enhancing people's ability to think creatively.

The Geneplore model is Finke et al's (1992) representation of creative cognition. Incorporated in this model are both the generative and exploratory cognitive processes which they describe in detail (see figure 3.3).

The model represents two distinct processing components beginning with the generative phase where preinventive structures are constructed. A number of processes are employed to generate these preinventive structures such as retrieval, association, analogical transfer etc. Therefore in the first phase a mental representation is constructed based on what is generated from initial interpretation of the design problem. This representation may include object forms, mental models, category exemplars, visual patterns etc. which may have a number of properties which "promote creative discovery". Such properties include divergence, incongruity, ambiguity and emergence which will contribute to exploration and creative discovery. So for example, a number of words or objects may be retrieved from memory and associated in new and different ways which then result in new preinventive structures.

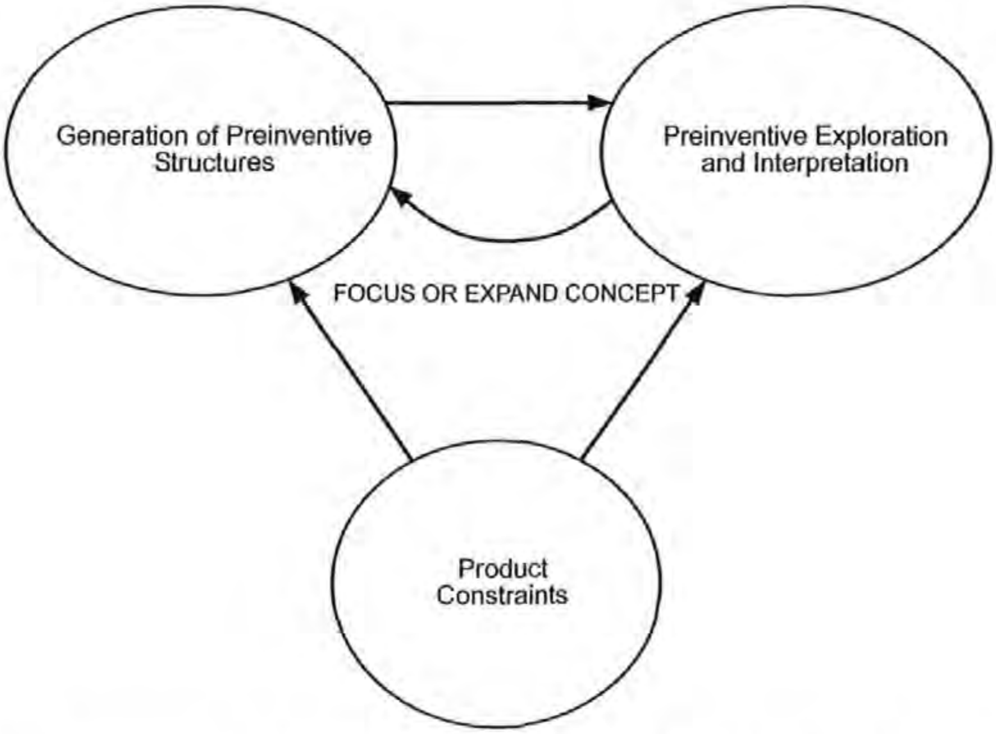

Figure 3.3: Basic structure of the Geneplore model (taken from Finke, Ward & Smith, 1992, p.18).

During the following phase of exploration, the preinventive structures are regenerated and modified by incorporating a number of processes such as attribute finding, functional inference, hypothesis testing and searching for limitations. This procedure may result in a creative product quite quickly or much iteration between the two phases may be required before a satisfactory conclusion is reached. At either phase, a number of product constraints can be imposed such as specific functions and features or performance criteria.

Finke et al argue that people may be creative in different ways. For example some people may be more skilled at generating the preinventive structures whereas others are better at interpreting them. They suggest that this may help explain the individual creative style observed within creative terms. In addition, they postulate that creativity may lie along a continuum. Creative geniuses, at one end of the continuum, may exist as they have the ability to employ these creative cognitive processes more efficiently and effectively than others do further along the continuum.

Evidence of creativity from a number of participants recruited for a series of experiments is presented by Finke et al (1992). These experiments incorporated a variety of procedures and controls which were imposed upon the participants as a way of enhancing the creative cognitive processes. For example, to avoid the problem of conventional mental sets, the suspension or delay in the application of expert knowledge is enforced. Another technique deemed to enhance creative thinking is "combinational play" which Einstein saw to be important in his creativeness (Finke, 1990). This technique involves thinking about different combinations of features and parts in different interesting ways and seeing (mentally) if anything meaningful emerges. This idea supports Ferguson's (1993) who states that design comes from past experiences which the mind draws upon and can manipulate to form a variety of devices that do not exist. Evidence of "combinational play" was observed in the studies at NPE, Rolls-Royce and discussed in chapter 6, section 6.4.4 and chapter 9, section 9.3.4.

Another important strategy for facilitating creativity Finke et al (1992) suggest is an approach which involves function-follows-form instead of the normal form-follows-function. In the latter approach certain constraints and design parameters may be imposed at the outset, which then determine what form the design will eventually take. In terms of the Geneplore model, if such constraints are imposed early in the creative process then it would restrict the types of preinventive structures that could be generated. However, Finke et al and others (Perkins, 1981; Bransford & Stein, 1984) propose that by allowing non-specific forms and structures to be generated first and then seeking to explore what they could be used for, can enhance creative discovery. They argue this approach can reveal new inventions and concepts that may otherwise have not been discovered. The Geneplore model can accommodate both approaches and Finke et al maintain that used together, they can complement each other.

3.6.2 Creativity in individuals

Kirton (1987a) using the Kirton Adaption Innovation Inventory (KAI) has endeavoured to identify the different cognitive approaches individuals use when attempting problems and the way they approach solving these problems. In table 3.3, the characteristics of both types of individual are listed as described in the paper by Isaksen and Kaufmann (1990).

Adaptors: tend to work "within the confines of the consensually-accepted paradigm". That is using tried and tested ways to find the answers	**Innovators: "treat the enveloping paradigm as part of the problem". That is find different avenues for their solutions**
resourceful	ingenious
efficient	original
thorough	energetic
methodical	independent
organised	unconventional
precise	insightful
reliable	unique

Table 3.3. Comparison of characteristics between "adaptors" and "innovators".

Both types have disapproving views of each other. Both have strengths and weaknesses. Referring back to section 3.2.4, it could be suggested that Dyson could be described as an *innovator* whereas Sanders is perhaps better described as an *adaptor*. Both designers were eminently successful in their development of innovative products.

Others have identified and described the characteristics of very creative people. For example, someone who exhibits certain patterns of behaviour such as inventing, composing, designing and planning could be described as having a creative personality (Guilford, 1950).

Sternberg (1988) also lists a number of personality attributes such as, tolerance for ambiguity, determination to get over problems and obstacles, willingness to develop, intrinsic motivation, element of risk taking and desire for recognition. De Bono (1994) suggests that characteristics such as having a vivid imagination, challenging authority and procedures and being curious correlate high with creativity.

MacKinnon, (1970) describes people with creative abilities as having independence, non-conformity and willingness to take risks. Similarly, West (1997) identifies an attraction to complexity, a concern with work and achievement, perseverance, independence of judgement, tolerance of ambiguity, need for autonomy, self confidence and an orientation towards risk-taking as characteristics of creative people. However, others suggest that in creative groups elements of dependent, conforming and careful behaviour can also be creatively productive (Kirton, 1987b as cited in Isaksen & Kaufmann, 1990).

There appears to be many similarities by the different authors as to the salient characteristics of creative people namely openness, challenging, flexibility, visualisation, imagination and expressiveness.

3.6.3 Creativity and design

Hori (1997) suggests that human activity involved in design is always in some sense creative. For example even in routine design, the designer will be creative as they create novel and new combinations of features and performance characteristics to meet design goals. It is within this interpretation of creativity that the research was conducted when looking at the creative aspects of design in NPE, Rolls-Royce Aerospace (Bristol).

Eder (1995) presents a model which includes all the factors he believes influences creativity mainly from an individual's perspective. However he acknowledges that aside from the human engineer who obviously plays an important part in the design process, that teams, groups and the social conditions affect the designer as well. For example, the procedures, attitudes and the cultural/creative climate developed by the organisation and management teams are also important factors to add to the design process.

Engineering design is not carried out by an individual, but by teams. Therefore a number of factors need to be considered. For example, team building and the development of inter-personal skills, the management of the design process, documentation and the acquisition of information. Management will set the goals and will determine what resources are necessary in achieving those goals. Eder's model of the design process has similarities to the models which are described in section 3.2.2.

Jarvis (1997) has proposed an application of the Geneplore model to represent creativity in the design domain. He argues in order to make it more meaningful, Finke's terms of "preinventive structures", "preinventive exploration and interpretation" and "product constraints" should be replaced with, "starting points", "explore starting points to produce concepts" and "apply constraints". Referring to the Schumacher (1987) model of creative activity which consists of three elements of plan, do and evaluate, Jarvis proposes there are similarities between the models and refers to his as the "Trinity model". Evidence of this model of creativity was found in the studies within the conceptual design phase at NPE (see chapter 6, section 6.4.4 & chapter 9, section 9.3.4).

Fischer (1993) proposes the following requirements and techniques to increase the creative potential of an individual:

- "developing a knowledge base
- creating the right environment for creativity
- look for analogies and the impact of representation on problem difficulty
- supporting the incremental unfolding of design spaces
- reuse and design
- exploiting what people already know
- explanation and argumentation
- taking care of low-level clerical details
- affection and appropriation"

(Some of these requirements and techniques are considered in the following sections.)

3.6.3.1 Enhancing creativity in design

Cross (1989), discussing the various design methods to stimulate creativity suggests that there are two basic groups of "creative methods" and "rational methods". Creative methods include brainstorming, synectics, which involves the use of many forms of analogical thinking, and enlarging the search space by employing such techniques as transformation, random input and counter-planning.

Rational methods, on the other hand, encourage a systematic approach to design whilst still trying to widen the search space for potential solutions (Cross, 1989). This includes making a list of what it is you want to do and then externalising it. This also formalises the process as you can then check what you have achieved. Others can be encouraged to add to the list and/or deal with certain aspects of the list.

Pugh (1993) puts forward a number of requirements that maximise the level of quality in the conceptual phase of design. One such requirement is that there should be "a complete and absolute embargo on 'gut feeling' decision making as past experience is just as likely to prove wrong as right in today's competitive world". What Pugh suggests should be conducted is the "method of controlled convergence" which he deems is an efficient way of selecting the final concept from several put forward. This method, he proposes, is both a generative and selective process whereby alternate convergent and divergent thinking is accommodated. Gradually through the iterative process, the best concept is arrived at. Due to the nature of the whole process, Pugh asserts, a far greater understanding of all aspects of the design will be known to all members of the team.

Although, by employing this method, designers work towards convergence in a controlled way, Pugh (1993) argues that this method does not inhibit creativity because they are still able to think about the problem in a divergent way. In fact, he continues, it stimulates creativity due to the lack of a rigorous structure and gives rise to new concepts which can be thoroughly explored and evaluated. This would appear to reflect the basis of the Geneplore model (Finke et al, 1992) where preinventive structures are explored, evaluated and re-visited until a final version is accepted. However, there has been a reluctance to accept the efficiency of this procedure from experienced people in industry.

According to Pugh, there are a number of common techniques which facilitate the generation of ideas in the context of controlled convergence. These are as follows:

- **Analogy**
  Where suggested solutions to problems arise from similar situations not necessarily from within the same discipline. Direct transference may not always be possible, but the basic idea can be modified and adapted to fit the particular situation/problem in order to resolve it. Analogy is a strong stimulant which can facilitate the design process and reduce timescales accordingly.

- **Brainstorming**
  Another technique for stimulating the generation of ideas is brainstorming. This is conducted by every group member generating as many ideas as they can in response to the problem without any constraints regarding the applicability, feasibility or

practicality of their solutions. At a later stage judgement is made on the ideas contained in the exhaustive list. Depending on the particular stage of the process, brainstorming can be beneficial. For example at the beginning of the design process it should be conducted with the specific product context in mind. At a later stage in the conceptual phase it can be implemented in the specific context of the Product Development Specification (PDS). Pugh suggests that in a slightly modified form it can be used in the controlled convergence method of concept generation and selection.

McGrath (1984) argues that concepts are often best generated in the beginning by individuals whereas concept selection and enhancement is often best performed in groups. However it is usual to find design teams within industry rather than individuals working on their own (Pugh, 1993) and it is possible that different creative environments afford different procedures.

- **Brainwriting**
  There are several different ways to carry this procedure out and it offers an alternative to the traditional form of brainstorming whereby individuals are invited to write down anything and everything for a given task for a set period of time.

- **Attribute listing**
  This is when characteristics and attributes of an artefact are listed and subsequently explored to see how each could be modified to improve the object/design.

- **Checklists**
  This method can aid stimulation of ideas generation by incorporating prompts in relation to key suggestions and questions to enable creative insights to occur which may have otherwise been missed.

- **Forced relationships**
  This is another fundamental procedure where you are forced to make a relationship between anything in one's awareness and attempt to relate it to the problem at hand.

- **Morphological approach**
  This procedure involves the application of the required attributes and forced relationship in a matrix approach.

- **Inversion**

  Where a solution already exists, by applying the inversion technique new ideas can be generated. This involves manipulating the solution by thinking about it in a number of different ways, for example, reverse, inside out etc.

- **Combination**

  Where solutions exist, 'combination' allows them to be combined and a new concept developed. Incongruity of combinations of solutions or features may encourage further exploration of ideas resulting in greater opportunities for innovation (Wisniewski, 1991 as cited in Finke et al, 1992). Koestler's (1964) theory of bisociation of matrices involves incongruity as a main feature for creativity whereby the sudden flash of insight or short-circuit reasoning comes from the juxtaposition of formally unrelated ideas. He argues this is an act of intuition.

Intuition is something a designer depends upon and is based on years of experience and a broad based-knowledge (Baird et al, 2000). Evidence of this phenomenon was found in this research project and is presented in chapter 9, section 9.3.4.

It would appear that employing different techniques and methods could enhance creativity. Computer programs are also being developed to enhance creativity and stimulate ideas in various ways. Some of these are described in the following section.

3.6.4 Supporting creativity

Candy and Edmonds (1994) describe the designer as a "knowledge worker involved in creative work that is not easily characterised by formal procedures". They argue that computer support for design therefore needs to be flexible and user friendly. It needs to complement and reflect the attributes and thinking processes that the designer is engaged in when designing. In a study where they looked at the design of the Olympic LotusSport Pursuit bicycle, they identified what the relevant characteristics were that needed to be considered in computer support for designers. If implemented within such a support system these characteristics would enable designers to:

- "Break with convention" where an ability to interact with a knowledge base system would be important.

- Allow immersion in the problem which is often recorded as being vital to the creative process. In terms of computer support this would suggest that a portable computer would be necessary.
- Support a holistic approach where the designer needs to be able to see overviews of the problem and solutions. Thus multiple views of the data would be useful.
- Consider parallel channels. This is important as many problems are solved by analogy where the user needs to be able to move between a number of different perspectives and information sources.
- Allow for sketching of ideas, solutions and alternative modes of visualisation. This has already been described as a vital aspect of design allowing for visual relationships to be explored and considered.
- Support of gestation of innovative ideas to come to fruition productively. This can take a long time and therefore the designer would need to be supported by databases which hold long-term personal knowledge.

MacCrimmon and Wagner (1994) have developed a software program to stimulate creative ideas. One aspect of the creative process they have focused on is that of new ideas being generated through the association of existing ideas and thus making connections. They present "internal connections" which may focus on the "form" and "purpose" of the creative idea and "external connections" which may be "local" or "distant". In generating ideas they then suggest that creative alternatives can arise from processes used in the different connection groups. These processes have been incorporated into the software program and specific procedures represent all four types of connection. These are as follows:

1. Relational Combinations for internal connections (form and function).
2. Ends-means Chains for internal connections (purpose).
3. Idea Transformations for external connections (local).
4. Metaphoric Connections for external connections (distant).

MacCrimmon and Wagner (1994) ran an experimental study to evaluate their software program GENI to establish whether individuals perform better in generating creative alternatives to a set number of management problems. The outputs were assessed in terms of their creativeness and results indicated that the participants who had used the software compared to the control situation did produce more creative ideas.

Other software specifically designed for assisting conceptual designers to build their design concepts in the automobile industry have been developed by Sugimoto, Hori and Ohsuga (1993). This particular technology utilises concept maps which are based on data analysis from databases of existing cars. The designers can interact with the concept map and reconfigure it thus effectively building and expressing new concepts. Whilst it was accepted that this technology was in its early stages, those who had evaluated the system found it invaluable in identifying concepts which would otherwise not have been found.

Hori (1997) has developed a software system to assist the designer to 'jump' from employing routine mental processes into other mental spaces in order to trigger a change in design strategy to facilitate creative design. The system uses the idea of concept space which can depict the designers own mental world. The example Hori uses is that of the concept space when involved in aeroplane design. Pieces of the design requirements and related parameters are configured by the system using multidimensional scaling techniques. The designer knows, intuitively or otherwise, which parameters and requirements are important, which less so and which correlate strongly with each other. The designers can then interact with the concept space and change it via the system. The system responds by automatically presenting a space resulting from the knowledge processing. This can then invoke a change in the design strategy used by the designer because what is presented on screen maybe different to the one held in their mind.

Hori invited a graduate in aeronautics to test the system and they began by placing nine requirements into the system. The system was able to add the relevant parameters and their corresponding values which related to those requirements drawn from the knowledge database. The user then added new design parameters and the relevant design knowledge and saw the concept space of the system change to accommodate them. Changes were also made to the stabilities giving them a high priority. The resulting design was shown to some experienced designers who immediately saw it was totally unacceptable and not feasible. However what it did achieve was to generate some new ideas and evoked some thought provoking discussions with the experienced designers. Hori suggests that the opportunities afforded by the system to present the concept space of a design and then subsequently to allow the designer to interact with it, has value. New and even off the wall ideas can be generated which may lead to the production of new and creative ideas. Therefore Hori argues that such a system can support creative design. This system would also appear to support creative models presented by Finke et al (1992) and Jarvis (1997).

Flint and Sparrow (1994) suggest that multimedia can have a catalytic effect on a designer's creativity. By introducing a number of types of media, what McKim (1980) describes as "visual brainstorming", other concepts may be stimulated that would not have been thought of previously. Interacting with the screen provides a spatial environment where new visual conceptual connections and the cross fertilisations of ideas can take place thus enhancing creativity (Flint & Sparrow, 1994). However they suggest that rather than a multimedia computer package 'giving' a designer ideas, it is a tool which provides a visual representation of a particular design's form and function.

According to McLaughlin (1993), creativity has been seen as a "black box" activity for many years and the development of computational models has allowed some of the assumptions about these processes to be tested. Some developments in this area are discussed in this section and are referred to later in the thesis in chapter 6, section 6.5 in view of the findings of this research.

In the literature there have been few references to the barriers to creativity in engineering design. However psychologists have found that when people are confronted with a problem solving task, which requires an innovative solution, using familiar objects they often fail to see how they can be used other than for the purposes for which they are usually used for (Luchins, 1942; Duncker, 1945). The explanation given is that they are blocked or fixated on the well learnt uses or properties of the object. They fail to recognise that any of the objects could be used differently to enable them to solve the problem. This phenomenon is referred to as "functional fixedness".

In a series of experiments, Purcell and Gero (1996) found that designers experience fixedness in design when they have to rely on everyday knowledge to solve a problem. In the comparison of industrial and mechanical design teams, there was little evidence of the former falling foul of the fixedness issue when asked to design a number of different items. However, the mechanical designers became fixated when they had to solve a problem which incorporated typical principles and characteristics of their domain knowledge base. The results also indicated that there may be different forms of fixedness which occur under different conditions for different disciplines and that these need be identified. The findings therefore suggest that careful consideration of the factors relating to fixedness need to be taken into account if a computational system to support creative design is to be developed.

French, Chaplin and Langdon (1995) argue that if computer aids are to facilitate creativity, then they need to be systematic. As French (1999) presents a linear and systematic model of the design process it is not surprising that he would argue a similar approach needs to be in place to aid this process. French et al (1995) also suggest that the use of analogies and systematic variation is valuable, but that brainstorming and synectics have been less productive. They argue that there are three routes to creativity through the development of insight, the abstract-concrete-abstract cycle and design principles. Of these three routes, support tools based on design principles such as "Schemebuilder©" currently being developed at Lancaster is best suited to the computer (Porter, Counsell & Shao, 1998). What they see as being of the most use to designers is an extensive design database which comprises solutions to a complete set of design problems that have been encountered in the past. Creativity, they argue is the adaptation of an old idea reused to meet a new purpose/criteria. This tool based on principles could present the designer with a relevant principle which may be worth considering and applying to the design. "Schemebuilder" is a package which can aid the designer to build a scheme of a functional model of the proposed design. This can be achieved quickly using block diagrams and other features of the package such as the comparison of alternative models designed this way.

Computers by their very nature process systematically. Therefore the question arises whether they can be effective aids for designers that enhance their creativity. Could it be that they constrain and inhibit creativity and lead to convergent rather than a divergent view of the problem. They may even restrict innovative thought. Symbiotic systems have been used to enhance the human capabilities of creativity and visualisation (Scriabin, Kotak & Whale, 1995). Such systems combine a domain expert with a computer which has the facility to support the process of visualisation an important attribute as discussed earlier in section 3.5.3. Scriabin et al (1995) report how symbiotic systems have provided alternatives for solving complex problems as they can be presented visually allowing the designer to interact and change the representation accordingly.

Kolodner and Wills (1996) argue that a designer needs to be perceptive when involved in creative design. They suggest there are a number of processes which underlie this perceptive trait. These processes include, "preparation, assimilation and strategic control". They conducted an experiment in which a team of mechanical designers had a particular problem to solve and reported their findings in terms of the stages described below.

a) *Preparation* was observed when the designers became immersed in the problem, reviewing it, re-describing it, and looking at it from multiple perspectives. During this stage the design specification evolves from an initially ambiguous, incomplete and unconstrained representation. Gradually by employing different cognitive processes such as visualisation, constraint relaxation and substitution, thought experimentation and other mechanisms, that interact and draw upon past experiences and problem solutions, a new more defined problem specification emerges.

b) *Assimilation* followed where the designers then considered each proposed solution and arranged them according to their different properties and how they might each address the sub-problems of the overall problem. Thus sense is made of proposed solutions, feedback from observations in the design environment and experiments from prototypes are considered.

c) The process of *control,* is exhibited throughout the design process when the designers make decisions about things such as which idea to expand upon and which constraint to relax. Kolodner et al suggest that a number of strategic control heuristics are employed which are based on reflection and assist them to decide what should happen next.

Based on these processes, an experimental system that computationally models them has been developed and implemented in a system called IMPROVISER (Invention Modelled by Problem Re-description, Observation and Evaluation, Interacting Serendipitously).

Knowledge-based systems are seen as a way of developing computer programs that can stimulate and support design processes. It has also provided a new insight and models of creative design (Gero & Maher, 1993).

Knowledge-based systems operate by providing the content and organisation of design knowledge that can then be used to generate a creative product. This role is akin to that of designers who can draw upon their experience and training. Some knowledge based systems can support human creativity whereas others seek to model that process. For example, Rosenman and Gero (1993) discuss how a design prototype schema has been developed to assist in solving routine designs, but that this could be extended to provide a model for creative design. Design prototypes could be drawn upon based on design from first principles and by the use of combination, mutation, analogy, a creative design could be generated. However there are limitations to the technology at the time the book was written relating to the configuration problem. In routine design the configuration will exist, but not so for non-routine design. Rosenman and Gero state this is a stumbling block to the development of such design systems.

According to Fischer (1993) domain specialists such as engineering designers do not want to have to learn the language of the computer to use it as a medium for design. The computer or system needs to be able to 'communicate' and use the language of the operator or designer. An example of such a design environment is "JANUS: a co-operative system for kitchen design" which has been developed. This knowledge-based system has a construction component whereby the kitchen designer can draw relevant design units from a palette. Operations on those units can be performed and the argumentation component presents hypertext to the designer to remind them of particular design principles they should adhere to. Thus the system has knowledge of properties and constraints of useful designs and can accommodate a new design unit being introduced. However, it is not an expert system which would automate designers' tasks and present them with solutions. This knowledge-based system negotiates the solution with the designer by providing explanations, prompts and identifies problems which will enhance and improve the final design. This particular system supports creativity by providing a rich knowledge base to enable the reuse and redesign aspects which are important conditions for enhancing creativity as discussed earlier. The direct manipulation of the design units allows designers to operate in the real world and deal with individual problems. The checklist provides prompts and cues to the designer without imposing prescriptive instructions, but helps the designer to think of alternative designs. This integrated design environment of construction and argumentation allows the designer to reflect on their design and supports the "reflection-in-action" model of design methodology as described by Schön (1983) in section 3.2.1. Fischer concludes that these design environments which enhance creativity need to be different from traditional computer systems. They need to be designed so that the domain experts from whatever discipline can benefit and use them as an interactive support tool without having to think about driving the technology.

Oxman (1990) postulates a knowledge-based design system that can enhance creativity and design. She argues that "design has an analogous relationship to learning" where prior design knowledge is adapted and modified in view of newly acquired knowledge. As discussed in this section there are various techniques which can facilitate creativity by generating new ideas and thoughts. Many of these methods such as checklists of transformations, metamorphic thinking, analogical reasoning etc. can now be supported by computers and are referred to as idea-processing methods (Young, 1989). Young (1991) considered the applicability of the idea-processing methods to weapons systems definition and design. Young found that some support methods could facilitate the problem definition and/or the solution definition phase.

Another creative design phenomenon, which has been found to be of importance in creative design, is that of emergence (Soufi & Edmonds, 1996). Evidence of these procedures were observed and recorded in an experiment undertaken by a small design team. Cross (1997) reported that rather than a "creative leap" occurring when a novel concept emerged, he described it as more of a "bridging" between the problem and the solution. He argues that this helps to explain and support the observed alternating between the sub-solution and sub-problem which result from the decomposition of the problem and the combining of solutions when designers are involved in creative design.

According to Gero (1996) designers involved in routine design will follow well defined schemas, but for non-routine and creative designs Gero argues that a new schema evolves. Gero presents a model of the "state space" which represents designs as having three subspaces of function, behaviour and structure. Computational models can construct a given "state space" which represents a given set of variables and processes. Gero argues that a change in the "state space", either by addition or substitution indicates creative design. Addition occurs when the boundary of the state space is extended beyond the original state space to encompass more variables. In the case of substitution, a deviation away from the boundary of the original states space occurs (indicating the deletion of some variables) plus an extension of the state space in to another area (indicating the addition of further variables). This explanation helps to explain the concept of evolving new schemas and the emergence of new shapes and behaviours of structures. Gero takes the argument further in stating that the addition of variables could be of two kinds. A homogeneous variable would be a similar kind of variable added from existing knowledge that could be integrated into the current schema such as making a minor alteration. On the other hand, a heterogeneous variable would be of a different kind and could not be integrated into the existing schema. Therefore a new schema would be produced. This explanation would appear to fit with the bisociation model of creativity proposed by Koestler (1964). Gero's explanation could be interpreted in terms of the different types of design as outlined in section 3.2.3.

Gero (1996) suggests there are a number of processes where computational models exist to substitute variables or even schemas such as mutation, analogy and emergence although the latter is still in its infancy. Gero thus presents a model of creative design which involves a number of creative processes which are explained in terms of additive and substitutive variables and schemas. As the variables change the schemas change and hence a new and creative artefact is produced. He argues that this concept of change leads to one of evolution in design and suggests that genetic algorithms may be used in this area.

Genetic algorithms have been used to design structures for routine designs and Gero discusses how genetic engineering could be used to develop emergent schema in an evolutionary design system.

As already discussed, drawing and sketching are an important aspect of conceptual design which allows a designer to represent his/her ideas visually (see section 3.4.1). According to Soufi and Edmonds (1996) emergent shapes often arise from interactions with such representations. It would therefore be useful for designers to have a tool which facilitated this activity and allowed them to structure and manipulate the emergent shapes. Thus research into computational modelling of emergence has been initiated and models exist based on the employment of a representation that can lead to emergent shapes (e.g. Gero & Damski, 1994; Liu, 1994 as cited in Soufi & Edmonds, 1996). It has been suggested that there are two cognitive processes involved when arriving at emergent shapes. One process is interpretative and perceptual which is looking to suggest some alternatives to the pattern identified. The second is one that is a transformational process that utilises an existing pattern using it as a cue to generate new structures, for example extending the boundaries of shapes to form new ones. Both processes could be supported computationally, but less so for the transformational one which is more unpredictable and less constrained. Soufi and Edmonds (1996) argue that for any computational model to be successful it would need to use multiple shape representations and use different and parallel deconstruction/reconstruction mechanisms for the designer to interact with.

The early stages of design, the conceptual phase, has long awaited the support of computer systems to facilitate the process. As discussed previously in section 3.4.2.1, there are many design support tools available such as CADs, but these focus on later stages of the design phases which require more detail, are often more routine and are therefore numerically orientated. The conceptual design phase requires more creativity and qualitative reasoning and Artificial Intelligence (AI) techniques have been employed to enhance this process. Rentema, Jansen, Netten & Vingerhoeds (1997) are involved in the development of AIDA (Artificial Intelligence supported Design of Aircraft) which aims to assist the designer in the more creative aspects of design. The AIDA system will comprise a number of different modules each of which will relate to different aspects of conceptual design activity and will include techniques such as rule-, case- and constraint-based reasoning and geometrical reasoning. The utilising of these techniques generates combinations of layouts for prospective aircraft based on existing cases, enables parameter studies to be carried out and ultimately produces an evaluation of the concept. If at this point the evaluation was insufficient to satisfy the design specification then the process would be repeated starting with another lay-out to be chosen. Some of these tools have already been developed and others are still in the processes of development.

Coyne and Subrahmanian (1993) also agree that computational systems which allow for human-computer interaction can enhance creativity by supporting the exploration of solution spaces.

Goel, (1997) presents recent theories of Artificial Intelligence (AI) research and the use of analogy-based creative design computer systems in this field. He suggests that analogies are useful for most of the conceptual design task and these form the basis of these computer programs.

AI can inform and model the cognitive processes and behaviours that humans engage in when involved in design activities (Smithers, 1994). Broken down these design processes include elements of problem-solving, searching, exploration, reflection, evaluation, decision making, creativity and learning. Computational models therefore seek to support and enhance such design processes or even replace some by the development of more sophisticated CADs. Smithers also suggests that research into AI should seek to identify how combinations of new and computational activities could enhance the design process to result in it being more effective and efficient.

Coyne, Newton and Sudweeks (1993) argue that connectionist models can be used to support one of the important aspects of design which is reasoning. They have also shown how such a model can retain information regarding the exposure to certain schemas. The model has then been able to draw upon this knowledge base to lead to the emergence of new schemas.

Research in AI regarding computational methods to assist with solving ill structured problems (ISPs) is fairly new (Smithers, Corne & Ross, 1994). Smithers et al present a process of "Design as Exploration" and how it can deal with ISPs. They also suggest the use of different algorithms as a way of forming a solving scheme for ISPs. Ramirez (1995) makes references to other ways design can be supported by computational models.

This section has considered various aspects of AI which can support and enhance the design process. Design processes involved in ill-structured, non-routine designs require complex problem-solving activities which include many different knowledge-based tasks and decision making (Simon, 1973). The studies have tended to focus on how the individual's cognitive processes operate when designing and have developed programs to replace or facilitate them in that process. However, this research project is looking at the much wider issues associated with creativity and design such as human factors and complex management practices related to large design teams in a mature engineering business. The issues relating to many of these factors are discussed in chapters 6, 9 and 10.

3.6.5 Creativity in organisations

Pugh (1996) discusses the issues of design management and the social aspects of design where the environment and context in which creativity takes place can be enhanced. Organisational routines may facilitate imaginative and effective work and efficient design management may be able to introduce such systems, for example by improving access to relevant expertise outside the team. Recent research conducted at Rolls-Royce Aerospace (Derby) has found evidence to support this (Baird et al, 2000). This issue is also discussed in view of the research undertaken at Rolls-Royce Aerospace (Bristol).

Isaksen and Kaufmann (1990) discuss how the climate of an organisation can affect its ability to foster the right atmosphere for enhancing creativity both from a technical and individual perspective.

Research has been undertaken by a number of researchers examining the climates of organisations and whether they are conducive to creativity (e.g. Majaro 1992: West, 1997; Ekvall, 1999). Instruments such as the Creative Climate Questionnaire (CCQ) have been employed to determine which environments have creative climates and which have stagnated (Ekvall, Arvonen & Walden-Ström-Lindblad, 1983 as cited in Isaksen & Kaufmann, 1990). An understanding of the climate for creativity within an organisation could highlight a number of benefits both for the individual and the company members

Isaksen and Kaufmann (1990) argue. This is achieved mainly by taking two approaches. One approach is looking to try and understand the characteristics of the highly creative individual whilst the other is seeking to understand the differences of how individuals express their creativity.

If we accept that there are two types of creative styles, *adaptors* and *innovators*, then a predominance of one or other of these can create a climate which supports the corresponding style (Kirton, 1987b as cited in Isaksen & Kaufmann, 1990). If there is a change in management and they are likely to have a different style, they may recruit others with a similar style to their own. This will over time change the balance and ultimately the departmental climate.

Nagasundaram and Bostrom (1995) argue that amongst other things, communication within an organisation maintains its particular organisational climate. The introduction of Group Support Systems (GSS) such as global electronic access for all employees can shape and change the nature of the communication and subsequently the climate of the organisation.

Factors such as how members meet with and respond to organisational principles, structures, procedures, traditions, systems, norms, and other realities of everyday life in an organisation all help to form the social climate of an organisation (Ekvall, 1999). A number of studies have identified what major determinants and conditions are necessary to support a creative climate in an organisation (Ekvall, 1999). They are:

- "goals and strategies of the business
- leadership styles
- organisational structure including management and control systems
- personnel policy regarding recruitment and rewarding
- resources of different kinds
- workload
- enhancing creativity"

Creative behaviour can be supported by a number of techniques (Holt, 1995). Organisations recognise the need to stimulate creative behaviours and computer-aided creativity (CAC) is a tool which can enhance these activities. For example, computer-aided-brainstorming (CAB) can be conducted using the internet enabling distributed creative brainstorming sessions. According to Holt (1995) one of the preferred methods is that of group CAB which appears to help facilitate creative thinking thus allowing groups of engineers to problem solve more efficiently. However Holt suggests that a lot more research needs to be carried out in this area before clear recommendations can be made. Evatt (1995) argues that CAB by its very nature requires the activity to be carried out systematically which he suggest stifles creativity by leading to a convergent rather than divergent view of the problem.

To create an environment conducive to creativity a number of suggestions have been made. For example, Peters and Waterman (1982) suggest encouraging employees to wander about different areas of their workplace from time to time (e.g. the Hewlett-Packard Company). Majaro (1992) advocates that for a company to improve their creativity and innovation output, then it must be prepared to hone its bureaucratic processes. Any changes to the structure of the company also need to be realised as they may well have a direct impact on the flow of information and communication lines which may ultimately affect creativity and innovation within the company.

Majaro (1992) also argues that a certain amount of slack in a company puts it in a better position to generate ideas and follow up valuable innovations. Even where companies run a "tight ship", there may be an opportunity to identify some "slack" by helping people manage their time. This can be achieved through encouraging personnel to keep a log book of daily activities which can then be assessed as to whether their days are spent effectively or not. In doing this exercise, it may become apparent that certain activities could be undertaken by other personnel freeing up time to those in the company with more creative talents to employ them more productively. However, the company must be mindful not to remove any slack by imposing further redundancies. Such ideas have been employed by companies such as the 3M (Minnesota Mining & Manufacturing Corporation) who allow employees to devote 15% of their time to the generation of ideas and management of innovation.

What West (1997) proposes as stimulating innovation in organisations are quality checks where information to all employees about their work must be available enabling effective teamwork with regular meetings, training and shared objectives, interdepartmental communication via different mediums and managerial support providing opportunities to challenge objectives, strategies and processes. He goes on to suggest that a company which fosters an open, flexible and supportive culture operating in a climate of shared communication and co-operation across boundaries can lead to creative achievements and cites many case-studies where this is the case. He adds interdepartmental communication should be valued and encouraged allowing for constructive conflicts rather than power struggles. However he recommends that organisations which want to encourage and reward innovation need to put in the resources, time and co-operation. West (1997) presents a number of exercises and techniques which can be use to measure the creative climate of an organisation.

Suggestions of ways to create and encourage a more creative environment within NPE Rolls-Royce Aerospace (Bristol) are discussed in view of the findings from the research in chapter 10.

3.6.5.1 Barriers to creativity

Studies referred to in chapter 1, section 1.3.2 provide an insight into barriers to creativity on an individual level (Haim, 1998) and an organisational level (e.g. Raudsepp, 1982; De Alencar & Bruono-Faria, 1997) and framed the issues at the start of this research. Further studies relating to this phenomenon are discussed in this section in greater detail.

Davis (1999) describes barriers to creativity as blocks, which can be either internal or external, that inhibit creative thinking and inspiration. He identifies five categories of barriers:

- learning and habit
- rule and traditions
- perceptual barriers

- cultural barriers
- emotional barriers

Rickards and Jones (1991) developed the Jones Inventory of Barriers (JIB) which has been used as a diagnostic tool in identifying barriers to creativity in organisational environments. The barriers have been modelled in four clusters: strategic, values, perceptual and self-image factors. Their study identified significant differences in mean scores for some barriers across a sample of occupational groups. These results indicated that individual's scores relating to the four clusters differed depending on their occupation.

Several studies by Amabile, Conti, Coon, Collins, Lazenby, and Herron (e.g. 1992; 1996) have eluded to a number of factors which can undermine creativity such as politics, harsh criticism of new ideas, an atmosphere of risk-avoidance and extreme workload pressure. There are similarities with the eleven characteristics identified by De Alencar and Bruono-Faria (1997) which they argue affect an organisation's creativity level (see chapter 1, section 1.3.2).

Majaro (1992) has also proposed a number of barriers to creativity found in organisations. He suggests that the restructuring of the company may, on the face of it, make it more effective and efficient, but lines of communication and the impact upon its creativity and innovation may not have been fully realised. Lack of slack in a company is another barrier. Too lean a company may enhance their productivity in terms of output per capita, but may inhibit their creative output. Bureaucracy is another barrier which can stifle creativity because it does not allow for flexibility which is an integral part of being creative. The structure of the company will also have an impact on its overall creativity. There has in recent years been a move to decentralising large multi-national companies which, according to Majaro, has the capability of improving creative performance. However, he argues that although some units will be more innovative than others, the cross-fertilisation of ideas across units may be a problem unless clear communication lines are in place allowing this to happen.

According to Majaro poor communication in a company could be a sign of "uncooperative, ill-motivated, suspicious and insecure individuals". He suggests both the overt and the covert reasons for obstacles needs to be understood. Communication can flow vertically in a company as well as laterally, for example between departments.

Majaro refers to a study he conducted in an electronic company operating both in the USA and UK working on similar products encountering similar problems. Although the managers met on a regular basis, they did not share ideas and solutions to problems identified in their respective units. Majaro calls this "a wall of silence" developed through a competitive "divide and rule" policy adopted in the firm. Poor communication in either direction is a barrier to creativity, but especially in the latter instance which may be due to a number of pressures. Majaro suggests these include information being withheld at the management level, where there is a conflict of objectives between departments, where shared attitudes and values are not present due to the diversity of the workforce in terms of educational background, culture and nationality and finally lack of awareness of the importance of communication possibly due to poor training.

The "imported talent" syndrome where "fresh blood" is brought in to enhance innovation is identified by Majaro as another barrier to creativity. This action can be to the detriment of those employed by undermining their confidence and motivation to be creative and innovative.

"Bean-counting" is a way of describing the way accountants behave in an organisation. They will seek to audit the way funds are managed, costs contained, profits produced and financial resources allocated and controlled. The nature of their job may well affect the way they are perceived in the departments as the activities of the departments will be analysed and evaluated and the results of their audits will be imposed. Majaro argues that "bean-counting" is not conducive to stimulating the creative process as creativity and innovation often demand an element of financial risk.

West (1997) suggests that if a company is introducing a number of changes in order to become more innovative and generate a creative climate, there is likely to be some resistance to those changes. He proposes a number of reasons for this. For example, the changes may be perceived as disruptive especially if they impact on principal ways of working even though they may benefit the organisation. If people feel their job, power, status or the diversity of their job is threatened they may resist change. This supports the findings by Raudsepp (1982) who suggests a barrier to creativity is "personal security".

Other factors which often cause resistance to change is misunderstandings about the change itself and its impact and where they have experienced so much change they cannot cope with any more. Finally there is probably less resistance, according to West, if the employees have been involved with the innovative process from the beginning and can see a rationale for it.

There are many common themes of barriers to creativity found in the literature and discussed here and in chapter 1, section 1.3.2. Many issues raised in this section are relevant and pertinent to the findings of this research and are discussed in light of the evidence in chapters 6, 9 and 10.

3.7 Conclusion

Several literatures which relate to aspects of design have been reviewed in this chapter. The literatures emerged slowly and incrementally from the research project. A 'bottom-up' approach was taken to develop a rounded description of relevance to the aims, questions and research findings of the project.

This has produced interesting insights into the variability of different perspectives relating to design. For example, some design models may be described as linear models whilst others may be described as iterative or spiral in nature. Models of individual design methods versus group based design have been described and discussed, as have rational versus reflection-in-action approaches to design. The social aspects of design have been discussed in terms of their relevance and importance in better understanding models of design and design processes. What is evident is that design can be described as a multidimensional space where there is perhaps a need to have a number of models to draw upon which can reflect the different types of design tasks and problems that have been described (see section 3.2.3). There also needs to be an awareness of how much models fit this space to enable researchers to better understand design practice.

A range of cognitive artefacts from basic tools to recent technologies, which support designers in their design activities, were found in the literature as being task dependent.

Basic psychological issues in relation to learning, visual perception and visualisation, which are implicated in the design process, were discussed in this context.

In the final section relating to creativity, similarities were found in the literature on the models of creativity, the characteristics of a creative person and the processes involved in being creative. Many ideas for enhancing creativity on an individual level are available from employing a range of techniques to using specifically developed software programmes designed to enhance conceptual design. Many of these are still in the early stages of development. As computer technology advances it is probable that the provision for conceptual design and ways to support creativity in organisations will extend to support group design processes more effectively. This research will seek to identify the main issues that need to be considered to enable and enhance creativity in conceptual design teams. Commonalities were found in the studies pertaining to barriers to creativity which can be at an individual and organisational level. Several suggestions were proposed as to how to circumvent these issues.

Figure 3.4 provides a visual representation of the literatures drawn upon in this chapter to support the research of the thesis and illustrate how they overlap and interact with each other. What the model depicts is how the sections of this chapter relate in one way or another to formal design models and types of design described in the literature. What it also shows is the relevance of those areas to creativity. This research has identified and highlighted a number of perceived barriers which correspond to and impact upon the different areas of conceptual design practice.

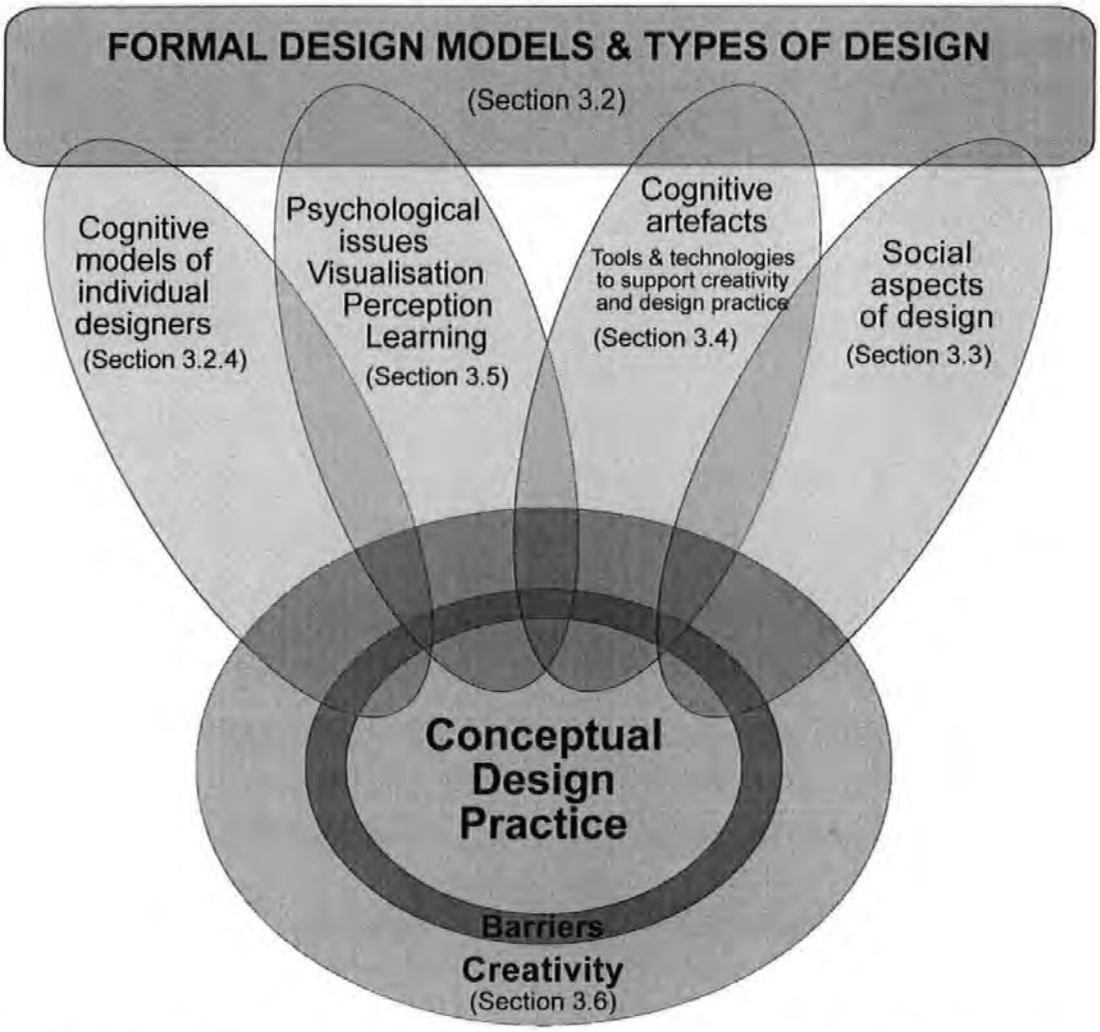

Figure 3.4: A visual representation of the literatures suggested as impacting on the conceptual design process.

Whilst the intention of the research study at the outset was not to impute the perspectives found in the literature to the findings of the study, important aspects of design as elicited in interviews and observed do reflect, on the whole, what is in the literature. The literature has helped to provide concepts and language to talk about design processes, creativity and perceived barriers to creativity found in the study. There were salient aspects of the designer's experience which relate to the literature and those links have been highlighted throughout this chapter.

This research project looked at design taking place in a 'real' setting. Formal models of design were not particularly helpful in describing exactly what was going on. Design was taking place in a busy, quite pressurised, stressful, under-resourced organisation which was operating in a changeable commercial climate and therefore these factors had some influence in how design activities were undertaken.

During the studies undertaken in this research the design engineers exhibited various aspects of cognitive processing, such as visualisation, whilst designing. They employed different approaches to design as required by the problems, projects and tasks at hand. Observations and records of their use of the tools and technology used in their practice and the creative techniques they applied were noted. However the main objective of this research was to identity the perceived barriers to creative design being experienced and how they might be reduced or, if possible, eliminated. In order to achieve this the whole environment had to be taken into account and the experiences of designing in that environment analysed. The following chapters of this thesis detail the studies undertaken and report the conclusions drawn.

As Cross and Cross (1996) state the study of design comprises three elements: "the technical process, the cognitive process and the social process". This research project has attempted to consider all three in reporting its ultimate conclusions in chapter 10.

Phase 1

Chapter 4: The Scoping Study

4.1 Outline to Phase 1

Phase 1 (see chapter 2, figures 2.2 & 2.5) of the research involves the Scoping Study and the Design Group Interviews (DGI) Study. This phase provided the necessary groundwork for familiarisation with the company and an introduction to the general issues experienced by design engineers. The Scoping Study provided an opportunity to identify the major issues experienced by engineers in relation to perceived barriers to creativity under macro conditions. The DGI Study was conducted to provide a more detailed account of the conceptual design processes undertaken in New Projects Engineering. It used the themes identified in the Scoping Study as a framework for the first stage of progressive focusing. The data were analysed using grounded theory which produced a number of categories. Suggested relationships between the categories were identified from the outcomes of the DGI Study and subsequently validated by members of Rolls-Royce (see chapter 5, section 5.4).

The findings from Phase 1 incorporating the Scoping Study and the DGI Study are reviewed together in relation to the literature in chapter 3 and documented in chapter 6. Conclusions drawing upon all the studies undertaken are presented and discussed in chapters 9 and 10.

4.2 Introduction to the chapter

This chapter describes the Scoping Study undertaken in the first phase of the research project. The Scoping Study was conducted to attain a broad overview of the working environment in which conceptual design at Rolls-Royce Aerospace (Bristol) was taking place and to explore the nature and sources of individual's perceived barriers to creativity.

Details of the process and the outcomes of the Scoping Study are presented. Four engineer designers from Rolls-Royce Aerospace (Bristol) were interviewed and conversations with another supplemented the data. Analysis of the transcripts from the semi-structured interviews led to the identification of the major issues relating to conceptual design for these designers.

These issues were grouped into six themes namely:

- knowledge sharing
- social mechanisms
- management structures and organisational constraints
- individual/personal resources and design process
- technical issues
- unfulfilled support needs

Evidence was taken from the transcripts to further explain and illustrate the content of the six themes in section 4.5. The outcomes from this study provided a platform for the Design Group Interviews (DGI) Study (see chapter 2, figures 2.2 & 2.5) which followed and is reported in chapter 5.

In chapter 6, the findings from the Scoping Study are reviewed in terms of the literature.

4.3 The Scoping Study

The purpose of this study was to conduct exploratory interviews in order for the author to familiarise herself with the working environment and to try to understand how the designers think and feel about the topics of concern for this research, that is perceived barriers to creativity. The outcomes from this study would develop a structure for later detailed studies of the research questions.

4.3.1 Participants

Four employees of Rolls-Royce Aerospace (Bristol) were interviewed.

One was a design engineer, the second was a Principal Design Engineer, the third was an Integrated Product Team Leader and the fourth was a Principal Stress Engineer. Codes relating to these participants are in the form of A(2)*[1]; B(2)*; C(1)*; D(2)* (see appendix B for explanation).

Arrangements had been set up in advance to talk to these engineers by Dr Chris Moore who at that time was the Head of Design Technology in the company. He provided a representation of engineers from the department who could talk about the broad remit and activities of engineering design.

4.3.2 Method

The semi-structured interviews (see chapter 2, section 2.4.4.1) took place over a couple of weeks in the early stages of the research. Participants were interviewed on site in a room which, exceptionally, allowed for the interviews to be taped. Each interview lasted in the region of 2 hours. The interviews were conducted with a minimum of direction from the interviewer and the interviewees were encouraged to talk about anything that they felt was important to their roles and responsibilities as design engineers.

As with any semi- structured 'active' interview a schedule had been prepared in advance (see appendix C) with a number of cues and prompts added to help elicit the information. As the interviews were more conversational in their nature, the interviewer 'actively' encouraged the respondent to expand their dialogue by allowing them to draw upon personal experiences and "narrative positions" and bring that to bear on the topics under discussion (Holstein & Gubrium, 1997). This approach allows alternative perspectives and bases of individual experience to be accessed. Transcripts were made of the interviews in preparation for data analysis. An outline of the issues raised is given in the following section.

4.4 The Scoping Study findings

Following the taped interviews, initial analysis (see chapter 2, section 2.4.4.3) of the transcripts was carried out. In this study the data were grouped into common categories or

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1 Where A--is the individual
(1)--is the category
*--is the interview number

themes (Boyatzis, 1998) highlighting the major issues experienced by those interviewed. The findings are interpreted in terms of the literature in chapter 6.

4.4.1 Knowledge sharing

This theme includes issues, human and technical, concerning access to and exchange of knowledge to support engineering design. From the transcripts it was evident there was a clear need for more information which could be easily accessed. Reported procedures were long-winded and sometimes illogical in view of those who used them. These issues are discussed fully in relation to the literature in chapter 6.

4.4.1.1 Access to experience

There appeared to be an appreciation and acknowledgement of the importance of senior engineers' expertise and a desire to be able to elicit that knowledge in some way. For example one interviewee stated that the team should,

> "[We] should interview retiring senior engineers to pick their brains about the sort of problems that designers were now meeting as they had encountered them before in the 1960's."
>
> B(2)2/tape1/counter1113

Their vast experience allows them to anticipate problems that less experienced designers fail to account for adequately. What was also apparent was the perception that if such knowledge was not 'downloaded', then once an expert in his field left or retired then that knowledge source was lost.

> "Older designers were laid off during the recession and they carry a wealth of experience of company knowledge. Thanked very much and they take that out the door with them when they go."
>
> C(1)3/tape3/counter706

> "Due to increased pressure regarding the projects I haven't got as much time now to seek out and research what went before. Therefore when it comes to senior level reviews, the 'old school' engineers will refer to older engines that had similar problems and ask them if they have researched it. However they have probably never heard about it and have no way of tracing it as it is not in the paperwork system. It's walked out the door."
>
> C(1)3/tape3/counter714

The need to draw on the expertise of specialists in their fields was often evident in brainstorming sessions held to overcome a particular problem in the design. However, these sessions were not always conducted in a formal way, but were run less formally with experts from different specialisms on the team meeting to decide the best approach to take.

Experiences of similar problems by other designers were also sought to develop a solution. Before concurrent engineering was adopted in the 1990s, all designers worked together in one large department which meant it was easier to get to know everybody and what design/problems they were working on. For example from the transcripts,

> "We seek out people with previous experience regarding who knows what. From an organisational slant we used to have one big design office (1.5 acres) where *all* designers would be located. Used a lot of leg work to find out the answers from people who had encountered similar problems before. We discussed problems and gathered the information informally to get at what was locked away in the designers heads."
>
> C(1)3/tape3/counter637

4.4.1.2 Wide discussion of designers

Open discussions regarding any design problems were commonplace. However as project teams are currently co-located links between different designers in different projects teams elsewhere are harder to establish and maintain.

> "Today things are organised differently. Projects are co-located and people are therefore co-located, for example, stressors, designers and management. You can't necessarily walk over to the next desk and speak to someone who has had similar problems and discuss it. Links are less as sometimes people are physically remote and involved in different projects and the sub-contracted people wouldn't know who to ask anyway."
>
> C(1)3/tape3/counter697

In addition to this problem, many aspects of the projects are sub-contracted out to other companies which means those employees would not be in the position to know who to ask for help anyway as noted above. This is the downside of 'projectisation' where individuals on project teams lose contact with their discipline base. They lose links to enable deeper discussion on discipline related issues because they are no longer working in a group of just stressors, for example, but work as a part of a multidisciplinary project team.

4.4.1.3 Design reviews

Design reviews (see section 4.2), which involve a panel of very experienced senior engineers, are seen as a very valuable exercise although they are often perceived as "a trial by ordeal" and a hurdle to get through by the younger designers. The interviewees suggest that this process could be put to better use by making these senior engineers and their immense expertise more accessible at an earlier stage in the design process. Their input at that point in a less formal setting, instead of at the end, could help to alleviate any potential problems and/or highlight any yet to be encountered.

> "We have a panel of very experienced and very senior people from the company. It has become a sort of a hurdle to get passed and done at the end of a stage. Get a feeling that that expertise could be put to better use if you were to do something which was less foreboding. This is like a trial by ordeal."
>
> C(1)3/tape4/counter427

> "What we miss out on is this pool of much more experienced people out there who act as a sort of punishment at the end. There are not enough of them and they are not available enough to have in on a daily basis, but rather than have them in at the end, have them in at a lower level session on 2 or 3 occasions before you get to the final review to suggest in course corrections so that you are more likely to be successful at that point. This is a gate in the process that you have to get through before you are allowed to go through to the next process."
>
> C(1)3/tape4/counter453

> "It would be really useful to have these people [seniors in design reviews] involved more often and in a less intimidating forum."
>
> C(1)3/tape4/counter481

However, the reviews are valued for example for the following reasons.

> "It's quite easy for a detail designer to have his nut and bolt and flange etc and work away on this, but once in a while you will get the Chief Engineer involved and he says, 'Hang on—you don't need that if you combine it with this piece.' It's a very mixed process, reviews with seniors, who can stand further back and can identify if we are putting ourselves into a corner or not. They can take a fresh look at it."
>
> C(1)3/tape4/counter378

Thus it would appear that a lot of experience-based information is held within the heads of the designers and improving ways of access may be very beneficial. The way this is achieved at the moment is that some information such as process capability[2] is measurable and relatively easily referenced through record systems/databases. There appears to be more of a problem when it comes to referencing less clearly defined information. For example, one of the interviewees described how useful it would be to have access to specific solutions to specific problems.

> "We lack a database on specific solutions to specific problems. Rolls-Royce started to address that by introducing filing systems. It was hard to get such a database going as it is hard to describe what the problems and solutions are so that anyone can search them in the future."
>
> A(2)1/tape1/counter823

2 Statistical data relating to a particular process such as manufacturing with regard to the various parameters of a component.

4.4.1.4 Access to archives: electronic & human

What also appears to be a problem is the way data and information are stored electronically in networked databases and vaults. There are no facilities to store this information in any alternative mode, for example, as a visual reference which would allow perhaps for a greater understanding as to what the design was all about. A system which could present previous concepts which had not been successful due to the limit of the current technology and could be re-visited in light of new technology, would be beneficial especially if this was in a visual form.

> "[We] tend to store things electronically, but have no visual reference. It's too mechanistic all you get is the name of the file. You can't add anything to say what the design is all about. No visual representation unless you look in the work folder. This is a problem."
>
> A(2)1/tape1/counter1081

The company has a technical library which contains detailed reports relating to the evaluation of designs. However, according to those interviewed it does not adequately support the conceptual stage of design. It is reported as not being organised to its best potential and lacks the resources to perform a literature search on specific topics.

> "There is some information there [technical library], but if you look at the content of our technical library there's a lot of it that is difficult to see its applicability to what people really need for their work [sic]."
>
> C(1)3/tape4/counter510

> "It [technical library] is not organised to its best potential. It is just a quiet little place out in a corner of the site somewhere. Don't think it's taken that seriously as a source of references."
>
> C(1)3/tape4/counter517

The problems with the current systems of storing data either in hard copy format or electronically are perhaps due to a shortfall in the organisation of such information. For example, the telephone directory lists everybody alphabetically and therefore you need to know somebody first before you can contact them. If however it were arranged in an alternative format such as profession/department or 'Yellow Pages' of specialism, it would at least offer the novice enquirer a place at which to start from. Keyword searches are another aspect of on-line inquiry that can facilitate searches, but only if the researcher is aware of the correct ones to use.

Other problems with electronically stored information appear to be those associated with administrative systems. For instance passwords to computers have to be renewed on a regular basis and failure to do so means having them revoked. The methods of accessing the different databases also appears to be difficult and if not used on a regular basis can be forgotten. Not all computers can access the relevant databases either, so obtaining data can become an inconvenience at times. Hardcopies of data do not appear to be kept up to date and therefore designers revert to "who they know" to find out what they want to know. The Integrated Product Team Leader interviewed stated,

> "Rolls-Royce pay lip service to databases by putting some information on a computer and thinking they are bang up to date with a modern database. But what they actually do is put it on a mainframe computer on a hostile piece of software which will then not print. For example our materials properties database is on the mainframe and it can't fit all the information on an single screen, but you can't scroll backwards through it and it's not compatible with workstations that designers use. So they can't print that from their machines so they have to go and find a terminal to be able to access it. This has made a designer's life harder because in the old days you would go to a book, but at least you knew where it was and the data were visible. Now the information has been moved and taken further away without thinking who was using it. Who is it a database for, for materials engineers or designers?"
>
> C(1)3/tape4/counter140

> "There is the printed stuff, but that's useless--barely up to date. So go back to [the] old boy network. You know who your contacts are and that's it."
>
> C(1)3/tape4/counter562

> "People who use them [systems] get slick with them. The mainframe based system etc.--they are so esoteric you have to know how to go through them else you'll get stuck. They are not like Microsoft products where there is a style which is all the same and if you pull menus down you'll find something you're looking for. For these systems you need to know that at a particular stage you have to press F10 otherwise you will get locked in and you have to go and reset your password."
>
> C(1)3/tape4/counter537

The experienced designers supported these statements.

> "Depending on the nature of the job will depend on how much people have access to the records. In principle [we] can have access to anything, but not easy access as not one complete system which holds all the information. The main problem is working out where the information is stored unless you happened to have been involved with the project. Even knowing it exists would help."
>
> A(2)1/tape1/counter1012

> "As an old manager used to say, 'It's all been done before, but it's finding out where'."
>
> B(2)1/tape1/counter1113

4.4.1.5 Absence of feedback from later stages of the life of a design

The flow of information is reported as being in one direction from design to production and the organisational structure of Rolls-Royce appears to make the assumption that this is optimal. Data could be fed back through the system to the designers from the production regarding service findings, but does not appear to be.

> "The whole system is set up to plug information from the design office through the various engineering functions and out to manufacturing to a product. It is not set up to chase back the other way even though now [we] do concurrent engineering. It is inherent in the chronology of it, that is when you do a design scheme you don't know what the detailed part numbers are going to be. Need to have a mechanism to trace it back the other way."
>
> C(1)3/tape4/counter014

So although the company practices concurrent engineering, the whole system is geared to providing information from the design office through to the various engineering functions to the manufacturing of the product. There appears to be no mechanism in place to enable a component designed by an engineer to be referred back through the whole process once it has left the design office. It would be beneficial to designers, for instance, to know if the component they had designed had worked successfully or had only partial success in the short and long term in manufacture and in use.

> "[We] don't get told any information about the things that have worked alright. If it's just enough it's no different from extremely well. This would be the type of information that should flow back the other way. For example it could be that the part is sub-optimal and that it was OK in this instance. Not quite right, but didn't give a problem in this instance. [We] just don't get feedback. So mistakenly the designer may think its OK when in fact they only just got away with it."
>
> C(1)3/tape4/counter115

Therefore there appears to be missed opportunities in the communication process regarding the awareness of what information is required and desired by different groups and a reluctance in some instances to share that information.

There are however communication sheets between detailers (see section 4.2) and designers which allow progress to be made on the design before the full scheme is completed. Therefore design and detailing are going on in parallel and heavily overlap. This can cause a problem in seeing where the design is going overall and hence communication between the two is essential.

Databases, which have been developed to facilitate designers in their design processes, appear to be of limited value. For example, it would be beneficial if some of the functions could be automated, such as help with the material selection process. With respect to previous solutions to specific problems, knowing what information is available, how it is referenced and then knowing where it is stored appears to be a problem.

Easier access to databases and other resources could be achieved by ensuring that compatible platforms are implemented so that they are readily accessible to a wider workforce, that the software is user friendly and use of them is not inhibited by individuals having to maintain multiple user IDs.

There appears to be information sources available in the company, but not used to their best potential and not stored on homogeneous systems. Thus it appears communication between people and systems is not as effective as it could be. Changes in knowledge sharing practices could benefit individual designers, the New Project Engineering department and the organisation as a whole.

4.4.2 Social mechanisms

Issues relating to the communication and social interaction between individuals and groups are classified under this theme.

Changes in jobs have meant changes in procedures, but these are not always followed by the designers as expected. Cultural changes take time to get used to with changes to attitudes and beliefs of certain concepts entrenched by practices and responsibilities being habitually followed. Some issues are not necessarily technical ones, but 'people' ones where there appears to be a difficulty in getting people to talk to one another especially if they have not met with them before. It was felt that this becomes particularly apparent in trans-national projects where different approaches to work are often encountered.

One of the interviewees highlighted this situation,

> "A lot[of the issues] are not technical issues, but people issues. Getting people to talk. It is difficult to persuade someone to ring up a complete stranger on the other side of the world."
>
> C(1)3/tape4/counter785

> "If you put everybody involved in a room before we started this [project] and had a damn good party. We would all get to know each other so that when you suggested you should ring say Joe in USA up they wouldn't have a problem. This is a team building and breaking down the barriers issue more than a technological issue. The British are more reserved whereas the Americans are different. They are a lot more willing to go out there to talk to anyone and ring someone."
>
> C(1)3/tape4/counter790

The company needs to address such issues as it becomes more and more decentralised. Social connectivity has been found to be an important aspect of teams enabling them to function effectively and efficiently (Baird et al, 2000).

There are cultural differences experienced between the two British Rolls-Royce sites of Bristol and Derby. Rolls-Royce, Bristol see themselves as "more innovative and radical in their design" whereas Bristol's view of Derby is that they are more "conservative and constrained" in their design. However this is probably more to do with the Bristol site being responsible for the military market which is more radical in what the customer demands. Derby however are concerned with the commercial market which tends to be more evolutionary in their design rather revolutionary.

There appears to be a resistance and a reluctance to change due to a number of factors such as having to re-train and the demarcation of duties. For example,

> "One of the things I found when I introduced structural optimisation was that there was significant resistance from both designers and management. A certain amount of designers were saying, 'That's not my job--that belongs to the stress man.' Although that attitude is breaking down now, but an awful lot of people resist it because they just don't want to learn another system."
>
> C(1)3/tape4/counter571

> "One of the most demotivating ways in which the design process is set up at Rolls-Royce is that once the designers have launched their part they hear nothing of it unless something has gone horribly wrong when they will be given a good rollicking."
>
> C(1)3/tape4/counter074

> "Another demotivating aspect where the brainchild's disappear off into the wide blue yonder and never heard of again. Nobody comes back to say, yes that worked really well!"
>
> C(1)3/tape4/counter130

Thus it would appear that there is both lack of feedback, information and understanding about other people's jobs and what they entail. Lack of ownership regarding the component the designer has designed can cause motivational problems as well it seems. Only when things have gone terribly wrong is the designer contacted and reproached. Otherwise after Derwent Stage 1 (see chapter 1, section 1.7.1) a designer's involvement is apparently almost non-existent. The decentralisation of the company appears to have had an impact on the social connectivity within the company that has been shown to be an important aspect of design teams (Baird et al, 2000). There are also cultural issues, which could impact on the social interactions between the two Rolls-Royce sites.

4.4.3 Management structures and organisational constraints

Data relating to the objectives of the company as perceived by those interviewed are included in this theme. Comments relating to the constraints imposed upon the designers in terms of reduced timescales and resources and their subsequent impact on design practice are reported. Other issues regarding polices, procedures and politics are also included.

4.4.3.1 Accounts led

There is a perception that there is a lack of recognition of the merits of engineering, the value of intellectual capital as a resource in the accounting structures and financial focus of the company. As a consequence, a wealth of knowledge and experience has been lost due to redundancies and staff turnover in the past. These concerns are expressed below.

> "There is a sense of a lack of acknowledgement from the financial side of the company, that is it doesn't need to nurture and develop engineering. I think the company regards engineering as a resource that can be switched off [when things are tough] and bought in when things get better. [Now we face] problems and crises as a lot of good blokes were laid off and years of experience have gone forever. They can't be replaced in the short-term now that we are coming out of recession. In the USA there is a tradition of a 'hire and fire' situation regarding the workforce as there is always somewhere else to go. Can't do this at Rolls-Royce in the UK as there are no other big players. We lose people to the States and can't get them back. Therefore mistakes have been made in the recession and we are feeling it now."
>
> C(1)3/tape3/counter336

> "Rolls-Royce used to be an engineering dominated company before the 1971 collapse. At that point the engineering contingent were considered to be those to blame for this and since then the company has been accountant led. What best financial deal they can get rather than considering what impact that choice may have on the ability to carry out the engineering job."
>
> C(1)3/tape3/counter1068

There is a perceived reluctance by the company to provide funds to develop new ways of doing things unless a thorough business case has been presented and accepted. Also because of contractual commitments to a particular software company, there is a reluctance to opt for alternative software products even though they may be beneficial to the design process. One reason for this particular issue could be due to again lack awareness of the true needs of designers. Senior designers may have little, if any, experience of operating CADs and therefore may not fully appreciate what the technology can or cannot achieve.

> "CADs are relatively new and therefore many seniors have had no exposure to this world at all. We used to have designers and engineers who had grown up with the tools and processes that the designers were still using--now that's changed. They may not understand the technology and probably are a little nervous of it. Therefore they are not making the decision regarding purchasing of new equipment from a position of experience with it."
>
> C(1)3/tape3/counter1078

The company is continuing to seek to reduce the timescales of product development and designers are forced to have a concept prepared within a certain time frame. This results in designers' satisficing on their designs and opting for the lowest risk solution which may not always be the best. In order to improve this compromise, it was said that the designers require technology which allows them to consider many more ideas and concepts in the time allotted to this stage of the design. Current practice within these tight timescales means that there is minimal room for manoeuvre on a project to accommodate mid-course changes of direction. For example, the two designers interviewed expressed their concerns.

> "[We] haven't in the past been under pressure to produce something in a certain amount of time, but it has changed recently. More often we are forced to have a concept ready in a certain amount of time with a certain amount of man hours allotted to it. So at some point in time you need to say [we have] looked at all series of diagrams and decide which ones are going to be taken further. A problem occurs if we think of something much later and decide that would have been a better option."
>
> A(2)1/tape1/counter973

> "This can restrict innovation. Specific timescales means you won't look at all the possibilities. It concerns me a bit......you will inevitably go for the lowest risk solution as well which may not be the best."
>
> B(2)1/tape1/counter979

The Integrated Product Team leader who was interviewed supported this view.

> "There is higher pressure in the design office now than when I joined. In some ways there wasn't enough pressure, but we are now at a point where the project timescales are about as short as you can get them. This means that downhill with a following wind, you have a good chance of making a success of it but don't have any room there for any mid-course corrections."
>
> C(1)3/tape4/counter409

4.4.3.2 *Training and support*

A number of guidelines exist to encourage designers to adopt a rigorous approach to their design practices, such as references to checklists and the retention of all relevant material. The company has adopted and reinstated some policies and practices which are perceived as beneficial such as the apprenticeship scheme, various training programmes and an employee's suggestion scheme.

However, there are other policies and internal politics which are perceived by some of the workforce to be inhibitory and bureaucratic. Some of these criticisms may be implicit comments on the hierarchical structure of the company itself.

> "Internal politics can stifle the design process. For example, Rolls-Royce signed an agreement with an [ITSS[3]] to supply all the CADs equipment but this is not the best tool for our needs as designers. [We] often get resistance to change and maybe not enough forward thinking by some."
>
> B(2)2/tape2/counter450

> "Rolls-Royce [interviewee thinks] will not go with the new software Pro/E as he does not believe they [Rolls-Royce] are focused on the needs of the design process. I believe they have a different agenda. They [Rolls-Royce] have a commitment to the [ITSS] and it has been perceived as doing all the things that designers need to do and has been connected with all different systems, 'Our strategic solution'. The one group not asked their opinion as to what systems to have were the people who use them. I suspect there is a significant input from financial people, but users have not been asked. They have something that works so what's the problem? Commitment to go with the [ITSS] is presented as one not open to debate."
>
> C(1)3/tape3/counter1020

> "The company is hierarchical. Basically [you] pass suggestions to your boss, but what actually gets past him and gets to the top those down amongst the weeds wouldn't know. Don't know how seriously it's taken."
>
> C(1)3/tape4/counter484

Thus it would appear that the role of the designer within the company is affected and constrained partly because of the organisational structure of Rolls-Royce and some of the policies that ensue. For example, financial and time constraints appeared to have had a direct impact on the scope and quality of the design project outcomes. The perceived values and culture in the organisation also affect them.

4.4.4 Individual/personal resources and design process

Included in this theme are the descriptions of what the designers perceive their creative design process as entailing. It includes statements about how they believe they are 'creative' and how they need to keep informed of the latest technologies.

4.4.4.1 Perceptions of creativity

The designers stress that the nature of the design process is iterative. They begin to think about a problem and generate some obvious solutions to it by drawing on acquired knowledge and previous experience. These are evaluated in respect of the design by trying

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to imagine how they might work in reality. The decision is then made whether to accept or discard ideas as the design evolves. However, this process will vary depending on the format of the requirement. For example, if the requirement is very novel then a group of experts is assembled to generate ideas initially.

Artefacts such as pencil and paper are used heavily when sketching in the initial stages of design. At this stage ideas and their expression are completely unconstrained.

> "There is always going to be a phase of the process that is really the 'fag packet' end where you just sketch on a piece of blank paper in a completely unconstrained way. No doubt about it."
>
> C(1)3/tape4/counter626

> "Free hand sketching, drawing and drafting is the physical process. Hundreds of sheets of things you draw and then discard as you evolve through the process. My 'old' boss used to say, 'You're paid as much for rubbing out as drawing with a pencil.' You draw with a pencil and design with a rubber."
>
> C(1)3/tape3/counter450

> "Some things I have sketched I have then dismissed and a day or two later I'll go back and say, 'that was good, why did I dismiss it and not modify it and come up with the solution.' I don't know."
>
> B(2)1/tape1/counter815

A lot of thinking and discussion between colleagues takes place as well, which does not appear to be appreciated by those who are not designers.

> "People outside of design have traditionally had a poor impression of designers for two reasons. One, they think, 'I can do that in two weeks' and two, 'the design office doesn't always appear to be a particularly busy place'. But a huge amount of time is probably spent thinking rather than drawing. He [the designer] researches the problem, talks to experts and people who have done similar things. This gives the wrong impression, but they are doing what they are paid to do. Then when they have all the information they will start sketching a few things out and do a lot of staring and thinking around the problem."
>
> C(1)3/tape3/counter667

The interviews highlighted a number of processes the designers thought they used when being creative in design. For example, reference to flashes of insight; a realisation of the fact the answer was there all along, but the problem needed to be thought about in a slightly different way; immersion in the problem so that it becomes second nature and analogical thinking where a previous solution to a problem can be adapted and modified (this is not always done consciously though).

> "So with say propulsion nozzles you work at it and get to the point where you're immersed in it [the problem] until it becomes second nature and then things start to flow."
>
> C(1)3/tape4/counter343

> "I often wonder if something has triggered it unconsciously that you haven't really acknowledged in your mind."
>
> C(1)3/tape4/counter658

> "I start thinking about a problem regarding obvious solutions to it. I start to delve and realise that some are not viable. I draw on practical experience to know what tolerances etc."
>
> C(1)3/tape3/counter440

The technology used is seen both as a constraint to creativity and an enhancement to it. Certain software requires that the designer thinks about what has to be changed and how that may be achieved in explicit terms and this is seen as a useful prompt in the design process. Other software is too syntactic and obstructs the thinking process.

> "CADs force you into being very precise at a very early stage. In the conceptual design phase you don't want to be too precise. CADs is a very good drafting and detailing tool, but not a designer's tool. That's what's lacking [we] need a tool which is designed at the outset with the designer in mind."
>
> B(2)1/tape1/counter718

> "Back of the fag packet sketching is what we still do. If I get a brainwave I grab a piece of scrap paper and sketch something down. Sketch a concept freehand. I can't do that on a CADs."
>
> A(2)1/tape1/counter740

4.4.4.2 Training and education

The benefits of the apprenticeship route versus the graduate route are highlighted. The apprenticeship route provides the designer with a 'hands on' experience and an ideal opportunity to not only gain a fundamental knowledge of materials properties and manufacturing limits, but also how the company operates as a whole. These skills and knowledge can implicitly be applied to and incorporated into the design being undertaken.

Constraints to the creative process are enforced once the designer has to think in terms of material properties and other parameters imposed upon the design.

> "The apprenticeship helped as it gave me a more 'hands on' experience...using the lathe, grinder, through the whole of manufacturing and the tools at that time. I became aware of the capabilities of the materials and what could be achieved. This helped when it came to design as I knew I couldn't actually design that, or achieve that or machine that."
>
> B(2)1/tape1/counter450

Designers coming from the graduate route have different qualities to offer. They may be more able to use computer packages such as CADs and have a better grounding in the theoretical issues of design. However, they lack a knowledge of the practical limitations of both materials and the manufacturing process.

> "Completing an apprenticeship gives you something. Graduates don't have a grasp of the basic manufacturing processes or the 'feel' for it that develops from your apprenticeship."
>
> C(1)3/tape3/counter368

> "Graduates can sit in front of a computer screen and draw a whizzo component but need to have gone to the forge shop and see the huge machines to know the practical limitations of the manufacturing processes."
>
> C(1)3/tape3/counter373

Expertise and knowledge is always being expanded as designers conduct a lot of "shelf-engineering"[4] in between the design of new engines. This enables the designers to keep on the edge of the technology and their skills honed which may be required by a customer at some point in the future.

4.4.4.3 Perceptions of the qualities of a designer

Asked what the interviewees thought were the necessary qualities for a designer a number of characteristics were offered. These included a need for flair, imagination, practical experience, open-mindedness and confidence in one's abilities and what was achievable. There was also the suggestion that designers fall into two types: the "intuitive" and the "technical" each using a slightly different approach to design.

A number of working practices in relation to the design process carried out by designers have been implemented to ensure information is recorded and retrievable at a later date. For example, the work scheme folder contains the sketches and other information pertaining to the design. However, this practice does not appear to be all that well adhered to as it requires the designer to write a report and be rigorous in their note taking. Their preference is to draw, and having to add something in text is something they appear reluctant to do. However, if the work folder remains as simply a collection of drawings, it does not necessarily convey to other designers what is going on in the heads of the originators.

> "Designers like to draw on paper--that's how they express things—so to ask them to write a report you may get 2/3 lines, but they are reluctant to do it as too much extra work."
>
> C(1)3/tape3/counter581

4 Shelf-engineering involves exploring new techniques and advanced engineering which may become feasible should new materials be available in the future.

From an organisational stance, working to timescales and being under a certain amount of pressure to generate the design can inhibit creativity. Interruptions by general office routines can also have an effect and often the designers come into the office at the week-end when it is quieter.

It would appear that the designers who were interviewed have a certain amount of insight regarding the creative processes they employ when designing. However, this was obviously articulated retrospectively and with regard to some processes, they were not at all sure how or why they had happened. They were clear though as to what artefacts, practices and personal attributes enhanced their design processes.

4.4.5 Technical issues

Numerous problems are highlighted in this category mainly to do with the technology currently being used.

The technical software packages the designers work with such as CADs assume that the design process should be a linear one whilst in reality it is more evolutionary and iterative with avenues which may terminate in dead ends.

As mentioned previously in section 4.4.3.1, designers have to satisfice on their designs. One of the reasons for this is limited resources. Thus where ideally at the end of Stage 1 they would prefer to have several concepts to explore in more detail, there are only enough resources to look at one to take forward to Stage 2.

The conceptual designers work with CADs, however they argue that such systems are not a designer's tool, but a drafter's one. A number of problems were highlighted in the transcripts regarding the use of this technology available to the designers at that time (see list below):

- losing touch with the scale of the design so they have no environmental view, as was previously available with drawing boards
- resolution (pixel size) on screen
- size of screen will never be comparable to what can be achieved with paper
- lack of integration with other tools employed

- no measuring facility—the designers have to put a ruler to the screen to measure elements of the design
- inability to sketch design on CADs, which are model driven
- inability for many designers to get around a screen and discuss a design
- too much unproductive drafting
- demands too much precision at conceptual stage of design
- too slow to provide real-time updates
- no intelligence
- incompatibility with other machines regarding data exchange
- huge proportion of mental effort expended in running machine as not very user friendly; a high overload of syntactic knowledge required by the packages
- transfer of CADs data is problematic especially across the Atlantic even when 'neutral' formats are employed
- difficult to look at model in different perspectives
- no real-time rotations
- design locked away in a computer to which only the individual designer can gain access and understand fully

The technology in use does not facilitate communication between different projects either on a national or an international front. The acknowledgement of the need for good communication between all groups is apparent, particularly as the company practices concurrent engineering. That way, problems can be dealt with efficiently and quickly. Electronic mail, at the time of the Scoping Study, was relatively new to the organisation and not all people had access to it. Even where it had been placed on workstations, it had sometimes been disabled.

> "Data exchange is an Achilles' heel of the systems as they are not compatible. They have to go through IGES or STEP[5] but the revisions are not the same. Rolls-Royce standardises on group systems, but not the other companies we work with. It's always a problem."
>
> A(2)2/tape2/counter480

5 IGES-STEP is the Standard for the Exchange of Product Model Data in CADs offering conversion capability.

> "You can transfer files through a translator or neutral format, but not in real-time. We are aiming toward doing something like this, but security can be a problem and a constraint."
> A(2)2/tape2/counter490

> "We have a team here and on the other side if the Atlantic. We struggle to communicate with them. The transfer of CADs data is a real headache. Neutral formats just don't do the job."
> C(1)3/tape4/counter760

Rolls-Royce Aerospace has developed a lot of in-house software and specialised tools, but again problems arise with the integration of some of these tools with each other. Also these tools are described as 'sledgehammers' and unwieldy for doing quick changes and then trying them out. The software packages that are in use can be unreliable and are not very robust. Another problem is the size of the machines that the designers work with. The feeling again is that because the roles and responsibilities of the designer are not fully understood and appreciated by some people within the company, they are provided with the lowest specification machines. This evidently has an affect on the type of software that can be used and the speed at which it will run. Indeed, not all designers have a PC on their desk as they are not expected to access and process information. What they are given is a drafting tool – a CAD machine – whereas what designers really need at their fingertips is information. Information about what the requirement is and what the materials can do to fit that requirement. The culture has been to provide the designer with drafting and analytical tools and not information managing tools.

> "Designers are dragged down by having to drive the system. It could be just our system –not sure if this is universal, but I see guys using 80-90% of their mental effort spent trying to beat the CADs and drive it because it is so complex and not particularly user friendly."
> C(1)3/tape3/counter500

> "The software has lots of commands which are quirky and different. Lines and arcs are OK to draw, but anything more complex becomes a very complex task, just to do the modelling. This soaks up a lot of intellectual effort which really should be aimed at the design process, i.e. deciding about how something should be rather than trying to define it in very fine detail."
> C(1)3/tape3/counter513

Due to the limitations of CADs, complex objects are often better understood by viewing a solid model. New computer technology has enabled this by a rapid prototyping technique called stereolithography. As described in Rolls-Royce literature on this technique, "stereolithography (SLA) works by slicing a CADs model into a series of separate layers. Each layer is used to define the laser path across the surface of a pool of resin. Where the laser spot falls on the surface, selective curving occurs. On completion of the layer, the elevator platform moves deeper into the resin, fresh resin covers the work-piece, and the process is repeated until the model is made." Producing a 'touchy feely' piece of hardware in this way helps to convey a concept or idea and helps designers somehow to know intuitively whether the design will work or not.

> "It's difficult if the concept is so different from the one used at present to get others to understand. I produced a stereolithographic model to portray the concept. Then immediately the 'penny dropped' and people came up with further suggestions."
>
> B(2)2/tape2/counter558

There are also problems with how designers use the systems they have. For example, they are not taught how to construct a model and therefore develop their own ways of doing things which may be quite inefficient. If this was standardised and taught to them it would save a lot of time. Another problem is the way they manage their CADs files which represent their designs. If designers do not practice good housekeeping skills with reference to their designs, it does not take long for all 256 layers on a CADs to become filled with irrelevant designs and models. This is akin to the scraps of paper that designers may have discarded under their drawing boards before the advent of CADs. However, in such a scenario the discrete steps that it took the designer to develop his/her design would still be apparent whereas with CADs that staged process is not so clear at all.

> "Boeing operate differently where their designers clean out all the construction geometry ending up with the clean model whereas at Rolls-Royce the information regarding their models may only be on the 6 uppermost layers with lots of rubbish on the other layers which you don't know what it is. It is still in there when they present the final model."
>
> C(1)3/tape3/counter539

The additional problem is that although these layers may contain irrelevant material they are important as they also contain the mistakes which if logged some way would be invaluable.

> "I think this as a huge wasted opportunity of missing not only their repeated work, but also the repeated mistakes."
>
> C(1)3/tape3/counter578

It would appear that technology currently used at Rolls-Royce Aerospace has a number of limitations when used for conceptual design. A number of additional problems were highlighted relating to hardware and software issues and general computer use such as housekeeping skills and common design practices. The designers' felt that improvements could be made on many of the issues.

4.4.6 Unfulfilled support needs

This is the final theme which was drawn out from the transcripts and lists a variety of aids and features which designers stated they would like to be able to use. These include:

- full parametric 3D modelling capability from the early stages of the design process
- help with scale and measurements which are not incorporated in the CADs software
- a sketching tool to be able to draw free-hand, for example a sketch pad which could do scans and sweeps of a sketch and save it for retrieval if they want to modify it.
- a database on specific solutions to specific problems which describes the problems adequately with keyword access preferably
- better tools to look at a greater number of "what ifs?"
- more information to enable an informed decision to be made, for example more details relating to limitations of variables within a chosen concept in order to be more confident in the decision
- more automation of the analysis to free up time for innovation, for example a fully parametric 3D modelling capability which could then be analysed in terms of stress
- systems which could bring up previous concepts which could then re-visited in the light of new technology
- to be able to 'revisit' previous sketches for further development
- to have access to Pro/ENGINEER™ (Pro/E) which have attempted to provide a more user friendly package for designers
- workstations with the capability of a 'super computer' for real-time optimisation
- user friendly software programs which make less syntactic demands
- systems which are more flexible and compatible and interface with other packages
- integration of tools which are already provided to obviate the need for re-entering data

- reliable and robust software
- need for specific tools for specific problems and also packages which allow individual cells in a spreadsheet to talk to each other
- programs which stimulate you by presenting cues to possible solutions
- a self contained package which can do everything including updates
- a decent real-time shaded image with rotation and zoom with ability to fly through like those which Boeing use
- CADs which are less demanding and more intuitive to drive
- tools that go beyond just doing geometry
- more computerisation of the things we currently do manually
- expert systems which could access data which is deeper than just geometric
- a database that indicates whom you should be talking to about particular technical issues
- a system that, in addition to prompting you and finding relevant historical data, also could critique a design, for example look out for vibration here, it may crack there etc.
- useful to have data relating to other issues for example manufacturability and cost
- a feed-box counter on screen which changed as your features did, that is could see the figures changing correspondingly for example:

▪ **COST**	▪ **WEIGHT**	▪ **LEAD TIME**

- having a machine which, when a designer puts in some parameters he wants to work with, it will come up with say 3 suggestions as to what would be the most suitable materials to use
- intelligent programs which highlight particular types of mistakes or facilitated the above process (e.g. adaptive searches)
- software to enable engineers to do all the sensitivity and optimisation studies on a specific concept
- analytical tools which will cover more ground that the 'sledgehammer' devices we currently use

- information searches and things which delve back through history-things that can pull out manufacturing process capabilities and materials data would be immensely useful
- fully integrated packages such as PowerPoint with CADs for presentation purposes

As seen, many suggestions were made by the designers as to how they could be better supported in their design activities. These included enhanced technologies in terms of hardware and user friendly software designed to support conceptual design and creativity. Expert systems and extensive databases were noted as other desired requirements to enhance their design practice.

4.5 Summary of the chapter

As a result of the Scoping Study, a broad overview of the working environment in which conceptual design takes place at Rolls-Royce Aerospace (Bristol) was realised. The findings from the study identified a number of themes relating to the perceived barriers to creativity as experienced by those interviewed. The major barriers raised were grounded in knowledge and information sharing activities, communication flows at individual and organisational levels, the constraints and policies imposed by the company, aspects of the tools and technologies used in design practice, education and training and individual resource issues. Finally those interviewed volunteered suggestions and ideas for enhancing and improving their design activities. The broad range of issues highlighted by those interviewed posed many questions which were pursued in subsequent studies with the design engineers. Thus the findings from this study provided a platform for the DGI Study. This study allowed for further progressive focusing of the issues which is presented and discussed in the next chapter (chapter 5).

Chapter 5: The Design Group Interviews (DGI) Study

5.1 Introduction to the chapter

This chapter describes the Design Group Interviews (DGI) Study following the Scoping Study described in chapter 4. The DGI Study was conducted to provide a more detailed understanding of the structure and infrastructure of the conceptual design process within New Projects Engineering (NPE). The perspectives of those working in NPE in relation to their perceived barriers to creativity and how these were encompassed were also explored. In relation to the overall research plan (see chapter 2, figures 2.2 & 2.5), the DGI Study identified the categories and relationship paradigm/models which were drawn from the data analysis using grounded theory.

Details of the process and the outcomes of the DGI Study are presented in this chapter. Sixteen engineer designers comprising six project managers and team leaders (group 1), six experienced designers (group 2) and five new designers and trainees (group 3) from Rolls-Royce Aerospace (Bristol) were interviewed. A total of 30 semi-structured interviews took place over a five week period.

Grounded theory analysis of the semi-structured interviews led to the identification of sixteen categories. These were:

- setting and context
- organisational processes
- timescales of project
- milestones and deliverables
- integration with other companies
- working practices (changes in)
- project management
- communication (technological)
- role information
- experience of designers

- design process
- communication (social)
- technology
- wants
- creativity
- workload and time pressure

Definitions of the categories from the analysis are given in section 5.3.1. A frequency plot (see figure 5.1) illustrated the extent to which the three different groups commented on issues directly related to the sixteen categories. As the analysis continued so important emerging relationships between the categories became apparent. These are discussed in section 5.3.3. Finally validation of the findings of this study through a series of presentations and development of an Interrelationship Digraph are discussed in section 5.4.

The categories and the relationship models developed from the data collected in the DGI Study went some way to explaining the occurrence of the phenomenon, 'perceived barriers to creativity'. The incidents were articulated under macro conditions and helped inform the basis of the interviews in the following Tracking Study (see chapter 7).

The findings from Phase 1 incorporating the DGI Study and the Scoping Study (chapter 4) are reviewed together in relation to the literature in chapter 6. Conclusions drawing upon all the studies undertaken are presented and discussed in chapters 9 and 10.

5.2 The Design Group Interviews (DGI) Study

The purpose of this larger study was to synthesise a more comprehensive view of the environment in which conceptual engineering design takes place. In addition the perspectives from different groups working in NPE in terms of their perceived barriers to their creative activities and how they circumvented them were sought. The findings from the Scoping Study were used as a basis from which to begin. This study provided a more authoritative sample to confirm and further describe the themes and ideas that were drawn from the Scoping Study.

5.2.1 Participants

Sixteen people from NPE were interviewed. They were an opportunistic sample who offered a diverse range of roles. A number of project managers and team leaders were interviewed together with several experienced designers (two of whom were participants in the Scoping Study) and performance engineers, new designers, graduate employees and trainees. Opportunistic sampling was not ideal, but it was necessary to interview those who were available and willing to take part. Due to their workloads and commitments to delivery dates, it was not always possible to interview the targeted designers.

The participants have been put into three main groupings (see appendix B for more detail):

- *Project managers and team leaders (Group 1) coded[1]:*
  G (1), Q, (1)*, R(1)* and I(1)*, J(1)**

- *Experienced designers (Group 2) coded:*
  A(2), B(2)*, N(2)*, M(2)*, O(2)* ,P(2)**

- *New designers and trainees (Group 3) coded:*
  K(3), L(3)*, H(3)*, T(3)*, S(3)**

5.2.2 Method

The semi-structured interviews (see chapter 2, section 2.4.4.1) took place over a five week period fitting in with the work commitments of those being interviewed (see appendix D for interview schedule). The total amount of interview time was approximately 40 hours. Due to the amount of time a given individual could spend being interviewed, interviews ranged from 30 minutes to 4 hours. [In the case of interviews lasting 4 hours, this was broken down over 2 days.]

In addition to the semi-structured interviews conducted, a further 20 hours approximately were spent either in attendance at meetings or reading through company documents. Again the length of time the meetings took and/or how long the researcher was able to attend

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1 Where A--is the individual
(1)--is the category
*--is the interview number

varied. For example, some meetings observed were quick impromptu ones, which took only a few minutes, whereas other meetings were scheduled for a full day.

The interviews took place in a secure area and therefore video and voice recordings were prohibited for security reasons. Hand written notes (fieldnotes) both from interviews and observations in meetings comprise the data collection from the time spent at Rolls-Royce Aerospace (Bristol). These are not included in the appendices for the same security reasons.

The data were then analysed using grounded theory and the findings are reported in the next section.

5.3 The Design Group Interviews Study findings

The data were subjected to the coding procedures of grounded theory as described in chapter 2, section 2.4.4.3 to classify the topics which were articulated by the interviewees. Grounded theory was used because it allowed the significance of findings to be drawn from the data, rather than attempting to impose pre-determined models or categories. Initial open coding produced a large number of conceptual labels which were then grouped into categories which reflected their similarity of meaning. This data reducing exercise allowed the data to become more manageable. Sixteen categories were drawn from the data and are defined in the following section.

5.3.1 Main categories *(Initial analysis/open coding: see chapter 2, figure 2.3)*

Categories represent a grouping of conceptual labels and thus a funnelling of findings. The sixteen categories generated from the data are briefly described below in terms of their meaning, and where appropriate, their properties and dimensions. Properties are the general or specific characteristics or attributes of a category. Dimensions represent the degree of that property along a continuum (Strauss & Corbin, 1998). An indication of where categories overlap, thus building relationships between the categories, is also given.

5.3.1.1 Setting and context

This category refers to the particular setting and context in which the research is taking place. Included under this category is any information relating to the NPE department at Rolls-Royce, Bristol. For example this includes how the NPE department is set up and managed and by whom. It also relates to information on the number of engineers and designers working in the department at present and the projects they are involved in. Data referring to the FOAS project (see chapter 1, section 1.7.4) specifically is also included in this category. The general material included in this category relates to the organisational context and was necessary as background information setting the context for this research project.

Overlaps: Setting and context overlaps with *milestones and deliverables, organisational processes* and *working practices.*

5.3.1.2 Organisational processes

This category refers to the position of the design project within the different formal process models apparent in Rolls-Royce. The main process followed is the Project Derwent process (see chapter 1, section 1.7.1 for a brief description) with Stage 1 being of primary concern in NPE. Thus, when an interviewee makes a reference to how this project is being run in relation to the Rolls-Royce philosophy of Derwent it is categorised here. Also under this category are references to meetings which happen on a regular basis and other organisational processes which affect the running of NPE.

Organisational processes can be perceived as barriers such as the requirement to present formal business cases in order to obtain certain facilities. For example, a business case has to be prepared in order for employees to obtain an external email facility and it has to progress through a number of channels before the authority to have it enabled is granted. As an experienced designer commented:

> "Rolls-Royce has a funny external email system. I applied in June for access to external email as needed to maintain our contact with USA etc. The Director needs to approve [the request], but only looks at applications once a month. Nothing was done during July, then I was told the application was lost, then holidays came along. So I only received external email this week (4 months later)."
>
> R(1)23/bk1/p138/ln79-100

This can obviously impinge on the ability of the employees to communicate with the outside world. Another example are where there are delays in getting extra licenses for software and having to make a business-case of the acquisition of certain software. This was highlighted by a new designer:

> "The servers have new applications which if they are not rolled out, we can't use them when we need them. Disciplinary action [would be taken] if use it. The delay is often for no apparent reason. Things become excessively complicated."
>
> H(3)27/bk1/p156-157ln123-128;140-142

This sort of issue can inhibit creativity where lack of resources and inadequate communication channels are experienced. The result of this is could be slower progress on a project and/or a delay in getting hold of the people and data necessary for the work to continue.

Overlaps: Inevitably there are overlaps between this category and *working practices, communication (technology), and project management* because of the restrictions imposed upon the designers as they work within the organisational processes. It also overlaps with the *experience of designers* category because the backgrounds of new designers differ due to the different organisational processes which are, or were, in place at their time of training.

5.3.1.3 Timescales of project

Reference to the restrictions of the FOAS project in terms of time are made here. There are a number of milestones and deliverables which have to be met regarding the project and the designers work to various timescales to meet them.

One of the major problems about having to work to tight timescales for the designers, project managers and team leaders is having call a halt to innovation too soon. Designers have to satisfice and managers are concerned that better, alternative designs are not explored. Thus working to tight timescales forms a barrier to creativity by (a) not permitting designers to use their creative skills to their full potential and producing perhaps better designs and (b) placing time restrictions on the processes they are applying to a design.

> "At this point we are having to say we've had enough innovation, but what if new and innovative ideas come to mind at a later point?"
>
> G(1)7/bk1/p35/ ln24-28

> "We are constantly working under pressure to tight timescales. Reports are going out before they are really ready. We are worried that all avenues are not adequately explored and thought through."
>
> Q(1)21a/bk1/p38/ln83-89

Overlaps: This category obviously interlinked with many others especially *milestones and deliverables of project* and overlaps with the *project management* category. Timescales set as an aim for implementing new technology means an overlap with the *technology* category.

5.3.1.4 Milestones and deliverables

This category relates to references made to both the FOAS project as a whole and the individual sub-projects that the engineers are involved in. Deliverables of the project are described in terms of what form they take, what the content material is , how many there are, how they are to be reported and when.

Overlaps: Obviously this category overlaps with the *timescales of project* category as well. Also because the of the way Rolls-Royce present their reports in different media formats, this sometimes overlaps with the *communication (technological)* category.

5.3.1.5 Integration with other companies

This category looks at perceptions and views of how Rolls-Royce and other members of the alliance associated with the project and their suppliers work together. Reference to how they understand each other and how this has developed over time is also included. Barriers to creativity can happen when there are misunderstandings or a mismatch of working practices between companies. Many examples were observed during meetings between the companies where team and individual ideas or expectations did not meet those of the partner organisations or in some cases the plans or strategy of the parent company.

Working practices do differ between the different companies and this was identified by the companies in their initial report as "something which had to be acknowledged and resolved by letting new ways of working evolve". However it was evident different working practices between companies could cause problems. For example, the format and methods for passing information and data to and from companies. Additionally it was also said that:

> "There is a reluctance for companies to provide too much information because of competition."
> A(2)12/bk1/p73/ln80-81

Having to modify attitudes and current working practices in order to accommodate integration with different companies may impede the creativity of designers when expectations differ.

> "The Integrated Product Team structure for the project was interpreted differently by different companies. For example [xxx] industries saw boundaries between the teams and did not realise they could confer with other people. They went through the Integration Team each time which became a huge drain on this resource."
> G(1)7/bk1/p37/ln47-51

However, there is also the potential for a facilitation effect that boosts creativity when new ways of looking at designs and developing them is produced from the interaction from different organisations. For example the deliverables for the FOAS project were produced on CD ROM. This had also led to the development of a website with a view to providing simulations and readily accessible links to reports which could be easily updated.

Overlaps: This particular category overlaps with the *working practice* and *project management* categories.

5.3.1.6 Working practices (changes in)

This category covers any reference to working practices. Such practices can be wide and diverse. For example they may be related to administration, others with the design process, and others to customer quality requirements. This category also records examples of the working practices that people are currently engaged in. These may also be working practices that are trying to be changed by others (e.g. managers) and the implications of the effect of that from other groups (e.g. designers).

The working practices recorded may be current ones or changes in practice and procedures which may or may not always be advantageous in comparison to the 'old' way of doing things. Suggestions for what might be better practice are also included here. Reference to any training that should be provided is also included.

Many issues were raised and noted under this category where perceived barriers to creativity were present. Some of these referred to the changes that have occurred over the years and what impact this has had on the designers and those who manage/lead them. Comparisons were made between how the design office and other major departments were organised and structured ten years ago and in the present day.

> "We work in an environment which has locked doors and where swipe cards are necessary to get in with. Previously we worked in large halls where people had much more access. Now we have less visitors and we have to go and see them. This is more of an inconvenience to staff in NPE."
>
> H(1)27/bk1/p158/ln176-185

Projectisation has led to the dispersal of specialised functions, such as stress engineering, into projects. This makes it harder for engineers to locate the specialists they need at particular points in the design process. As a consequence of this situation and the increased capability of the technology it has led to a greater expectation of what the engineers should accomplish in the design process. This is an example of a change in working practices for the designers.

> "Our department can now do stressing and therefore get more of it. More is expected of us as we are capable of doing more in depth and accurate jobs in the time available."
>
> H(1)27/bk1/p153/ln50-55

Further discussion of this important and salient category is found in chapter 7, section 7.4.6 and chapter 8, section 8.3.5.

Overlaps: Inevitably this category overlaps with many others, such as the *technology* category. Changes in working practices usually means changes in the use of certain technology. There is also an overlap between *working practices* and the *project management* categories. There are times when this causes conflict and tension due to the fluidity and nature of the work undertaken in NPE. There are also instances when an overlap occurs between this category and *communication* at both *technological* and *social* levels.

Inevitably there are times when *working practices* overlap and integrate with *organisational processes*. For example, Rolls-Royce Aerospace is currently introducing "key systems" for the different departments in an attempt to formalise processes. Key systems comprise the information, tools and methods required to implement a process in manufacturing or engineering prescribed to a fine level of detail. However, the argument is that for preliminary design projects this is not feasible as all innovation and creation takes place here with no formal structure. Formalising the process would inhibit creativity, if it allows it to happen at all.

5.3.1.7 Project management

This category includes any references made to the running of projects in NPE. For example, it may be from the perspective of the individual managers who run small projects or the designers themselves. This will have different meanings due to the different perspectives on the project itself of these individuals. Problems in project management, from either perspective, occur when new projects are taken on and changes in resources have to be made.

> "Rolls-Royce will have a number of core team members on the [FOAS] project, but people can be pulled off at any time to work on other projects. This has a problem with continuity. It's approaching a serious level and we need to address this issue. It can't continue we need stability."
>
> G(I)7/bk1/p37/ln63-67

Overlaps: This category overlaps with *working practices* where changes in working practices have meant changes in how a project is managed. Some overlaps with *organisational processes* and *timescales of project* categories were encountered due to the pressures and constraints exerted by them.

5.3.1.8 Communication (technological)

As analysis progressed it became clear that two themes to the communication category were emerging. Therefore the category became too large and was split into two to accommodate the differences between communication when referring to *technology* or *via technology* and communication on a more *social* level. References to what types of technology; when and how often they were used and the advantages and disadvantages of them are also included in this category. There are both negative and positive aspects (sub-categories) to both these categories which have been highlighted.

There were very apparent barriers here due to the inadequacies of the technology systems being used.

> "Communication could be better. For example the use of video conferencing. It is not very good due to time delays, pauses etc. Its OK for short meetings, but not so good for 3-4 hour meetings."
>
> A(2)12/bk1/p73/ln103-104

Overlaps: There are overlaps between the two categories of *communication social* and *technological*. For example there maybe a breakdown in communication due to both a technical, (e.g. failure of IT network) and a social problem, (e.g. location of teams at different sites).

5.3.1.9 Role information

Included in this category is information that relates to the individual designers who have been interviewed. The range of roles and responsibilities for the different 'levels' of people are also included. Brief overviews of their roles and responsibilities both to the NPE department and the FOAS project are given and provide useful background information.

Overlaps: Some of this material supports the other category *experience of designers*. This category overlaps with *working practices* in some instances where, in describing their role, designers also describe their working practices.

5.3.1.10 Experience of designers

Reference to the demographic time bomb is included in this category (i.e. the impending retirement of experienced designers). The extent and intensity of problems; who or what is involved; what measures are taken to address such problems are also included.

The designers come from a variety of different backgrounds and avenues into the company and as a consequence have different approaches to the changes in working practices, communication and technological issues. This category also includes anything associated with experience gained in Rolls-Royce and other organisations. Lack of experience can inhibit creative design. However it can also enhance creative design by being unconstrained by knowledge of previous designs.

> "We have a problem in that we are losing people with experience in 2D conventional drawings in the future."
>
> G(1)15a/bk1/p75/ln2-4

> "Rolls-Royce apprentices have a different background as their skills have developed over time. Graduates have a different background and don't want to get into detail."
>
> Q(1)21/bk1/p121/ln135-140

Overlaps: There is a great amount of overlap with this category and others, such as *role information.* In terms of *technology*, there is an overlap where there is an obvious lack of skill or experience. This category also overlaps with *working practices* and *organisational processes* again where attempts or suggestions have been made to address the "demographic time bomb" issue.

5.3.1.11 Design process

Included in this category are references to the design processes that designers say they go through when designing and therefore differs from the *working practices* category which relates more to the designers' operational context. Reference to different types of design involving different types of input and actions; length of time taken; intensity and detail are included.

In establishing what technology is used, the benefits and the disadvantages of the software and systems are also recorded in terms of whether it has enhanced or impeded the design process. These are discussed in chapters 6 and 9.

There were instances where the references to the design process indicated when there were barriers to creativity. For example,

> "Designing involves holding a lot [of information] in your head. For example, what you can and can't do."
>
> S(3)25/bk1/p146/ln56

There were other instances when the design process was enhanced using new technology. For example,

> "Speed enhanced [technology] results in lots of iterations in less time which reduces thoughts and thinking, but opens the avenue for trying lots of new concepts. Therefore I can try lots of new ideas through curiosity, but need to focus as constrained by time."
>
> H(3)16 & G(1)15/bk1/p83/ln63-70

Overlaps: This category inevitably overlaps with the *technology* category as a variety of technologies are used in the design process itself. This category often overlaps with *working practices* and at times it is hard to differentiate between the two. However as the categories interplay with each other in such a complex way, it is inevitable that this will occur. The design process is governed to some extent by the categories *milestones and deliverables.* These have to be met and therefore the design process designers go through is directly implicated in that. Part and parcel of the design process is communication with others; therefore this category overlaps with *communication (social)* and *communication (technological).* NPE deals with the conceptual stage of design and therefore this category also overlaps with instances where *creativity* is mentioned.

5.3.1.12 Communication (social)

This category includes references to all aspects of communication which involve people rather than technology. For example, who talks to whom; why; frequency and length; intensity; type of communication (work related or otherwise). It may be communication with colleagues, team members (both in Rolls-Royce Aerospace, Bristol and elsewhere) and other people from other departments within Rolls-Royce. Three sub-categories have been identified here where examples of *good* and *poor* communication are recorded together with *social interactions. Social interactions* have been included to be able to accommodate the observations of the informal interactions between people in a range of situations.

As communication is an important aspect of design, barriers to creativity occur, for example, when there are problems with sharing information.

> "Communication with other departments is not so easy as it used to be. You need to be tasked, raise a task and obtain a booking code. Therefore this impinges on the flexibility of informal ways of communicating as we did before."
>
> Q(1)26/bk1/p144/ln51-54

> "Communication with others is a problem when you want to see whether an idea is feasible or not. They are reluctant to give you any answers unless it is specific, but designers want a general yes/no answer."
>
> A(2)12/bk1/p71/ln45-47

Overlaps: Overlaps occur between the category *communication (technological)* where people are using, for example email when communicating with someone else. When designers need to communicate with other companies, this category overlaps with the *integration with other companies* category. There are also overlaps with the categories of *design process* and *working practices.* This is because there are protocols for initiating contact with other departments.

5.3.1.13 Technology

This category includes comments relating to technology used in the design process. For example this is technology used to draw and visualise a design and may include drawing boards, Computer-Aided Design systems (CADs) and data resources. *Technology* has two sub-categories, which seek to differentiate between negative and positive comments regarding aspects of the design technology used. The comments relate to advantages, disadvantages, complexity, characteristics and features of a particular tool or system.

Many issues were raised in terms of how the technology can enhance or inhibit creative design. These are discussed in chapters 6 and 9. For example,

> "CADs have no real advantage over the drawing board. It's slow especially starting something from scratch. It's too mechanical a process even to draw a line. A great barrier to creative design. They are drafting tools with perfect accuracy."
>
> P(2)20/bk1/pg102/ln36-40

Overlaps: There is an overlap with a number of categories, namely, *design process, communication (technological* and *social)* and *working practices* as technology is central, in one way or another, to all of these activities.

5.3.1.14 Wants

This category includes anything that the engineers have expressed as wanting or needing, for example to what extent it is required by those interviewed and why. It might be certain issues regarding technology (future or otherwise), changes in working practices or training. There are implications for creative design which are discussed in later chapters.

Overlaps: This category overlaps with various other ones including *project management, technology* and *working practices.*

5.3.1.15 Creativity

In this category reference to any aspect of creativity is included. Examples include frequency; different experiences, length of time and intensity. This is mainly as a result of the design process that the designers undertake. Occurrences of creativity amongst designers and what it means to them are recorded here. Creativity may be referred to in terms of what technology can or cannot do to facilitate the creative process. Also reference to the different types of designers is included in this category. For example,

> "You need lots of imagination, creative imagination, to make revisions 'fit' the problem space. Most [designers] have technical imagination, but innovative designers have 'Star Trek' vision."
> I(1)10/bk1/p51/ln113-116

Overlaps: This category overlaps with *design process* and *working practices* to some extent as the designers refer to instances of creativity whilst involved in design activities.

5.3.1.16 Workload and time pressure

In this category references are made to levels of intensity regarding workload and the extent to which pressures are felt due to time constraints. These vary depending on whose perspective they come from and what they are in relation to.

> "It's a balancing act between fulfilling one project against any new ones coming in. Changes in the political scene means a project is started and then stopped. It's hard to plan for workloads which are constantly going up and down."
>
> Q(1)26/bk1/pg122/ln32-35

Overlaps: This category overlaps with *project management, timescales* and *working practice* where perhaps restrictions are placed upon what can be achieved due to inadequate or inappropriate working practices.

5.3.2 Overlap of categories

As the analysis progressed it became evident that many categories overlapped with other categories as briefly noted above under each category definition. Grounded theory ultimately seeks to illustrate how these categories interrelate to form an explanation of the phenomenon under study, namely, 'perceived barriers to creativity'. This is achieved through a conditional/consequential matrix and relational accounts which are fully presented in chapter 10.

5.3.3 Frequencies of categories

To get an initial picture of what the data means, the frequencies with which each particular category was raised by the three different groups were plotted (see figure 5.1). The different groups refer to the collective interviews conducted with project managers and team leaders, experienced designers (who included performance engineers as well as design engineers) and new designers and trainees (these were people who had been recently trained or in the process of being trained as design or performance engineers) (see section 5.2.1).

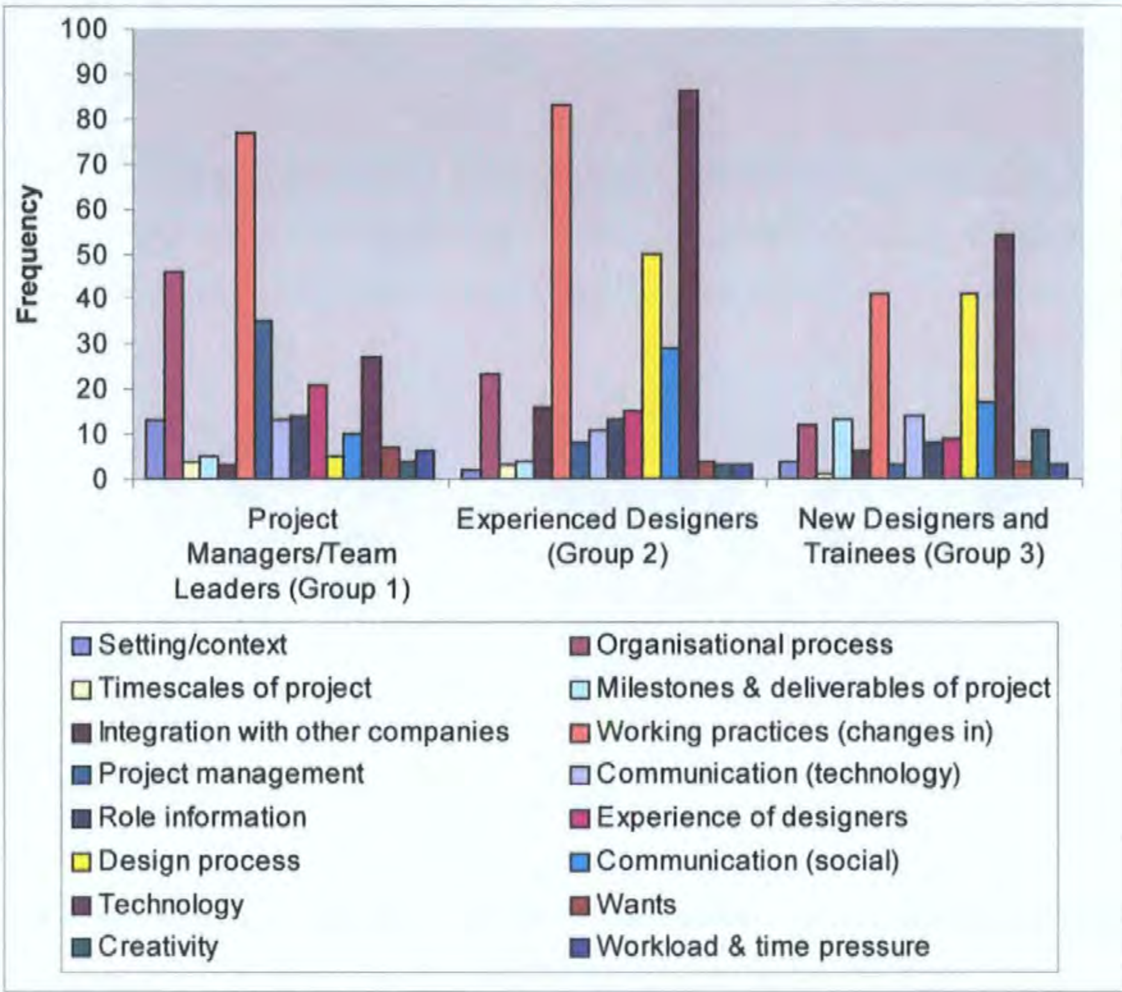

Figure 5.1: Chart illustrating the frequency of categories mentioned in the DGI Study.

5.3.3.1 Discussion

The peaks on the chart correspond to the most frequently mentioned categories and illustrate the extent to which a particular category was raised. Inevitably some peaks differ between the three groups interviewed. Relationships between the categories and the three groups are discussed below.

Technology is a frequently occurring category, which suggests this is big issue for the experienced designers. This includes sub-categories of both the negative and positive aspects of technology that were mentioned.

It is perhaps not surprising that designers have the most to say about this topic and many problems and issues are raised under this category. For example concerns were expressed in relation to the hardware. Problems of robustness, reliability, compatibility and access to server file-space were mentioned often. Issues relating to the reluctance of the organisation to invest in more licences of relevant software and updating current software frustrated the designers.

Many problems were raised regarding the difficulties in using many of the packages and systems. There were certain idiosyncrasies associated with different software which caused the designers problems when using it. The limitations of the software in terms of conceptual design and social interaction were well articulated as well. For example,

> "The drawing board was more social. The computer is more demanding and you can't talk to someone at the same time."
>
> P(2)22/bk1/pg142/ln36-37

On the positive side there were a large number of statements made which referred to the benefits of the new technologies now in place within Rolls-Royce Aerospace, Bristol. For example compared to the CADs the new software Pro/ENGINEER™ (Pro/E) was viewed as being more flexible and easy to learn.

The group referred to as new designers and trainees (group 3) raised similar concerns to those presented above by one of the experienced designers although, as can be seen from the graph, less were made. It is difficult to make direct comparisons as a number of factors are not standard for all groups. For example, the length and number of interviews. However, inspecting the transcripts identified that similar topics and issues were raised by this group of less experienced designers. The project managers and team leaders tended to make comparisons of the 'old' technology with the new in terms of their roles. They appeared to feel more removed from and less involved with the project. For example,

> "The design takes place on a small screen. So how can you see the whole picture if you want to see the whole engine? It's a problem for the supervisor as they can't see [the design] and discuss it as they used to. You have to print it out to be able to see."
>
> Q(1)21/bk1/pg116/ln16-20

Another high peak indicating an important category is that of *working practices*. As can be seen from the graph groups 1 and 2 made a lot of statements in relation to this category. The issues raised here were in relation to how the office layout had changed and how that impinged upon their working practice. For example because the NPE department is a secure area, access to the office is difficult unless you have specific clearance. Therefore the days when the people used to just wander through enabling them to have impromptu discussions with people and ponder over problems no longer happen. Such encounters now have to be organised in advance and therefore the spontaneity of a colleague helping to find a solution has been lost.

Another issue raised by groups 1 and 2, was the 'old' verses the new practices in managing and monitoring projects. With two systems in place at the time of this study (one manual and one electronic), neither system really gave an accurate up-to-date record of the status of a project. One of the major issues for the project managers and team leaders was the development of a "key system" for NPE. A "key system" is a collection of methods, tools and information to allow the individual to carry out a process. For example, at the time of the interviews, the turbines department had developed a key system which was on the network. So that when an engineer in that department keyed in their role, a complete list of requirements, for example what tools, references etc, needed to complete their task would be issued. Rolls-Royce's aim was to have in place a key system for each area of the company, but for NPE the company's chosen approach was seen as too formal and inappropriate.

Another important factor highlighted by the experienced designers group was the lack of 'housekeeping' skills by some individuals regarding the use of the software available. It was an issue that had serious implications for others. This group was also concerned about how improvements in technology meant that more was expected of them when engaged in design. For example, where a component would have previously been sent to be stressed by a stressor in another department, current practice and new technologies provided this capability. Therefore the designers were expected to do this for their designs as well, thus involving more time to be spent on the designs. A comparison between the 'old' way of designing and nowadays the use of CADs was often discussed in the interviews.

> "CADs have no real advantage over the drawing board. It's slow especially starting something from scratch. It's too mechanical a process even to draw a line. A great barrier to creative design. They are drafting tools with perfect accuracy."
>
> P(2)20/bk1/pg102/ln36-40

The third group, new designers and trainees commented on the changes in working practices less. This could be because being relatively new, they had no other experiences to compare them with although some did realise how isolated they were from the rest of the company. The problems associated with the 'housekeeping' of computer files also affected them.

There is much more reference to the *design process* for groups 2 and 3 compared with the first group. These two groups provided individual descriptions of their approach to design at different stages and the artefacts they used in the process. Comparisons were made regarding the benefits of 'old' and new technologies in terms of the design process. One of the major concerns for the experienced designers was having to satisfice with their designs due to time and money constraints.

> "Now have to go with the first solution. No time to look at alternatives. In the 'old' days, every solution had to be investigated to get the best. Aerospace in the 'old' days was the height of creative thinking, but this was expensive. Nowadays the focus is on efficiency and reducing costs and time."
>
> P(2)20/bk1/pg103/ln69-75

As the project managers and team leaders had less involvement in design activities it is not surprising they had less to say on this topic.

The next highest peak relates to the category of *organisational processes*. From the interview transcripts project managers and team leaders appear to have a lot more to say about this area than the other two groups. For example they commented on having to cope with the politics of the organisation, something they would probably be closer to than the other two groups. Due to their position in the company they have to implement what is decided at higher levels within the company such as creating "Focal Points" within departments. "Focal Points" were engineers who had been chosen to be the resident 'expert' on a particular topic/piece of software or other technology who others could consult when necessary. Other concerns for this group were resourcing issues mainly of hardware and software for the department.

All three groups commented on the training available especially for new trainees and the problems and benefits that were encountered.

Groups 1 and 2 also made several references to the business cases that needed to be presented when asking for access to email or new software for example.

> "We need to do a business case to show how NPE would benefit from the new software."
>
> O(2)19/bk1/pg99/ln105-107

Not surprisingly, *project management* issues were most salient for the project managers and team leaders group. Their major concerns were ones relating to human resources. Due to the complex nature of the department, where new projects were frequently introduced, given a high profile and re-prioritised, it was a constant problem ensuring the continuity of team members through the life of a project. Often they had no option, as the directive came from senior management, but to pull designers off one project to enable them to complete another. This led to further concerns being raised regarding working under pressure and designers having to satisfice.

> "There are core team members, but people can be pulled off at anytime to work on other projects. Therefore there is a problem with continuity. It can't continue, we need stability."
> G(1)7/bk1/pg37/ln63-67

Another team leader supports the above statement:

> "I monitor what they [designers] are involved in. Designers have to satisfice. They are no longer able to perfect their design. They are constantly working under pressure to tight timescales. Reports go out before they really ready. I'm worried that all avenues are not adequately explored. What about things which haven't been thought through? I'm worried about this on the FOAS project."
> Q(1)21a/bk1/pg38/ln80-89

Communication (social) appeared to be more of a problem for groups 2 and 3. This is probably directly related to the way designers work, that is having to communicate to other fellow designers and other departments within Rolls-Royce. Indeed many of the comments included in this category were in relation to the problems they had encountered in trying to communicate with a colleague. For example where teams were distributed, communication was problematic because most of it was done through a variety of mediums. However, where face-to-face contact was made this was much preferred.

Another problem that was raised was in accessing other engineers, for example specialists to seek advice and/or input on a particular project. Rolls-Royce Aerospace had recently introduced a booking system whereby a code was assigned to a project and individuals involved in the project booked their time against it. The problem occurred when designers required help from colleagues who were no longer prepared or able to provide any answers unless they could book that time out. Many of those interviewed found this frustrating as in many instances all they required were short yes/no answers in order to progress, but administrative/organisational barriers were put in the way.

> "If I need to ask for specialist help, it has to be requested in a formal way, that is obtaining a booking code in advance. Can't get 'off the cuff' answers any more. All time needs to be accounted for. It makes concept designing harder. Maybe all that's needed is a matter of minutes for an answer, but now they provide too much detail."
>
> P(2)20/bk1/pg101/ln19-29

A similar issue related to this was that of access to other engineers and designers from their own specialism. Before projectisation they would have been working as one functional group, but now they were physically located somewhere else dispersed on other projects. Another concern was that there appeared to be some reluctance by other companies working on a project to share relevant information due to it being of a sensitive nature. This is understandable, but nevertheless frustrating for those wishing to make progress with projects.

These particular issues appeared to be less problematic for the new designers and trainees who reported having no problems seeking advice and help. However, in their situation they are more likely to ask for help from those within the department rather than outside. There could be two reasons for this. Firstly because they have not had time to build their own networks yet and therefore knew few specialists who they could contact. Secondly, the queries they have are much more specific as they are currently working with people on projects or project elements rather than being solely responsible for a set of outcomes.

References to *integration with other companies* is raised more by the experienced designers. This is due to them having more direct involvement and contact with other companies than the other two groups.

The interviewees who were project managers and team leaders commented more on the role and responsibilities of NPE which reflected their own management roles. This explains why that category *setting and context*, on the graph was higher for this group than the other two groups (2 & 3).

When comparing the columns of the histogram across all three groups for the category *Communication (technological)* the level of comments raised here appeared to be similar. This was probably because all interviewed had access to the same technology and therefore experienced the same problems. The types of problems encountered were lack of access to some communication mediums such as email, the limitations of some current technology such as video conferencing and the procedures necessary to go through to allow communication with others (the aforementioned booking system). Other areas, which were referred to in this category, discuss the different types of communication media used to report and present deliverables associated with different projects.

Role information is another category which provides more of the background detail and therefore does not provide any evidence of problems relating to the phenomenon.

Group 1, compared to the other two groups made more comments in the *experience of designers* category. Some comments referred to the 'mix' of people working in the department and their levels of experience. Many of their comments were in relation to the "demographic time bomb". This issue was important to this particular group because they were worried about loosing the expertise and skills from the department.

Comments were also made to highlight how this particular problem was being addressed.

> "We have a problem in that we are losing people with experience in 2D conventional drawings in the future."
>
> G(1)15a/bk1/p75/ln2-4

There appeared to be some anomalies in the data. For example, interestingly the category *milestones and deliverables* appears to be more of an issue for the third group than the other two groups. It might have been thought to be an issue for the project managers and team leaders reflecting the level of responsibility they have for overseeing and monitoring progress on the projects. However, for the third group it might be explained in terms of them having less of an understanding of the overall structure of the project and where their contribution fits in. Also they might have been less confident of their capabilities. Group 1 on the other hand might have become accustomed to working in this way and consider it less of an issue. However for the category *timescales of projects* slightly more concerns were raised by the project managers and team leaders because the time restrictions meant they could not always allow for as much innovation as they would like.

> "At this point we are having to say we have had enough innovation. Can this be achieved? What if new and innovative ideas come to mind at a later point? Can they be incorporated into the design?"
>
> G(1)7/bk1/pg35/ln24-28

> "Limited resources and funding means a restriction on what can be achieved."
>
> G(1)7/bk1/pg37/ln56-57

The first group raised slightly more comments in the category *workload and time pressure*. This was due to the constant juggling they had to do between project management, deadlines and administrative work they completed.

> "It's a balancing act between fulfilling one project against any new ones coming in. Changes in the political scene means a project is started and then stopped. It's hard to plan for workloads which are constantly going up and down."
>
> Q(1)26/bk1/pg122/ln32-35
>
> "We [team leaders] monitor where they [designers] are on a particular job. For example—finished or not? If not why not? This is not kept up-to-date as liked as there is no time."
>
> Q(1)21/bk1/pg117/ln47

The third group mentioned *creativity* the most. This could be due to them thinking that certain aspects of their work is creative whilst the more experienced designers saw it more of a routine exercise.

The *wants* category contained references to what the different interviewees would like to see improved or made available for them to use in their design activities. The project managers and team leaders tended to want more training and the "demographic time bomb" addressed adequately. The other two groups wanted improvements to the communication mediums for example, shared data environments and large intranets between companies.

The frequency plotting of the data has highlighted the relevance of particular categories and hence issues for the different groups interviewed. Whilst converting such data into a quantitative format could not be subjected to any statistical analysis, it has provided a visual representation of the salience of issues concerning perceived barriers to creativity for the groups. This representation could make a contribution to improving the design environment. For example, the company may not be aware of the impact of changes to working practices on all employees. As discussed this was a salient category for groups 1 and 2 and therefore their involvement in any decisions about changes to working practices may prove to be valuable for the company. Similarly aspects associated with communication appear to be important as well.

The relevance of a number of categories and their emerging relationships are discussed in the following section.

5.3.4 Important emerging relationships *(Core analysis/axial coding: chapter 2, figure 2.3)*

A number of categories have emerged as important to the objectives of the research according to the richness of the dialogue which they represent. These categories are also prominent in the plot of the frequencies as discussed in the previous section. During the analysis, the categories were separated into three groups to facilitate the process of integrating and refining the categories. Relationships and links between the categories, in terms of structure and process in relation to the phenomenon being studied, were developed. The structure sets the stage and refers to particular circumstances under which problems/issues or events relating to perceived barriers to creativity arise, whereas process refers to the actions/interactions of people, organisations and so on in response to the problems and issues. Thus the combination of the two (i.e. structure and process) helps to explain the complexity of the phenomenon which in this research is 'perceived barriers to creativity'.

In the first group listed below were the categories which were identified as those which represent issues and activities that the three groups interviewed engaged in:

- integration with other companies
- working practice (changes in)
- project management
- design process
- communication (social)
- creativity

The second group of categories which were drawn from the data during the analysis to date represent the barriers to creativity which are perceived by those interviewed:

- timescales of project
- milestones and deliverables
- communication (technological)

- experience of designers
- technology
- wants
- workload and time pressure

The final group of categories form what were referred to as environmental categories as they provided the context within and around which everything else happened.

- setting/context
- organisational processes
- role information

A number of examples drawn from the data highlighting perceived barriers to creativity were developed and analysed in terms of the 'paradigm' and models as described in detail in chapter 2, section 2.4.4.3.

An example of a barrier to creativity experienced under macro conditions is shown in figure 5.2 in terms of the 'paradigm'/model.

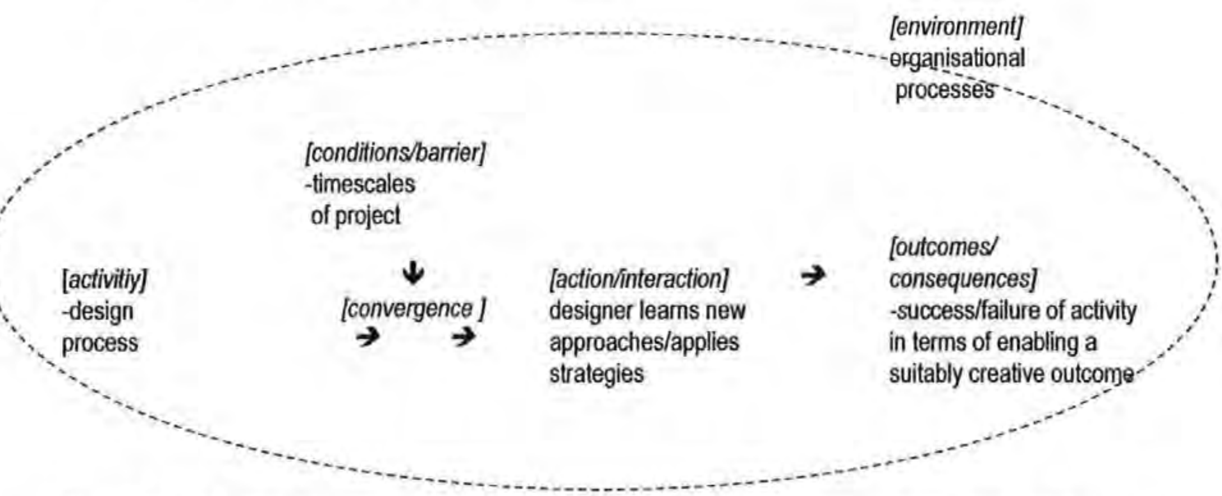

Figure 5.2: 'Paradigm'/model representing the occurrence of the phenomenon: perceived barriers to creativity under macro conditions in the working environment.

As explained in chapter 2, section 2.4.4.3 *intervening conditions/barriers* are the precursors which create the event or situation taking place. *Activity* is what the participants are involved in at the time the barrier occurs. *Actions/interactions* may be rules regulations, polices or procedures which may or may not be taken to resolve a problem. It may also include a strategy developed to overcome a problem. *Outcomes/consequences* are a result of the action/interactions and have inherent properties. These can be singular or many, be immediate or cumulative, reversible or not, foreseen or unforeseen, narrow or widespread (Strauss & Corbin, 1998).

Several more 'paradigms'/models are presented in section 5.4.2.3.

5.4 Validating the findings

As discussed in chapter 2, section 2.5, it is vital to validate the findings to ensure that a true account of the phenomenon under investigation is accurately reported. To achieve this, at a number of points in the study, managers, designers and new graduates and trainees were invited to confirm and validate the research findings. As participants in the research, they were able to judge whether the evidence fed back to them adequately substantiated the conclusions drawn at each stage of the ongoing analysis. Furthermore issues of reliability and validity are addressed by grounded theory through multiple sources of evidence. As described in chapter 2, section 2.5 Patton (1990) suggests there are four basic kinds of triangulation that contribute towards the verification and validation of qualitative analysis namely, "methods, sources, analysts and perspectives".

"Methods" was covered by the employment of different qualitative methods of enquiry which are reported in chapters 2, 4 and this chapter. "Sources" was covered by the interviewing of sixteen different people during the course of the DGI Study which was in addition to the four interviewed in the Scoping Study. Descriptions of where the findings between these studies are supported and validated by the literature reviewed in chapter 3, is discussed in chapters 6 and 9. The third kind of triangulation described by Patton (1990) is "analysts", which refers to the participants validating the findings. This was achieved through a number of presentations and a workshop which involved members of Rolls-Royce. The outcomes of the presentations and workshop are described in the following section 5.4. Finally the "perspectives" aspect of triangulation, was achieved by interviewing a range of employees from the company. They included, project managers and team leaders, experienced designers, new designers and trainees.

5.4.1 Presentation 1

The findings of the Scoping and DGI Studies were initially presented to the Whole Engine Process Improvement Manager, Rolls-Royce Aerospace on a visit to the University of Plymouth.

When studying the dominant peaks illustrated in figure 5.1, he felt the categories *technology* and *changes in working practices* reflected the impact of business process re-engineering that Rolls-Royce had been going through. The high frequency of statements relating to these categories reflected the emotions felt about the changes at the time. He also noted from the frequency graph that the category *integration with other companies* was higher in the designer group than the trainees and not so high in the project manager's group and confirmed the variability of these categories in terms of the groups.

The Whole Engine Process Improvement Manager felt that the data illustrated in the graph did reflect what was going on in NPE. He felt that had a similar exercise been undertaken elsewhere in the company, similar categories would be found, but that the frequencies of statements in relation to them would record a different shape. For example, a link between work load and time pressure was not evident in this graph particularly, as it was less of an issue in NPE. However, further down the Derwent process, he would expect to see more emphasis on these categories, as it would be more in the forefront of their minds.

5.4.2 Presentation 2

A second presentation of the findings from the DGI Study was made during a workshop to members from Rolls-Royce Aerospace (Bristol). Eight members of Rolls-Royce (Bristol) attended the workshop. These included the departmental manager of NPE and a selection of project managers, experienced designers and recent graduates/trainees. Also in attendance were two researchers one from British Aerospace, Sowerby Research Centre and the other from University of Sheffield. Two project supervisors from the University of Plymouth were also present.

The aim of the workshop was to:

- present the findings from the series of semi-structured interviews which were conducted with engineer designers in the current phase of the research project at Rolls-Royce Aerospace, Bristol
- validate the categories which were drawn from the data analysis
- generate a structural model by employing Brassard's (1989) Interrelationship Digraph activity (see section 5.4.2.2)
- encourage discussion regarding the issues presented

A brief overview of the data analysis process, grounded theory, and definition of the categories was presented before focusing on the graph containing the histogram of frequencies in relation to the categories generated from the DGI Study (see figure 5.1).

As stated in the previous section when this graph was presented to Whole Engine Process Improvement Manager, he had made a qualified remark referring to the frequencies of the issues as potentially being very different further down the Derwent process yet including all the categories. This was supported in the workshop by a comment from a new designer/trainee who stated, "There is a different working environment in NPE from the rest of the company."

At the workshop, a comment was also made about how the shape of the histogram was surprising. For example, the anomaly between the frequency of the category *milestones and deliverables of project* mentioned by all three groups. The histogram indicates that this appears to be more of an issue for the first group (new designers and trainees) than the other two groups. The interpretation offered was that this might be because they have less understanding of the overall structure of the project and where their contribution fits in. They may also have less confidence in their abilities compared to experienced designers. A new graduate/trainee provided a different perspective:

> "It is often the case that new graduates only stay on a project for six weeks or so. They feel that because they are going to be moved on there is a need to complete the job in time. More experienced designers are given 6 months or more on a team."
>
> *Quote from transcript from discussion of presentation at Rolls-Royce, 24/06/99*

As already discussed, *technology* had emerged in the histogram as being a huge issue for the experienced designers. This was supported by the departmental manager stating that, "Basically it all comes down to technologies and working practices." Not surprisingly, it was also noted by the manager that *organisational processes* were of most concern to the project managers and team leaders. He made the comment that, "Project managers are concerned about the process to get the output." This is perhaps due to the fact that they have to work within the boundaries of the organisation and are in the position of having to implement the polices and changes in procedure in their departments. However, the manager admitted that although there were numerous manuals outlining various company procedures he made the comment that, "Nothing is set in stone, there are no books to say how it's done." He also commented, "Project managers are trying to cross boundaries, but designers keep to their own domains."

The author reminded all present that the graph displayed only the frequency of the categories mentioned during the semi-structured interviews and therefore represented individual perceptions that needed further study to discover if this was what happened in practice. Comparisons across groups did provide some indication of the particular salience of the categories for the different groups at the time of the study. The author argued that the very nature of semi-structured interviews meant that it was fundamentally the interviewee who led the conversation, with the researcher ensuring the interview did not go too far off track. Therefore it was considered that the histogram was a valid representation of what was important to all those interviewed.

From the comments made in relation to the histogram, it would appear that the data are a valid representation and reflect what is important to these different groups within NPE.

5.4.2.1 Brainstorming exercise

This exercise (see appendix E) was undertaken to validate, embellish and extend the categories, as defined by the research, with the members of the group from Rolls-Royce.

The sixteen categories were written individually on "Post-it" notes and displayed on a whiteboard beside the phenomenon 'perceived barriers to creativity' being researched. The members from Rolls-Royce were split into two groups, quite arbitrarily, and invited to write down what they felt were barriers to creativity on their own "Post-it" notes. They were allowed to debate their ideas and reach some consensus regarding their statements whilst carrying out this exercise. Approximately 10-15 minutes was allowed for this exercise by the end of which it appeared all ideas had been exhausted.

Members were then invited to present their examples of 'perceived barriers to creativity' on a one-by-one basis to the author. By process of a general debate between the members from Rolls-Royce and the team from University of Plymouth, agreement was reached regarding whether each example was already represented by a category defined by the researcher, or that a new category had now been elicited. Presented in table 5.1, are the categories which were drawn from the data and the examples elicited from the Rolls-Royce members during the workshop in response to the set task. Clarification of the category definitions was required in some instances by the author for the workshop members.

As each of the examples was presented, debates surrounding some of these issues occurred. One question put forward was "Where is the innovation in the company?" It was argued by some of those present that innovation could be anywhere and not just in engineering. For example, it may be in the marketing department. Interestingly, it was suggested by an experienced designer, "Do we need to be creative when it has all been done before? You just need to know where to find the information you need." This designer went on to suggest that sometimes it is better not to be too different and to exploit what is already out there.

The comments put forward as to what the perceived barriers to creativity are suggest that finding out the relevant information, who knows what and who knows somebody who knows are the main concerns for the designers.

The manager argued that all people are creative to some extent. For example, he argued that with respect to creativity against costs, "You can still be creative without increasing costs. Everything is dependent on costs." What the manager meant by that comment was that being too creative may not be cost-effective. This would link with what one of the experienced designers argued, "We work to tight timescales now and do not have enough time to look at numerous alternatives."

Categories which were drawn from the data analysis	Examples elicited during the workshop from Rolls-Royce employees
Timescales of project	Timescales—benefit as they focus the mind as not enough time to analyse
Workload and time pressure	Not enough time to think or talk
Experience of designers	Experience of designers-getting the right team Need balanced teams Loss of experience, where is the knowledge
Design process	Design by analysis rather than design by thought
Role information	Knowledge pool
Integrating with other companies	Freedom of intellectual property rights Freedom of data interchange
Project management	Aptitude Horses for courses—not everyone can be innovative. Use the innovators to do the innovating
Communication (social and technology)	Who knows, who knows? Where to find the knowledge is important Who knows information Difficulty accessing existing historical data (still!!)
Creativity	Personal rewards—motivation Innovation elsewhere Creativity-a gift Not being that different It's all been done before, but where?
Technology	Too over prescriptive IT systems Technology tools—help or hindrance What sort of technology to be used?
Setting/context	Working environment—physical, mental and social/interactive Distractions stop you being creative

Table 5.1: Comparing the categories generated from the research data analyses and the Rolls-Royce Workshop. (examples are as written by the Rolls-Royce participants in the workshop).

Working to tight timescales can be looked upon as a benefit though, as it focused the mind. However, the manager also maintained that creativity could be found where a designer is restricted by a number of parameters and had to be creative within that context. Such varying interpretations of the meaning of creativity expressed in the workshop reflect the difficulty generally about stating a true definition of creativity. As discussed in chapter 1, section 1.3.1, definitions of what creativity is vary widely according to the domains of the definers and the domains of the creative. The term as is used here reflects the perceptions of the designers as to when they think they are being creative and when that process is being obstructed and/or compromised. Therefore two people may have different interpretations based on how they perceive creativity to be, but the nature of it becomes clear from the context. Hence creativity is likely to include for example, the pursuit of ingenious cost-effective solutions. It may also include working within certain boundaries and constraints for example, customer requirements, technological (both technology and the laws of physics), materials and time. This interpretation of creativity fits with that suggested by Hori (1997) who argues that many aspects of even routine design involve being creative.

It would appear that the outcome of this exercise was successful in validating the categories that were drawn from the data collected at Rolls-Royce Aerospace (Bristol). Examples of perceived barriers to creativity presented by the Rolls-Royce members were debated and agreement was reached on the acceptability of the already existing categories which had been developed by the author. Finally, the three groupings in which the categories had been placed by the researcher were presented.

Having reached this juncture, a second exercise (see appendix F) was undertaken using the agreed categories as a basis to work with.

5.4.2.2 Interrelationship Digraph (ID)

The Interrelationship Digraph (ID) management tool (Brassard, 1989) (see chapter 2, section 2.4.4.4) was used by the workshop members to provide a multidirectional approach to mapping out the logical and sequential links between interrelated items in relation to the phenomenon 'perceived barriers to creativity'. The purpose of the ID was to establish where most of arrows were emanating from or converging to. According to Brassard

(1989) outgoing arrows indicate a basic 'cause' which, if resolved, could have a "spill-over effect" on a large number of other issues and categories. Incoming arrows however may represent a secondary issue or bottleneck which may also need addressing.

The categories, written on "Post-its", were placed in their groupings (as presented by the researcher) and mapped onto a large piece of paper. The paper was placed in the middle of the table which permitted all the Rolls-Royce Aerospace (Bristol) members to gather round and participate. The participants were then introduced to the exercise and given some instructions (see appendix F). Those involved in the workshop were encouraged to begin drawing single headed arrows from either a category, which was grouped as an issue or activity, to a category which represented a barrier to creativity (see figure 5.3). The basis on which the arrows were drawn, was from their identification of which barriers most influenced the issue they had chosen. They then had to draw an arrow to connect the two categories. They were also asked to draw out which of the environmental influences affected each of the barriers and issues. Two-way arrows were avoided so as to encourage a decision to be made about the major influence. However, if a reciprocal arrow was needed between two categories then this was acceptable as it demonstrated an iterative loop (Brassard, 1989). Where one arrow crossed another, a 'bridge' was drawn (i.e. the arrow was drawn with a bulge in the middle when it met another arrow). They used coloured pens to draw the arrows to differentiate between weak and strong links.

An ID requires some discussion about the placement and relationship of the arrows, but as the first version of the ID is normally reviewed and revised, it is not so important to get everything right first time. Hence throughout this exercise, the Rolls-Royce members continually debated about how to link the categories using the arrows by referring to specific examples of situations where they perceived they had encountered barriers to creativity. A few of the examples mentioned were captured. For example, they stated the level of creativity in the 'activity' *project management* category was influenced by the *timescales of project* category because of the constraints of deadlines to meet. Therefore an arrow was drawn from the *project management* category to the *timescales of project* category. The designer, it was argued, has to be creative to keep within those constraints. Another example was captured for the linking of *milestones and deliverables* with *workload and time pressure*. As can be seen from the figure 5.3 reciprocal arrows between the two categories were drawn. This highlighted the interplay between them where set targets and goals to be achieved on the project were perceived as barriers to creativity due to an increase in activity and urgency relating to the category *workload and time pressure*. The issue of creativity kept coming to the fore and as mentioned before some working assumptions had to be stated. Arrows between categories continued to be drawn until the Rolls-Royce members had exhausted their examples and the corresponding links.

Returning to the purpose of generating an ID, the research does not assume that perceived barriers to creativity can be explained by a simple cause and effect represented in this exercise as a linking of two or more categories. However, some observations about the outcome of the exercise can be made. Strong links (as indicated by a ━) between the categories were identified by the participants and are highlighted in table 5.2. That is arrows were drawn by the participants which emanated from the categories in the left-hand column which through debate and discussion were then linked to a number of the remaining categories (right-hand column). Another representation of the results of this exercise is depicted in figure 5.3.

As mentioned previously according to Brassard, where most arrows emanate from indicates a 'root cause' suggesting it to have the greatest influence on the problem which in presented. Using this criteria, in this particular ID communication (social) was thus perceived to be a 'root cause' to perceived barriers to creativity. As shown in the table it linked to all other categories and in figure 5.3 the greatest number of arrows can clearly been seen emanating from it. This outcome did not surprise the participants at the workshop as they felt it reflected the reality they experienced in that communication was the most important factor in their day to day activities. Without access to information, resources, data and clear and open communication channels, then their work and creative activities were hindered and impeded.

Categories drawn from the data	Categories linked to
▪ **Issues/activities**	
Communication (social)	— ALL OTHER CATGORIES
Design process	— Creativity
Creativity	— Technology
Integrating with other companies	
Project management	— Timescales of project — Workload and time pressure — Milestones and deliverables
Working practices	— Design process
Technology	— Creativity
▪ **Barriers**	
Timescales of project	
Workload and time pressure	— Milestones and deliverables
Experience of designers	— Workload and time pressure — Working practices
Communication (technological)	— Integrating with other companies
Milestones and deliverables	— Workload and time pressure
▪ **Environmental**	
Role information	— Experience of designers — Technology
Setting/context	— Project management
Organisational processes	— Creativity — Technology — Project management
Wants	

Table 5.2: Relationships between categories generated from the research data analyses and the Rolls-Royce Workshop.

A convergence was also identified (see figure 5.3) whereby *technology* had most arrows converging onto it thus highlighting this issue as a secondary problem or a 'bottleneck' according to Brassard (1989). From the examples provided by the members, the constraints imposed by the limitations of the current technology, the inadequacy of the software in supporting creative design and the apparent lack of the organisation to recognise the relevance of issues the designers had with using the technology demonstrated why such a convergence had emerged from this exercise.

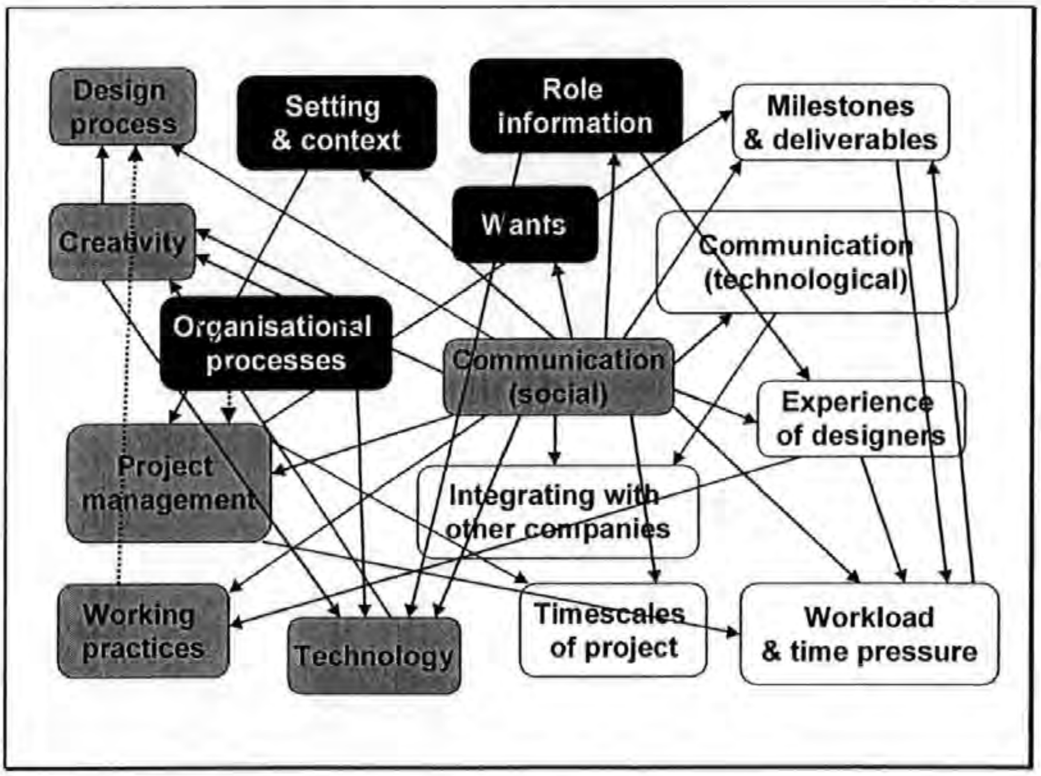

Figure 5.3: Representation of the Interrelationship Digraph created at the workshop. The grey areas represent the 'activities' grouping, the white areas the 'barriers' and the black the 'environmental' grouping.

The success of the generation of the ID and its interpretation was limited. For example, as a consequence of the discussions and debates between the participants, it became evident that using the categories in this exercise was not as helpful as first anticipated. Indeed, the participants found it was necessary to move three of the categories into other groups (see section 5.4.2.1). That is, *technology* from the 'barriers' group was swapped with *integrating with other companies* to the 'issues' and 'activities' group and vice versa. *Wants* was moved from the 'barriers' group to the 'environmental' group of categories. Although the researcher had assumed grouping the categories into higher order groups would facilitate the generation of the ID, it did not add any value to carrying out the exercise and indeed the participants ignored the groupings.

Another problem that occurred during the exercise was that the participants wanted to link some categories to everything as they generated numerous examples from their activities. This resulted in an explosion of connectivity reflecting the complexity of their environment and how they operated within it. What therefore become apparent during this exercise is that the categories were at too high a level and it may have been more beneficial to have used problem statements instead of categories. This would have meant having more statements on "Post-its" linking to others, but it could have provided a more finite detail of where and when problems occurred. In fact Interrelationship Digraphs usually utilise concrete examples which are generated by the participants to produce the mapping of the problem presented. There was not enough time to carry that activity out fully during the workshop and therefore it had been decided in advance that working with the defined categories would suffice. On reflection, this decision had been of little benefit and was found to be a constraining factor resulting in limited interpretations of the outcome of the exercise.

Whilst the exercise had not facilitated a clear understanding of how these categories related to each other due to the highly complex situations the participants encountered, it had allowed different perspectives to reach a common understanding of the issues involved in relation to perceived barriers to creativity through the process of negotiation. This is a process fundamental to social constructivism and the development of shared meaning and provides a good example if the ontological perspective of this thesis.

5.4.2.3 Discussion of 'paradigm'/models

In the second part of the presentation, a number of 'paradigm'/models were presented to the participants of the workshop to generate some discussion and ultimately validate them. The results of the ID exercise went some way in achieving this although it was agreed much of the discussion in generating the ID had identified the phenomena occurring under macro conditions. Using the categories to develop an ID was not very illuminating in providing examples of perceived barriers to creativity under micro conditions. However, by presenting excerpts from the data and applying them to the 'paradigm'/model a rich discussion relating to the issues took place. The models illustrate the interrelationship between factors and outcomes and do not necessarily indicate causes and effects in relation to each of the problems presented in this section of the report.

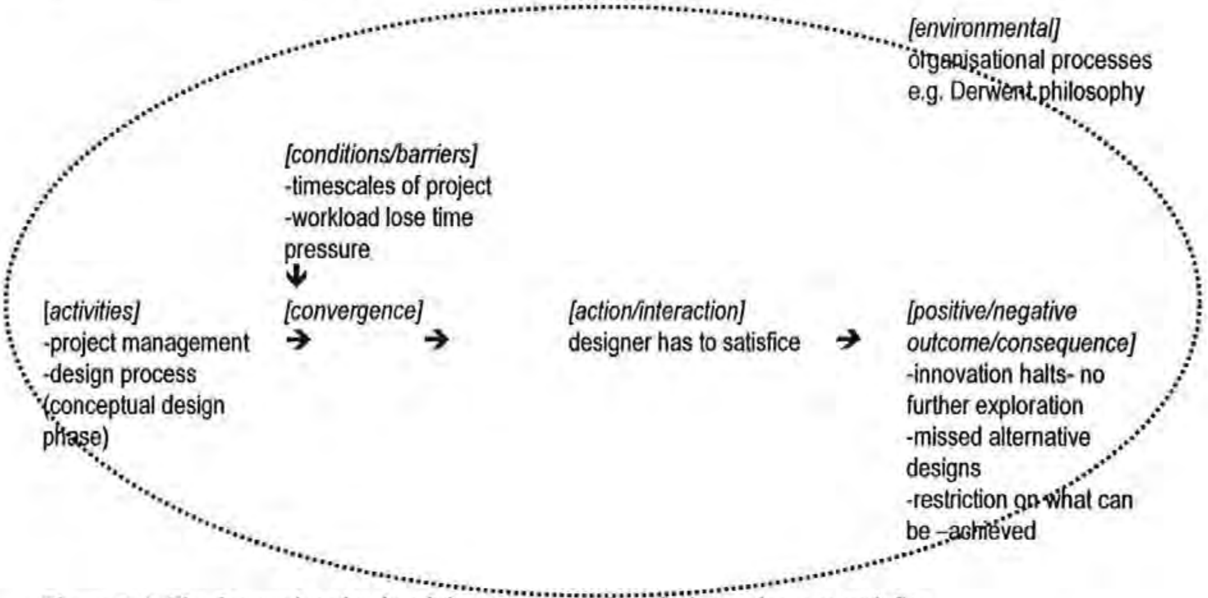

Figure 5.4: The factors involved and the outcomes when designers have to satisfice.

Figure 5.4 indicates how designers involved in the conceptual design process, where they are exploring new designs, have to satisfice because of the timescales imposed on them. This is also at odds with the Derwent philosophy where 70% of resources are input at this stage with relatively few changes further down the line.

The model represents the data taken from the transcript representing two of the groups. For example,

> "Designers have to satisfice. They are no longer able to perfect their design. They are constantly working under pressure to tight timescales. Reports go out before they really ready. I'm worried that all avenues are not adequately explored. What about things which haven't been thought through? I'm worried about this on the FOAS project."
>
> Q(1)21a/bk1/pg38/ln81-89

> "Now we have to go with the first solution. There is no time to look at alternatives. In the old days, every solution had to be investigated to get the 'best'. The Aerospace industry in the old days was the height of creative thinking but expensive. Nowadays the focus is on efficiency and reducing costs and time."
>
> P(2)20/bk1/pg103/ln 69-71

A definition of having to satisfice, "a designer having to make an early sub-optimal compromise" was provided as some of the participants had not encountered this term before. The manager argued that, "There is no pure design solution. It is not just a case of time or money. It has to be technically acceptable." Due to the language and semantics, there appeared to be some disagreement between members of the workshop as to what was meant by optimisation. It was argued by the manager that optimisation was based on profit, meaning that if it can be done more cheaply, then it should be done that way. It was also dependent on what the customer requirements were. If they are happy, then the design is acceptable.

What was also suggested was that perhaps the designer is unfulfilled and feels he could do better if he was not working to such tight timescales. It was asked whether, "The issue of the designer's motivation had been fully articulated." The response from a Rolls-Royce designer was that, "Designers feel they are here to make money, the project always wins in the end."

It was asked whether an engineer could argue for the timescales to be extended. It would appear that this was possible if alternative rational judgement had been demonstrated. Also if there was a risk factor involved, then an extension can be negotiated at the Exit Review Gate Stage 1 (see chapter 1, section 1.7.1). There were no problems with changes being made, but this had to be managed with the outcome of a satisfactory solution. This sort of decision appeared to depend on the particular project, department or even site. For example, at Derby the timescales are shorter due to the nature of the business undertaken there. It was suggested that in some cases where money is no object, it did not matter so much when the job got finished. However, in NPE there were limited resources and limited time. FOAS is somewhat different though, as it was said that it is removed from mainstream profits and had alternative priorities. Therefore there is time to be iterative in the design process to develop and enhance the project designs.

A consensus was reached whereby it was agreed all design teams work creatively especially with FOAS where it is all about being creative. However it is creativity in terms of meeting the business need in respect of budget, limitations, profit, timescales and customer specification.

It would appear from the evidence provided by the discussion that this model was validated by the members of Rolls-Royce who were present at the workshop.

The next figure presented (figure 5.5) focused on the problems encountered with technology and working practices.

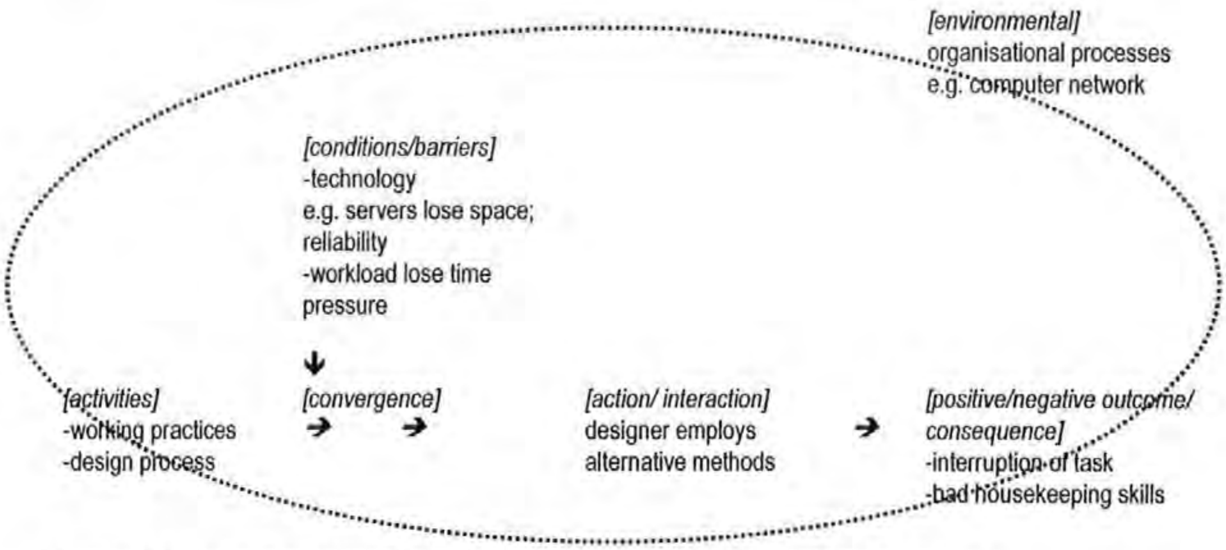

Figure 5.5: The factors involved which result in strategies to circumvent the problems.

In this example, the model illustrates the perceived barriers relating to the category of *technology* that are encountered when designers undertake certain *working practices* and are involved in the *design process*. The designers then have to employ different methods of saving their work. This ultimately results in bad housekeeping skills in respect of working practices and an interruption of the thought processes involved in design. An extract from the actual data where this happens is below.

> "There are problems with space on [computer] drives. The user working drive is Y, and you put a copy on Q. Therefore we are using more space and therefore problems occur with reliability. With the old system AMOS, if you exceeded the filespace it would not let the user log out until they did some 'housework'. It would be good to go back to this system. At the moment it's a case of first come first served."
>
> N(2)18/bk1/pg79/ln117-122

> "There is lots of space on PCs across GSL (Secure LAN), but no space on PCs across the Aerospace company. There is no space on the UNIX (GSL network) but lots of space on the UNIX Aerospace network. ProE [Pro/ENGINEER™] and CFD are on the UNIX (GSL). The problem with hard drives on computers is that they are not backed up, so nothing is saved there.... There is a reluctance to delete or archive things because people pinch the space you have just made."
>
> H(3)27/bk1/pg157/ln149-153;160-161

It was stated, interestingly, that although the research had identified that problems with servers, space and reliability of the computers and the network, these problems had not been mentioned by project managers and team leaders. This was accepted by the manager, but seen as something he personally was unable to do anything about. The manager recognised this as a continual problem which the designers "whinged" on about. He saw it more as poor skills on the part of the designers due to their, "...lack of internal discipline." The manager's perspective was slightly different to the others present in that he saw space was being allocated, but not used adequately and efficiently by individuals.

It was highlighted by another member of Rolls-Royce that part of the problem was due to the variation in ability of the individuals to use the technology. This could suggest that employees are not provided with the necessary skills to use the systems properly. The designers commented that everyone had a small amount of space to use and as a result people pinched other areas of space from wherever they could for example on different drives. Another problem which was highlighted, was that people were loath to throw anything away in case they needed it at a later date. Therefore it was stated, "The old problem of paper storage has now transferred to computers."

It is a problem and one that will get worse unless it is adequately addressed. This could be done by training and providing a better structured network support system where technological issues and working practices are dovetailed. Therefore the seeking out of possible solutions should be carried out 'bottom up' where the needs of designers are listened to otherwise what is put in place may be seen as another barrier. One possible solution may be to archive some data by saving it to DAT tapes and/or CD ROMS.

The third macro example of perceived barriers to creativity is shown in figure 5.6. This focused on the problems encountered in categories *communication* both on a *technological* and *social* level.

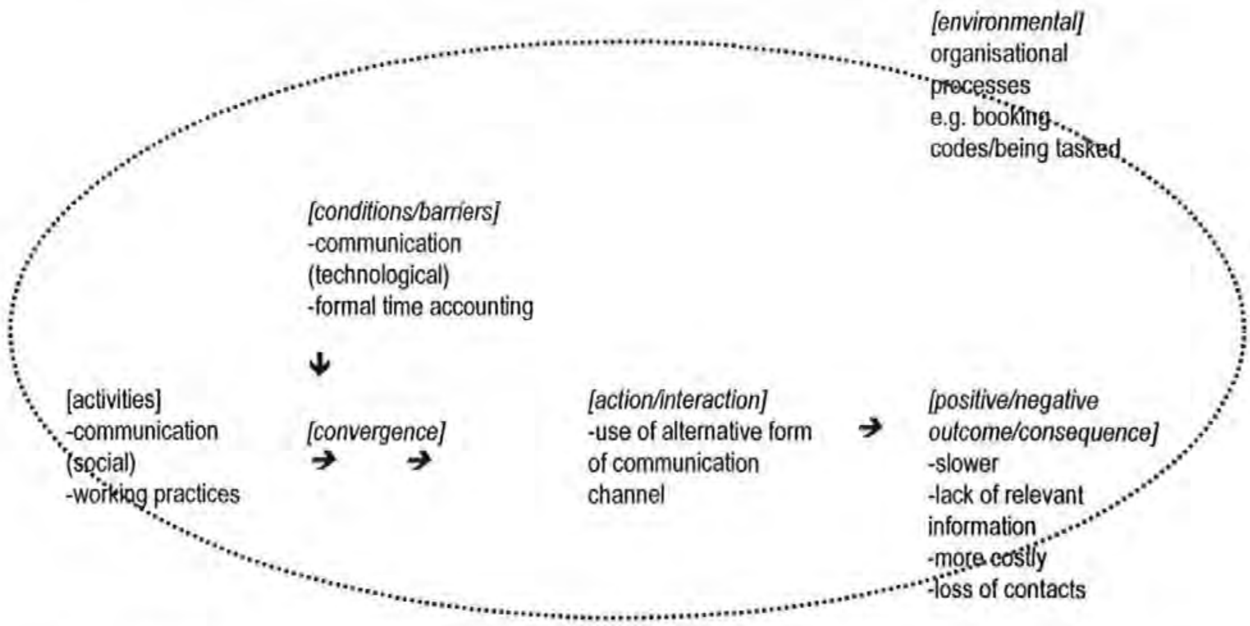

Figure 5.6: The factors involved and the outcomes when designers have communication problems.

In this model, an illustration of poor communications is presented. For example, during their *working practices*, designers may need to communicate with another designer, or company, or department. It appears the communication channel can inhibit that process due to *organisational processes* in place such as having to 'task' or 'book' someone to a project. A possible action of the designers is then to find an alternative route, which may be using a personal network, that has been established resulting in a positive outcome. On the other hand though, if such a network is not available to them, they have no alternative, but to continue through the correct channel. This may ultimately result in a more protracted and delayed answer to the initial request.

> "Communication with other departments is not so easy as it used to be. You need to be tasked, raise a task and obtain a booking code. Therefore this impinges on the flexibility of informal ways of communicating as we did before."
>
> Q(1)26/bk1/p144/ln51-54

The issue of having to task people for information was seen as a real problem which is going to get worse as Rolls-Royce Aerospace implement their new systems. Participants at the workshop who included managers and experienced designers, new designers and trainees were all in agreement about this. For example, a new designer and trainee stated, "It's difficult to make contact with others and just call and see them." The manager supported this statement by saying, "People will not speak to others if they are not scheduled on their task sheet."

It was apparent from the data collected in the DGI Study that what designers in NPE required were quick 'yes/no' answers to their problems. This again was supported by the manager of NPE who stated during the workshop, "Task booking and time management means you lose the quick 'yes/no' answers."

> "If I need to ask for specialist help, it has to be requested in a formal way, that is obtaining a booking code in advance. Can't get 'off the cuff' answers any more. All time needs to be accounted for. It makes concept designing harder. Maybe all that's needed is a matter of minutes for an answer, but now they provide too much detail."
>
> P(2)20/bk1/pg101/ln19-29

During the activities involved in the workshops it had been mentioned several times that communication impacted on everything and underpinned a lot of their design activities. Yet here was an example of Rolls-Royce controlling communication by setting out clear procedures for that very activity.

The rationale behind the need to task people is that Rolls-Royce Aerospace want to ultimately employ a system whereby all jobs have a prescribed list of what that job entails. That is a "key system" whereby the information, tools, methods, processes and so on which are required to complete the job are known in advance. The argument from members of NPE is that this is too prescriptive and does not allow for flexibility. Designers may not know in advance who they need to talk to, for example a stress engineer, but unless talking to a stress engineer is included at the beginning, that time will not be available. This was seen as the, "...worst thing in the creative field." As new systems which task time so rigidly are introduced, it means a restricted use of communication and as one project manager put it, "The ability to talk is lost."

Whilst the current system in place is fairly flexible there are still problems which are noted in the transcripts from the semi-structured interviews. The manager of NPE stated that what was required was, "...a balance between control of the organisation and the ability to be flexible." Another member from Rolls-Royce saw it as a, "...balancing act between cost control and time management." The management of Rolls-Royce are aware that this poses problems, but as yet have no answers.

It would appear from the discussion surrounding this model that there were some very pertinent issues relating to communication that all members of Rolls-Royce Aerospace (Bristol) saw as being important. Evidence in the data suggested that some designers encounter problems already. From the discussions held in the workshop, it would seem that these are likely to continue and, unless incorporated into the budget, will increase in their severity.

As already discussed in section 5.3.1.10 many of those interviewed expressed a concern about the "demographic time bomb". Figure 5.7 provides an illustration of this particular problem in the context of perceived barriers to creativity.

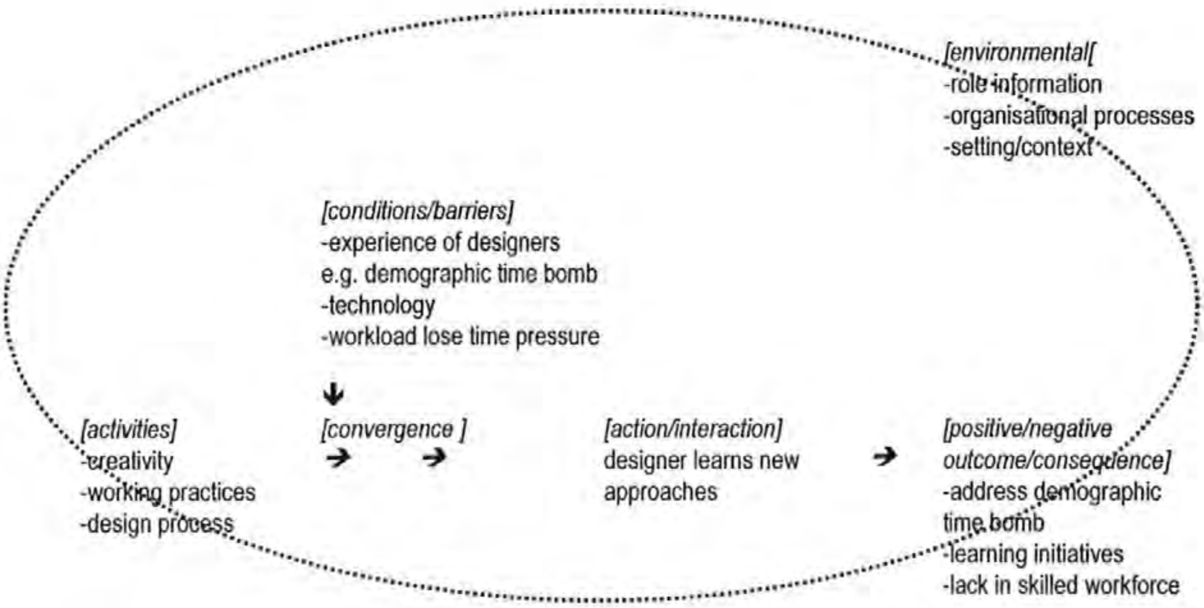

Figure 5.7: The factors involved and the outcomes in relation to the problem of the "demographic time bomb".

This model illustrates how certain perceived barriers relating to the categories of *technology, workload and time pressure* and issues regarding the demographic time bomb impinge on the designers ability to work creatively. This also impacts on the *working practices* and *design process* of the designer. The company has attempted to address the issue of the demographic time bomb by incorporating new learning initiatives in the forms of, for example, learning packs and focal points within the department. However, for the designers who have to partake in these initiatives then *workload and time pressures* increase.

> "The problem is workload and finding time to train others. We are working under pressure. Ideally training [on GENESIS] should be part of initial training. [We could train to] three levels: novice—initial recognition of using it; intermediate user—able to produce answers, but needs to check with expert; and expert user who would be able to do whole job."
>
> N(2)18/bk/pg78/ln85-94

> "Demographic time bomb—things being done to address it. Try to 'grow' new skills. Try to get them [designers] to produce learning packages. Not as successful as had hoped—people don't have the time."
>
> Q(1)21/bk1/pg118/ln 65-71

According to the members of Rolls-Royce Aerospace (Bristol) present at the workshop, the skills base is a problem across the company. As people leave, so their expertise and knowledge goes with them. However, more often than not, they return as sub-contractors who can then be hired and fired as required. One statement from a Rolls-Royce member was, "It's the norm for people to retire and then return six months later as sub-contractors."

It was mentioned that motor companies recruit Rolls-Royce employees because they know they have been trained well. The view from those interviewed was that Rolls-Royce offer no incentives for people to stay although they are trying to redress this by offering awards for technical expertise. As one young company member put it, "People have moved to other companies. People are moving into jobs with more responsibility and more independence."

Rolls-Royce apparently is trying to, "...reflect a professional career structure to match individual needs." It was thought by some of the researchers present at the workshop that perhaps employees should be in charge of their own careers. There may also be an element of demoralisation because Rolls-Royce are running peoples' careers.

5.4.3 Summary of outcomes from the workshop

The workshop was perceived as interesting and worthwhile by the members of Rolls-Royce Aerospace (Bristol) who were present. It provided an opportunity for them to reflect jointly on issues affecting the way they work and to articulate commonly held beliefs and experiences. Each of the 'paradigm'/models which had been presented had provoked a discussion around those issues and problems providing valuable additional insights. However it must be remembered that simple cause and effect cannot explain the complexity of the situation which the models may suggest. A number of interactions made up the contextual situation in which the phenomenon occurred and the DGI Study produced data which provided a snapshot in time which could not therefore identify and explain all the influencing factors.

The workshop was also deemed a success by the researchers present by validating the categories and models presented. In particular it provided the opportunity for issues which had emerged from individual interviews to be aired, developed, confirmed or qualified and extended by a group of Rolls-Royce Aerospace (Bristol) staff. Whilst it had generated a lot of discussion about a number of issues related to the categories it became apparent that specific instances would need to be identified to gain a more thorough understanding as to what was really going on.

5.4.4 Presentation 3

A third presentation of the findings from the DGI Study were held during a Design Technology Working Group Meeting held at Rolls-Royce, Derby. Several members of staff from the Derby site attended the workshop. Two project supervisors from the University of Plymouth were also present.

The aim of the workshop was to:

- present the findings from the series of semi-structured interviews which were conducted with engineer designers in Phase 1 of the research project at Rolls-Royce Aerospace (Bristol)
- present the findings from the Interrelationship Digraph generated by participants at the workshop held at Rolls-Royce Aerospace (Bristol)
- encourage discussion regarding any commonalities and/or differences in the issues presented in the histogram between the two cites of Derby and Bristol

A brief overview of the data analysis process, grounded theory, and definition of the categories was presented. The graph containing the histogram of frequencies in relation to the categories generated from the DGI Study (see figure 5.1) and the Interrelationship Digraph (see figure 5.3) were also presented and discussed.

Questions were asked regarding the plot of frequency data as to whether designers talked more than project managers or team leaders. As stated in section 5.4.2 the histogram represents the number of times issues relating to the coded categories were mentioned by the three groups interviewed across all the interviews that were conducted. Slightly more interview time was spent with project managers and team leaders than the other two groups. Therefore in response to their enquiry it was the case that the designers had raised a greater volume of issues in relation to some of the categories than the other groups.

The Derby participants thought that the project managers and team leaders tend to look 'outwards' and are more concerned with *organisational processes* and that is why more comments in relation to that category were made by that group. They were surprised about how low *time pressures and workload* was with few references noted in the histogram. However, it was determined that time pressures placed upon engineers working at the Derby site are greater than those experienced on the Bristol site. This is due to the different timescales that the two sites are working to. Derby works to a 36 month engine design cycle whereas the FOAS project in Bristol is looking at engine designs destined for service in 2017. Derby also commented they would have had a lot more to say about *milestones and deliverables* of the project than their Bristol counterparts.

The Derby group also made reference to some commonalities they would expect had the interviews taken place on their site. That is they would expect to see a similar plot with reference to the *organisational processes* and *working practices* categories. In relation to the ID the Derby group could understand and agree with the outcome, but highlighted the main difference as being the time pressure and this would have been reflected in their ID should they have generated one.

Their observations were similar to those made by the Whole Engine Process Improvement Manager (see section 5.4.1). He had commented that the categories would remain the same if engineers at the other site were interviewed, but that the shape of the histogram would be different reflecting the different stages along the Derwent process in which they operated.

5.5 Summary of the chapter

The data from the semi-structured interviews conducted in the DGI Study provided a fundamental understanding of the structure and infrastructure of NPE and the conceptual design process being undertaken by designers. It also produced accounts of experiences of creative activity as perceived by project managers and team leaders, experienced designers and new graduates and trainees. Detailed grounded theory analysis of the fieldnotes led to the development of sixteen categories relating to issues which generated perceived barriers to creativity. These were:

- setting and context
- organisational processes
- timescales of project
- milestones and deliverables
- integration with other companies
- working practices (changes in)
- project management
- communication (technological)
- role information
- experience of designers
- design process
- communication (social)
- technology
- wants
- creativity
- workload and time pressure

The frequency of the issues relating to the categories was plotted in a histogram providing a visual representation of the major concerns of these three groups and allowed for some tentative comparisons to be made between the different perspectives. Further analysis led to the emergence of relationships between the categories and the development of 'paradigms' and models to represent the interplay of those categories in demonstrating the phenomenon, 'perceived barriers to creativity'. In other words this began to indicate the what, how, when, and why of the phenomena that had occurred.

As a means of validating the findings to date, three presentations and one workshop all involving employees of Rolls-Royce, were arranged to present and discuss the findings. The workshop included a brainstorming exercise which confirmed and validated the categories and their definitions and the development of an Interrelationship Digraph which highlighted how the category of communication influenced many other categories. However, all examples of the phenomena were under macro conditions (broad in scope) and further research is required to consider actual instances of perceived barriers to creativity under micro conditions (narrow in scope) to facilitate a better understanding of the phenomenon. This therefore led into the next phase of the research; the Tracking and Shadowing Studies documented in chapters 7 and 8 respectively.

The final stage in Phase 1 was to interpret the findings from the Scoping and DGI Studies in terms of the literature which was critically reviewed in chapter 3. This is discussed in detail in the next chapter.

Chapter 6: Review of Phase 1

6.1 Introduction to the chapter

This chapter reviews the outcomes from the first phase of the research namely the Scoping Study and Design Group Interviews (DGI) Study. The findings from both the studies are interpreted highlighting any commonalities or differences. Observations from the data are reviewed in terms of the literature documented in chapter 3 and augmented in this chapter under the six themes identified in the Scoping Study. Evidence of 'perceived barriers to creativity' are identified and discussed. The final section of this chapter outlines the next phase of the research.

6.2 Summary of findings from the Scoping Study

Chapter 4 reported in detail the Scoping Study that was undertaken in Phase 1 of this research. The outcomes from this study gave a broad overview of the working environment in which conceptual design was taking place at this particular site and a discovery of how individual designers engage in creative design. This was achieved through a number of exploratory semi-structured interviews. Analysis of the transcripts produced six major themes namely:

- knowledge sharing
- social mechanisms
- management structures and organisational constraints
- individual/personal resources and design process
- technical issues
- unfulfilled support needs

6.3 Summary of findings from the Design Group Interviews Study

Chapter 5 reported in detail the DGI Study that was undertaken in Phase 1 of this research. The outcomes of the DGI Study were a description of the structure and infrastructure of the conceptual design process within New Projects Engineering (NPE), as well as evidence of perceived barriers to creativity and how they were overcome or eliminated based on a spectrum of experiences and perspectives. This was achieved through semi-structured interviews with three different groups of people, that is six Project managers and team leaders, six experienced designers and five new designers and trainees.

Fieldnotes taken from the 30 semi-structured interviews and a number of observations during meetings which took place were analysed using grounded theory and facilitated the development of the sixteen categories namely:

- setting and context
- organisational processes
- timescales of project
- milestones and deliverables
- integration with other companies
- working practices (changes in)
- project management
- communication (technological)
- role information
- experience of designers
- design process
- communication (social)
- technology
- wants
- creativity
- workload and time pressure

These categories were subsequently validated and models were generated to illustrate the relationships between the categories that represented the phenomenon (see section 5.4).

6.4 Interpreting the findings from the studies in terms of the literature

When analysing the data from both studies there were many common issues articulated by the different people interviewed. These are discussed and referenced to the appropriate literatures throughout the rest of this chapter. Where appropriate, the themes and categories which 'share' common evidence are grouped together in some of the sections. The reason why the names of the themes and categories differ is due to the different approaches in the analysis. The themes generated from the analysis of the Scoping Study provided a basis for the DGI Study, but this study was subjected to a much more detailed analysis and some categories became subdivided whilst several others were created.

6.4.1 Knowledge sharing covering: communication (social)

In the Scoping Study the theme named knowledge sharing is closely related to the category of communication (social) from the DGI Study. Examining the data from the transcripts and field notes has identified a lot of evidence which represent common issues.

Many of the issues raised, which have been categorised under these headings, relate to literature on transactive memory. Wegner (1987) proposed transactive memory as a system which allows individuals and groups to access a wider knowledge base than is available to an individual. For example, if an individual knows that someone else may have the answer to a particular query or problem, it allows that individual to gain access to a wider memory resource. Further knowledge/memory sources known to that individual can then be subsequently accessed and developed resulting in a memory system being "more than the sum of its individual component systems" (Wegner, 1987). Transactive memory systems are constructed when individuals acquire knowledge about other individuals' domain expertise. As it develops, it becomes more complex "involving the operation of the memory systems of the individuals and the processes of communication that occur within the group" (Wegner, 1987). Hence it cannot be located within any individual nor elsewhere, although it becomes an inherent part of the group.

It would appear that an effective transactive memory system exists at Rolls-Royce Aerospace (Bristol). Evidence of this became apparent when designers referred to asking someone who they knew the answer to a technical or organisational question and/or to draw upon experts from different specialisms.

> "I had to modify an engine to fit an air frame so I decided to fit a yoke device. I knew [a colleague] had worked on this before so I looked up the archive and had a chat with him to see what could be done."
>
> B(2)8/bk1/pg40/ln2-9

There were many references made in both studies to the senior engineers of Rolls-Royce who had a wealth of knowledge that was used but could be used more effectively by sharing that knowledge with others. Where this system appeared to fail though was when new design engineers joined the company and were ignorant to this additional knowledge and memory source. This problem was acknowledged by the workforce with references made to knowledge in the "designer's head being somehow downloaded" and hence accessible to all. There was an associated issue regarding the loss of such expertise due to retirement. This is discussed further in section 6.4.4.

A number of the designers expressed a desire for senior members to become more involved with designs at an earlier stage rather then "passing judgement" on them at the Exit Review Gates.

> "[The Exit Review Gates] are controlled by very senior people and you have to stand up in front of them and give a presentation. Actually we could use that experience to sit around a table and talk about the problems to these guys earlier in the process so you don't end up catching changes at this point. You would then catch them earlier and steer the design better."
> C(1)3/tape4/counter436

Baird et al (2000) supports this as she identified early consultation in the design process as being more productive than consultation which takes place after much of the preliminary work has been done already.

There is probably potential for improving the power of an organisation's transactive memory by making links more visible to others than they are in a conventional, socially based system. Brown, Jagodzinski and Reid (1995) outline a computer based system to enhance the accessibility of transactive memory.

One of the other major concerns which came out of the transcripts and fieldnotes from the studies in Phase 1 was the problem with access to the information stored within the databases on the company's network systems. Reference was made to the benefits of having additional ways of referencing and storing material, for example, a visual reference to previous engine designs and problems.

Rieber (1995) has identified the importance of visualisation in a number of disciplines and has described how it can provide useful insights to complex issues. The merits of visual representation facilitating comprehension of problems and concepts is well known (Olsen,

1991) and becoming increasingly important. Olsen, Korfhage, Sochats, Spring and Williams (1993) propose that as databases become larger and larger, the use of visualisation may become a valuable tool for the retrieval of documents and information. They discuss the issues and problems with the usual avenues of document retrieval and highlight the advantages of employing a visual technique. They argue that certain human capabilities such as spatial awareness of objects and the ability to distinguish between a vast range of colours can be exploited by the visualisation technique they have developed. Their approach to a visualisation method is to "give the user the possibility of creating a visualisation space, defining the dimensions and determining the mapping of documents onto this space" (p.74). It is based on the user defining what are called "points of interest" (POI). There could be any number of these that are defined. Then any documents that are retrieved can be placed spatially in relation to these POI's. So it could be that a particular document may reflect exactly a particular POI and therefore be placed on top of it. However, it may be of relevance to two POI's and therefore be placed somewhere between them. If it had a bit more relevance to one POI than the other, then it would be closer to it and so on. The VIBE system, as it is called, uses "the keywords given for each POI to determine a score for a document on a POI" (p.75). Icons of different size shape and colour can enhance the visual representation by indicating its overall importance in relation to the score assigned to it. The whole visual representation allows the user to interpret what and how documents are related to each other. In order to be able to do this, the user has to have a good knowledge of the data.

Individual documents are viewed by clicking on them and will be opened by VIBE if there are a cluster of them in relation to their assigned importance. Although at the time this paper was written this was a prototype, it had been employed for a research project and a comparison to the traditional type of retrieval method to that of VIBE is documented. The main advantage of the VIBE system compared to the traditional method is that the former has the ability to visually present a very large data set which then allows the user to explore and navigate through. The VIBE system is a dynamic one whereby as the user changes the keywords and their weightings so the visual representation will change. A possible application of this visual approach in Rolls-Royce would be in helping to identify the right person to talk to.

A computer supported transactive memory system along the lines suggested by Brown, Jagodzinski and Reid (1995) would be another possible solution to this problem and requires further investigation.

Communication between the teams, which are distributed, can be problematic because of problems locating the person who is needed for their particular input. Most of this was due to the technology being inadequate (see section 6.4.5). As highlighted in the literature (chapter 3, section 3.3) shared workspaces need to address the psychological and social issues of interaction between dispersed groups (Tang & Leifer, 1988; Gribbons, 1991; Ishii & Kobayashi, 1992; Scrivener & Clark, 1994; Easterbrook, 1995; Fussell & Benimoff, 1995).

Shared workspace technology was not available at Rolls-Royce and any future developments would need to incorporate the opportunity for face-to-face contact as this was the much preferred option. The designers felt problems could be sorted a lot more easily and quickly this way.

> "Company X are reluctant to provide information. I think face-to face would be better."
> A(2)12/bk1/pg73/ln84-85

This supports the findings of Kidd (1985) who recognises the importance of the face-to-face dialogue with experts in finding solution to problems.

6.4.2 Social mechanisms covering: communication (social)

Concerns were expressed when requiring specific expertise on how to get to know people and make an initial contact as reported in chapter 4, section 4.4.2. This was seen as increasingly important now as the company had become decentralised in recent years. Employees no longer work in discipline specific groups, but in teams on projects. Projectisation has led to such groups being dispersed and contacts with fellow specialist harder to maintain or even lost. Baird et al (2000) also found reluctance in engineers initiating contact with an unknown engineer working at a distributed site. However once contact had been made, and a close working relationship developed, social "permissions" would facilitate communication at certain times between colleagues (Baird et al, 2000).

This social connectivity was found to be reinforced by engineers seeking out fellow colleagues who were trustworthy and reliable to assist with problems or questions that drew upon individual expertise or experience. This has been supported in the literature by a number of studies that have acknowledged the importance of communication between designers during the design process itself (Reid, Reed & Edworthy, 1999; Reid & Reed, 2000).

An example of this social connectivity taking place was observed during one of the meetings and is summarised below.

> There was a lot of debate over a number of proposed designs for part of the FOAS project. The designers present took turns in stating why they thought a particular design was best. Comments made by others sometimes made them reflect on their decisions. Criteria had been set in advance, on which a decision on the choice of design would be based. They were reasserted a number of times to remind the people present. At times drawings were fetched and pored over to establish and highlight potential problems. Ultimately a consensus was reached and a choice made.
>
> Z(5)/bk1/pg125-130

On a different occasion and with respect to a different project, an impromptu meeting took place to inform others working on the project that there was a potential problem that had not been taken into account. If this had not been brought to their attention it could have caused serious difficulties later for the project.

Thus social aspects of design are important throughout the whole design process. There is an increasing awareness that models of design need to incorporate the social element (e.g. Bucciarelli, 1988; Cross & Cross, 1996). This is especially so as design is not often done in isolation, but as a team member and within an organisational context (Pugh, 1996).

6.4.3 Management structures and organisational constraints covering: organisational processes, integration with other companies, working practices, project management

This section covers many of the categories which were developed in the latter part of Phase 1 and share commonalities with the theme from the Scoping Study *management structures* and *organisational constraints.* Some of the issues raised in this section appear to be as a result of changes in company policies and the current economic climate in which the company operates. The aero-engine industry is very competitive and market forces demand reduced time-to-market (Moore, 1997).

As described in chapter 1, section 1.7.1 Rolls-Royce Aerospace follows Project Derwent, a process made up of a number of stages and gates through which an engine design needs to progress from conception until entry into service in a reduced time compared to engine development of the past. Whilst in terms of reduced timescales this has had more impact on the civil engines developed at Rolls-Royce Aerospace (Derby), timescales are still an issue for those working on the Bristol site in NPE. However the reasons why this is experienced is different.

One of the main issues was a resourcing one. When interviewing the project managers and team leaders they expressed their concerns over the need to move designers from project to project. They felt they had no option as different projects demanded a higher priority because decisions were made by gate keepers in higher levels of the organisation. This led to a dilemma especially as they worked to tight timescales with milestones and deliverables on projects still to be fulfilled. Man hours for each project then had to be re-evaluated and some consensus reached.

> "There is a conflict between what projects [NPE are] involved in. The status of project takes precedence. Seniors take decision to allow people to be moved off. They reach an agreement through negotiation between other project managers and team leaders. It's always a problem when a new unexpected project comes in which has a high profile. Therefore we are always fire-fighting, but don't want to miss the opportunity."
>
> J(1)11/bk1/pg59-60/ln60-64;70-71

Related issues of concern for these project managers and team leaders were that of continuity and stability on projects. If designers were constantly being moved this could disrupt their progression on the designs, the cohesiveness of team activities and sustained thought processes of groups and individuals.

Many concerns about the loss of expertise from the company were expressed in the two studies conducted in Phase 1. This not only relates to the loss of a very valuable knowledge source, but also an important resource constraint in that fewer people were available to work on different projects. This is discussed in more detail in section 6.4.4 of this chapter.

One of the major implications of increased work pressure and working to shortened timescales was the reference by engineers on having to satisfice on their designs. Concerns were expressed by those interviewed that there was not enough time to explore alternative design concepts and solutions to problems. This eliminates opportunities for incorporating any better solutions the designers may have later. This could be a major barrier to creativity when a period of "incubation" is often experienced before the solution (best design) becomes apparent (Poincaré, 1952).

> "I monitor what they [designers] are involved in. Designers have to satisfice. They are no longer able to perfect their design. They are constantly working under pressure to tight timescales. Reports go out before they really ready. I'm worried that all avenues are not adequately explored. What about things which haven't been thought through? I'm worried about this on the FOAS project."
>
> Q(1)21a/bk1/pg38/ln80-89

However according to the engineering design literature, satisficing in designs also occurs due to cognitive limitations of the designer (Ullman, Dietterich & Stauffer, 1988; Ball, Evans, & Dennis, 1994; Ball, Ormerod, & Maskill, 1997). Ullman, et al (1988) propose that once graduate engineers in the mechanical design process have generated the initial design concept, they continue to "patch it up" and modify it iteratively. The theory behind this exercise they suggest is that, "design alternatives are not considered outside the boundaries of design episodes (which are short stretches of problem solving aimed at specific goals)" (p.33). Ball et al (1997) suggest that not only do designers satisfice on their designs due to "motivational factors and working memory limitations", but that this happens due to "inhibitory memory processes that arise subsequent to recognition based emergence of familiar design solutions" (p.347). This conclusion was drawn from their investigation into the conceptual design practices of expert electronic engineers. The recent development of software which can stimulate and support creativity may well provide a possible solution to this inhibitory factor (e.g. MacCrimmon & Wagner 1994; Hori, 1997; Fischer, 1993).

Many of those interviewed found certain aspects of the organisational processes frustrating and inhibiting. For example, in order to obtain certain software, email accessibility and other 'privileges' a business case had to be prepared. One project manager had to wait in excess of three months before getting access to email. In a climate of increasing electronic communication capability this finding was surprising and the fact he had to make a business case in the first place even more so. Likewise software was not necessarily 'rolled-out' to all employees. Business cases had to be presented to ensure the applicant had a viable need. Similar policies were in place where long term commitments to particular software companies were made with little if any consultation with the designers who used them.

Another process, which was causing concern, was the introduction of booking codes for projects. Whereas in the past designers had been able to call on their network of colleagues for advice and assistance in finding a solution to a problem, it was no longer as simple as that. If designers did approach colleagues it was likely they would be told to obtain a booking-code first against which their time could be accounted for. This had to be set up by the project managers. If a lot of input from a specialist was needed then this system did not cause too much of a problem. However, problems occurred when a short yes/no answer was all that is required. People were reluctant to respond to them unless they had a booking code. This was frustrating for the designer who may be in the middle of their design and needed a short answer to be able to progress. This new booking system also posed problems for project management. For example, the project managers need to calculate the amount of man hours required to get the task completed, but the problem with many designs is that they cannot tell in advance what advice or specialist help may be required as the designs develop. Therefore they are in a very difficult situation. To circumvent this problem dummy codes were used to compensate for the extra time required. This was an issue highlighted again in Phase 2 of the research and is evidenced in chapters 7 and 8, and discussed in chapter 9.

Task sheets[1] were viewed as another common practice which appeared a bit haphazard. They have an important place in the life of a project, but at times seemed surplus to requirements. Verbal instructions, common sense, seeking out clarification sometimes superseded the need and outlived the task sheet. The project and associated tasks were often underway because the time taken to raise one meant that it often arrived after the job had been done.

1 An internal document which the Project Manager completed setting out the task required in relation to a project. It was then passed to the design engineer to carry out.

Another issue to come under this theme was when working with other companies. There were problems not only in understanding how their working culture differed, but also in the politics that came into play. For the designers and even the project managers and team leaders explanations as to why something had "gone cold" were not always apparent. This caused frustration and uncertainty as to whether the project would progress and consequently how much effort they could afford to put into their design activities in case the project was ultimately cancelled.

One of the major changes the designers had experienced in their working practice was the removal of the drawing boards and the introduction of an open plan office with computer workstations. There were several things that had subsequently changed in their working practices because of that decision. When working with drawing boards they felt they provided a type of boundary or 'shield' in which to work. On the other hand the designers also found that having the boards present actually facilitated communication and led to a better understanding about the different roles and responsibilities of employees in the department.

In the past, a lot of social interaction, problem solving and discussion took place about a design at the drawing boards. For example, people would walk through the department, see a particular design that interested them and stop, and then discuss it with the designer. Now fewer people are able to walk through NPE as it has become a secure area and the designers feel this was detrimental to their building up of networks of people. Also opportunities for sharing practice are reduced as well. As Scrivener and Clark (1994) point out drawing and sketching has an immediacy that can enable spontaneous communication between people. This could be interpreted as a barrier to creativity where channels of communication with others who may provide an idea, a solution to a problem are curtailed.

The project managers' experience of removing the drawing boards was that they felt less "in touch" with what the designers were designing. At the end of the day the computer is switched off and really only the designer knows where and how they have stored the designs. When design took place at a drawing board, these were left open for all to see in passing and peruse in more detail if they wished. Additional advantages of using drawing boards in comparison to the new technologies available are discussed in section 6.4.5 and 6.5.

There appear to be several management and organisational issues which are perceived to be barriers to creativity. A reduction in resources such as manpower, aspects of technology and time have led to designers satisficing on their designs and curtailing their creative activities. Inflexible organisational procedures and changes in certain working practices appear to inhibit communication flows and the opportunity for shared problem-solving activities.

6.4.4 Individual/personal resource and design processes covering: role information, experience of designers, design process, creativity

This section identifies the overlaps between the two studies undertaken in Phase 1 of the research in respect of the above named categories.

Many of the experienced designers (group 2) who were interviewed had reached their current role through the apprenticeship route. The length of their apprenticeships enabled them to have a much richer experience that the graduates who join the company nowadays. The apprenticeship training had provided a lot of 'hands on' experience with materials and machinery used through the whole of manufacturing. This provided an insight to the capabilities of the materials and what could or could not be manufactured successfully. It is possible that those who were apprentices have a wider range of design and solution prototypes in their repertoire as a result of this type of experience. Designers who have taken this particular route learn certain aspects of the products and processes that they come into contact with that cannot be learnt from a computer or a drawing board. Lave and Wenger (1995) refer to this apprenticeship model of learning through observation, coaching and practice as "situated learning". It also helps the apprentice to understand and operate in the social context of their environment. According to Baird et al (2000), this is an important aspect of design teams and how they function where knowledge acquired in this way may express itself as intuition when working with 'real-life' problems. This supports Hubka (1995) who argues that a 'feel' for design is based on a broad range of experience and conceptual knowledge.

In terms of the Geneplore model (Finke et al, 1992, see chapter 3, section 3.6.1) the designer who started as an apprentice, would perhaps be able to generate more preinventive structures to be considered during the process of creativity. In addition, because of their wider experience of prototypes and negotiation of the design space based on a larger personal transactive memory system, they would perhaps produce new emergent designs or solutions more readily than those who have not had this background would.

The perceptions of the experienced design engineers, who had progressed through the apprenticeship route, about the new designers who had come via the graduate route was that they appeared to be better equipped to evaluate and logically/analytically test potential solutions because of the theoretical input from their degrees. It is possible that their attempts at solving problems may be from a different perspective. In terms of the Geneplore model this type of designer would be better at the preinventive exploration and interpretation stage. However, they need to have access to a more extensive library of possible preinventive structures.

One experienced designer summed up the graduate's approach to creative design.

> "Graduates differ in their approaches. Some try to solve it by plugging away at it. Others say it's impossible to do. Some struggle and can't 'see' until someone else comes along and explains it and then the penny drops."
>
> P(2)20/bk1/pg103/ln65-68

Previously the practice had been to assign new graduates to functions such as stress or operational analysis which suits the mathematical knowledge they have gained at university. Now new graduates are given more important tasks and "sitting with Nellie" (i.e. working under the guidance of an experienced designer) to learn how to do them is not always appreciated. Some of the experienced designers who were interviewed felt recent graduates had a different perspective where they thought they were over confident of their abilities. This had also been acknowledged by the Whole Engine Process Improvement Manager, Rolls-Royce Aerospace at one of the validating presentations (see chapter 5, section 5.1) where he stated, "Despite graduates thinking they know everything, old and young need to be able to work together and accept that they have different things to offer." Collins et al (1989) discusses the importance of apprenticeships and they suggest it could be a way of enhancing the teaching and learning of problem-solving skills required by new designers.

It was also felt by the experienced designers that the new designers (graduates) lacked a certain amount of inquisitiveness, did not ask enough questions and found it difficult to get to grips with the meaning of design features and details represented in some diagrammatic forms. One of the many reasons to help explain this situation could be related to the change in the working environment. The project managers and experienced designers who were interviewed commented on how working with computers was much more demanding. It was difficult to talk at the same time as operating a CADs for instance. They felt drawing boards facilitated a much more social and interactive environment. Evidence for this came during an impromptu meeting in NPE whilst this research was being undertaken. Whilst the drawing boards were no longer used to draw designs there were a few in the department which provided a large enough space for a 'General Arrangement'[2] (GA) to be laid out for inspection. Such a GA was unravelled and it was observed that it soon became a focal point for discussion not only for those who had wanted to see the GA in the first place, but also it obviously sparked off others' interest and soon several designers were engaged in the debate.

One of the major concerns of those who were interviewed was the loss of expertise in Rolls-Royce which had happened during the recession in great numbers and was also continuing to some extent. It not only meant valuable skills and knowledge which others held in their heads had gone forever, but that any gaps were not being filled adequately. They often referred to this as the "demographic time bomb waiting to happen". What they were referring to was when the more 'mature' designers left, there were few, if any, to replace those skills. For example, in this particular department, a designer who spent most of his time running the CADs machine was due to retire. There was only one other person in the department who could operate a CADs machine competently.

Some of the project managers and team leaders had acknowledged this was a problem and had attempted to introduce "skill owners" and "learning resources packs". Ideally they felt

2 A GA is a print out of any engine design highlighting where the principle features are positioned in relation to each other such as the HP and LP compressors.

some formal training should be available, but due to the pressures they were working under there was little time for experienced designers to sit with new designers and trainees. They suggested a "Teach-yourself Package" that could be integrated into their initial training and developed to different levels would be ideal. Not all people need to be experts in everything, but for example, if using a particular software package those trained at level 1 should be able to do the rudimentary things. Others, who had been trained to be experts (skill owners), could carry out the more complex things and help others as and when needed. It had been hoped that the "learning resource packs" would be produced by experienced designers in an attempt to 'grow' new skills. A meeting took place with some project leaders and experienced designers to evaluate how much work had been done to date. Several issues were raised, for example, whether it was best to use workbooks with a case-based training approach plus a suggestion that this should be available on-line.

Another issue revisited was the list of competencies which was being drawn up in each department in relation to individual's jobs. The rationale for this was to facilitate the search for particular skills. For example, if a good stress engineer was required, their level of competency could be investigated and where to locate them. The outcome of the meeting was that little progress appeared to have been made due to an apparent lapse of 'actions' being followed. Whilst attempts had been made to address this issue of the "demographic time bomb" by a number of different routes, neither suggestion had progressed very far due to workload and timescale factors experienced by the designers.

One of the engineers interviewed referred to there being what he thought were two different types of designers, the "innovative" and the "technical". He felt there were lots of designers who had the technical imagination, but few who were creative and innovative. Those who he assigned the "innovative" designer type had lots of creative imagination which could be revised to fit the problem space. What he referred to as "Star Trek" vision. One such designer did in fact have many patents and felt his ability to design creatively was a gift. Chapter 3, section 3.2.3 refers to literature which also highlights the different types of designer and their approaches to design (e.g. Roy, 1993). Kirton (1987b, as cited in Isaksen & Kaufmann, 1990) lists a number of characteristics for the "adaptor" which match what the engineer called the "technical" designer. The characteristics pertaining to the "innovator" match closely with the other type of designer described at Rolls-Royce. Arguably if investigated, the former may use an "adaptation" cognitive style and the latter a "refinement" cognitive style (Oxman & Oxman, 1992). However the type of cognitive style and approach to design which is employed may depend on what type of design was being undertaken. According to Culverhouse (1993) depending on whether the designer is involved in "repeat, variant, innovative or strategic" design will depend on how much new knowledge is required. It is essential to have both types of designers involved in projects. Their strengths and weaknesses need to be applied as and when applicable. For example, it could be a case for the division of labour; that is, different people doing different things at different times or for the creation of an integrated team working where the strengths of both can be applied in a co-operative working environment. Perhaps those identified as "technical" designers would be more suited to working on the repeat and variant designs (boundary B) leaving the innovative and strategic designs (at boundary A) to those more able to be creative (Pugh & Smith, 1976b).

It was obviously difficult for the engineers who were interviewed to articulate retrospectively what design process they follow. One designer stated the stages he went through simply as:

- sketching (using pen and paper)
- model (using the current computer technology)
- analyse
- optimise
- detail and manufacture

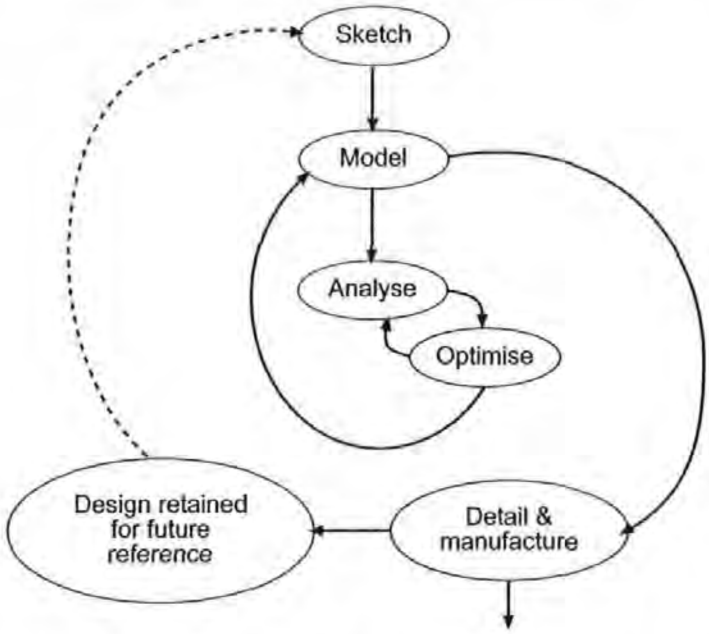

Figure 6.1: A diagram representing one designer's schematic model of his design process.

A lot of iterations happen between "analysing" and "optimising" and back again to the "modelling" before the design leaves the domain of the designers and goes to the detailers and on to manufacture. What the designer had omitted to indicate was the amount of social interaction which also takes place during the process. This was clearly evident in the shadowing study and is reported in chapter 8, section 8.3.9.1.

The designer's reference to the iterative nature of design did not appear to reflect the systematic prescriptive descriptions of the design process as suggested by Pahl and Beitz (1984) and Hawkes and Abinett (1984) for example. It does perhaps appear to be more akin to the spiral-to-circle process model described by Rechtin (1997) where characteristics of systematic and iterative approaches to design are accommodated (see chapter 3, figure 3.2). It also supports Ferguson's (1993) argument that due to the unpredictable nature of engineering design, the final goal cannot be deduced at the start, as inevitably there will be unforeseen problems encountered throughout the design process. For example one designer described:

> "I had a unique problem to solve. An old engine to fit into a new aeroplane. It was too costly to change therefore I couldn't change the mounting system. Therefore had to look for an adapter. This problem had surfaced before, but the solution was not adequate this time. I looked at the yoke design we had come up with before, but it didn't work as there was too much load on the engine and so I had to modify it again. I talked to [X]. He then modified it."
>
> P(2)20/bk1/pg103/ln77-84

The designers working in NPE are involved in the conceptual stages of design where most creative design takes place. In terms of Culverhouse's 4 path model of design, the type of design undertaken in NPE is more likely to be either "innovative" or "strategic" design. Ill-defined problems such as the NPE designers experience require a "reflection-in-action" (Schön, 1983) approach to the design process rather than a rational problem-solving approach (Newell & Simon, 1972) which is better suited to well-defined problems.

In the very initial stages of the design process, literature searches are conducted to help map out the design space. Those interviewed referred to the use of different artefacts, such as sketches initially drawn using pencil and paper, in the design process. Such tools are referred to in the literature as cognitive artefacts (CAs) (Norman, 1992) and external representations (ERs) as they allow the user to externalise their thoughts and ideas (Reisberg, 1987; Ullman et al, 1987; Mayer & Gallini, 1990). Norman argues that CAs can be either passive or active but in order to aid cognition should follow certain design principles such as providing feedback.

There are many benefits to externalising thoughts and ideas. For example, it enhances communication not only to others (Schenk, 1991; Scrivener & Clark, 1994), but also amongst the designers themselves (Ullman et al, 1990; Spillers & Newcome, 1993). This was certainly evidenced in the log books which some of the designers kept. As designs progressed, calculations were made upon different parameters and to better understand a particular design. As ideas were eliminated so a particular concept became more detailed with annotations to describe the parameters and characteristics of the chosen design. This activity may reflect what Goel (1995) describes as changes from "lateral" transformations where sketches are unstructured to "vertical" transformations where a preferred solution is taken transformed into more detail characterised by more precise drawings.

Working memory has a limited capacity (Miller, 1956) so by putting one's thoughts and ideas down on paper it can be viewed, reviewed and expanded upon whenever necessary. Ullman et al, (1990) found that sketching served as an extension of the designers' cognitive capability in enhancing mental stimulation. This could also allow for new interpretations of the sketch and new ideas to emerge (Purcell & Gero, 1998). This type of exercise would appear to facilitate the reflective conversation described by Schön (1983). Schön and

Wiggins (1992) take this theory a bit further by proposing a "moving and seeing" paradigm whereby sketches are reinterpreted and perceived in different ways. Certainly there was evidence to support this approach in Phase 1 of the research where designers stated they needed to be self critical and questioned aspects of their own designs. In moving through this process of interpretation and reinterpretation of sketches and idea generation it can be seen that the cognitive processes involved are similar to those described by learning theorists, such as Kolb (1984).

During the DGI Study a number of new designers and trainees were interviewed and evidence of their approach to design documented. One such trainee was exploring the design of a shroud for a nozzle. He began by looking at various sources such as publications and, magazines and documents from the technical library. Figures relating to the different parameters were referred to from the relevant logbooks and then tried out on various designs. In his logbook annotated notes indicated why particular designs did not work. Those which he felt more confident about were supported with quite detailed annotations. These different types of drawing are what Ferguson (1993) describes as the *lingua franca* of engineers in design and provides evidence of the "thinking" sketch beginning to evolve into the "prescriptive" sketch which provides much more detail. This approach to design appears to support the depth first approach favoured by novices (Perez et al, 1995) (see chapter 3, section 3.2.3).

As discussed in chapter 3, section 3.5.3, visualisation is an important aspect of problem-solving as a means of representation and communication (Rieber, 1995). Some of the designers interviewed commented on how they visualised ideas to problems even before putting anything down on paper. This evidence is supported by Athavankar (1997) who ran experiments which demonstrated the role of visualisation in the early creative phases of design problem-solving. Another aid to the visualisation process, by adding a tactile 3D dimension model to the designing process, is the use of the technique such as stereolithography. By a process using a laser, layer by layer a solid model of a particular component is produced. This technique is used by the designers in Rolls-Royce Aerospace (Bristol) and provides an example where technology is used for "illumination" rather than just support (Baird et al 2000) and may enhance the processes involved in creativity. This physical manifestation of the component they are designing helps to convey a concept or idea to others as described by an experienced engineer below:

> "It's difficult if the concept is so different from the one used at present to get others to understand. I produced a stereolithographic model to portray the concept. Then immediately the 'penny dropped' and people came up with further suggestions."
>
> B(2)2/tape2/counter558

It can also assist designers in deciding whether the design will work or not by supporting their intuition.

> "I use stereolithography a lot. It is important because I can look at it, obviously not real in terms of weight etc., but it is beneficial because of the visualisation of the component. I just know whether it is right based on experience really. If I had a brainstorming session or meeting of all Chief Engineers and showed them the design you have already got-- they would be able to say whether it can be built that way of not or whether it interfered with air flow or not. You can look at it from any angle."
>
> B(2)2/tape2/counter321

When the interviewees were asked about their creative designs and how they were generated, again they found this hard to articulate. However, their references to dealing with a problem such as "you go to sleep and leaf through the problem sheets in your mind ('immersion') and then wake up and know how to do something suddenly" ('flashes of insight') appears to reflect the creative processes often referred to in the literature (Poincaré, 1952; Wallas, 1970) (see chapter 3, section 3.6). The example below provides some insight to a new designer's thoughts on his experience of creativity.

> "You think about it in your bath tub, back of the fag packet stuff. Then it comes to you all of a sudden and you scribble it down, then you develop the idea and add more detail to the drawings. See how it interacts and fits with other bits. You wouldn't see this at first glance, but once drawn, then you can. I think about it at work all day and get a creative block, but after a while it pops into your head. The best creative ideas come when you are not deliberately thinking about a problem. Then you are not inhibited by logical thinking. Your thoughts can be more radical. It's as if the creative side dries up and the logical side shoots the creative side down. But when you are not thinking about things specifically, the creative side comes through."
>
> S(3)25/bk1/pg147-150/ln78-89

Their descriptions also fit quite well with the Geneplore model of creativity (Finke et al, 1992), and its modified version, the "Trinity model" (Jarvis, 1997) (see chapter 3, section 3.6.1). In the latter model ideas are generated forming "starting points", then challenged and modified by "exploring starting points to produce concepts" and then constraints are applied where and when necessary. It also provides evidence of "combinational play"

(Finke, 1990) where different aspects of the design are manipulated to see if anything new emerges.

> "The classical model is brainstorm and then down select and work up that one. But you are more likely to start with something and then shoot of into something different. You may have parallel or serial ideas. There is an element of the classical model, but usually a lot more evolutionary where you have two or three parallel ideas which may shoot off in a different direction. Not as clear as the classical model of design suggests."
>
> C(1)3/tape3/counter465

Examples of the designers referring to creative techniques facilitating their creativity was often found in the data. For example a new designer said how helpful it had been to brainstorm ideas to solutions to problems in the first stage of design. He had not seen that happen in NPE but had compensated by doing an "individual brainstorm" in his log book and then bouncing the ideas off people. The brainstorming technique is one of many advocated by Pugh (1993) which can be used at various stages of the design process to stimulate and generate ideas.

A variety of other techniques and methods were also said to be employed such as analogical thinking and inversion which have been found to enhance creativity (Finke et al, 1992; Pugh, 1993).

Boden (1992) and Finke et al (1992) present evidence to suggest that both dropping constraints and working within constraints can enhance creativity. It is interesting that during the workshop (see chapter 5, section 5.4.2) one of the Rolls-Royce designers had made the comment that working to tight timescales focused the mind and could enhance creativity by working within that constraint.

From examining the transcripts and fieldnotes generated in Phase 1 of the research clearly those interviewed had a perception as to what made a 'good' designer.

> "Design can't be taught [they] need to learn by doing. It's easy to impress with complex designs, but may not be the best design. Minimalist is best. You need to be self critical asking yourself questions. You could have many iterations which come up with better solutions but you need to know when to stop due to time constraints. You need to accept criticisms from others and use them to produce better designs."
>
> P(2)22/bk1/pg141/ln7-16

Referring back to chapter 3, section 3.2.2, Pugh describes his broad model of design as incorporating not only core design activities bounded by product design, but also what he refers to as personal and business boundaries. Pugh (1996) says, "If the constraints of the business design boundary are too severe, it will be necessary to take corporate action, restructuring the business to provide designers with more information, more resources and more support" (p.330). Clearly there was evidence from this study which indicates that the business boundary in terms of information, resourcing and support could be improved and enhanced as these are imposing a constraint of the design activities of designers in NPE in many ways. Similarly the design taking place in NPE is dependant on the characteristics, skills and experience of those engaged in the activity. These have been shown to be very proficient and innovative in some cases, but the concern is what happens if such skills are lost?

6.4.5 Technical issues covering: technology, communication (technological)

There were many commonalities between the two studies of Phase 1 of the research with regard to technology.

One of the main concerns was about the types of technology available to the designers. In both studies those interviewed had expressed how they felt that the designers' introduction to CADs was inappropriate. There were many problems with this technology both in the operation of it and its utility as a design tool. For example, CADs were seen as too mechanistic and precise for designers to use at this stage of conceptual design as evidence in chapter 4, section 4.4.5 and chapter 5, section 5.3.1.13 indicated. To draw a simple horizontal or vertical line is complicated and as one designer put it, "soaked up intellectual effort". Thinking is inhibited regarding the design because there is always the need to think about *how* to do something first. Whereas using pen and paper is quick and easy allowing for that 'artistic' ability to be expressed more naturally.

Those interviewed felt that drawing boards were a lot more interactive and provided a better social environment to share and develop design ideas. Also a better feel for the scale and size of the design was experienced and others could follow the design stages they progressed through. Working with computers was very much on a personal level with limited capacity to share ideas.

> "You see the scale and get a 'feel' for it. A gut feeling about it being right or wrong...like proof reading a hard copy instead of checking by reading off screen."
>
> H(3)27/bk1/pg152/ln16-19

Perceived barriers to creativity are therefore experienced through too much cognitive effort being applied to using the technology rather than creative design itself. These findings are supported by Robertson et al (1991) who argue that although CADs should support design they have not fulfilled designers' expectations. Designers see them as drafting tools when what they really want is a designing tool. Instead of minimising the "cognitive complexity" faced by the designer, they add to it because of the complicated interfaces and commands that have to be learnt. Further evidence can be found in the literature which confirms the inadequacy of CADs in supporting conceptual design by, for example, Allwood and Kalen (1994) and Baird et al (2000).

Some advantages of using CADs for certain aspects of the design process have been highlighted by Ertas and Jones (1996). For example, for some to be able to view things in 3D helps designers to understand the design in greater depth. CADs have features which enable a designer to zoom in and manipulate the design. At Rolls-Royce Aerospace (Bristol) there was extensive training on how to use the CADs but it was felt by the project managers that many would never realise its full potential because it was so complicated to use.

Allwood and Kalen (1994) in their review of design and CADs conducted from a psychological perspective suggest that a better understanding of the design process in different design domains might enable better decisions to be made about when and what type of computer support is required. They also highlighted other issues, for example, what affects the introduction of new technology can have on both individuals and organisations and how proper training should be provided for CADs users. The evidence from Phase 1 suggests that some of the problems in terms of the technology are not unique, but are common to CADs users and could be alleviated for example by better training, organisational support and appropriate cultures for creative design.

In the latter part of Phase 1 there was greater use of the new design software Pro/ENGINEER™. Of those interviewed who had experience of using this technology, all felt this was approaching the type of tool a designer needs in the early stages of design. It was thought to be more intuitive than operating a CADs because it is more flexible, user friendly and approaching the use of using a pencil rather than clicking all the time when using a CADs. Its additional features such as parametric modelling, simulation, analysis tools and quick iterations allow for design concepts to be developed more quickly and flexibly. Designers still began by drawing rough sketches especially at boundary A (Pugh 1996), but they stopped sooner. Once they transferred their designs into this software they could build designs quickly. They felt that Pro/ENGINEER™ allowed them to experiment more with the "what ifs?" and really understand the features of a design problem. However they also realised that the increased opportunity for exploring also created some problems in that it extended deliberation and they needed to focus because of the time constraints. Also they thought less about the feasibility of the particular design, focusing on its design merits, rather than whether it could be assembled or not. In a sense this could be a barrier to creativity because the software is so easy to use, they introduce it earlier and therefore may not explore the alternative designs they may have otherwise generated using pen and paper. In the opinions of those interviewed they did not feel the software enhanced creativity, but provided wider capabilities for exploring the design. Thus technology can be seen as both a constraint and an opportunity to engage in creative design.

A number of problems with the technology were highlighted in this phase of the research. For example, there was felt to be inadequate hardware resources to run the software programs available. A variety of different platforms were used which caused problems with data exchange and communication between individuals and companies. Therefore some intensive design practices had to be implemented in concentrated bursts of activity to be able to circumvent this problem. Another problem was reliability of the software that caused problems with thought processes being interrupted by software crashes thus highlighting another barrier to creativity.

Designers using the version CADDs5[3] at Rolls-Royce had poor housekeeping skills because the very design of CADs provides 256 layers with which to build your design. The designer operating the CADs knew what each layer represented, but anyone else would have a great difficulty in understanding the progression made through that design. Problems also occurred with the amount of filespace available to users which was, for the

3 CADDs5 was the particular version of the software supplied by the IT services supplier (ITSS) that designers were using for design activities.

most part, due to poor housekeeping skills and inadequate space and archiving facilities for designers' work files.

This section has highlighted the importance of providing the correct tools for the designers to use at appropriate stages of their design activities. Adequate training for designers and comprehensive provision of hardware and software is also required if the technology is to be used to its full potential.

6.4.6 Unfulfilled support needs covering: wants

Many of the support needs of the interviewees in the Scoping and DGI Studies were technology based and could be placed into two main categories as follows:

Hardware: Faster and more powerful machines would enable more and quicker optimisations to take place. Platforms which were compatible with each other would also be beneficial.

Software: This category can be broken down further into software packages which provide features and facilities to enhance creativity and design and those which provide better access to information (see section chapter 4, section 4.4.6 for a more detailed list).

There are many examples in the literature where suggestions have been made to provide CADs with better interfaces to facilitate the design process. For example in their review paper, Allwood and Kalen (1994) suggested that features on CADs be enhanced and made more intuitive by incorporating more comprehensible icons. The interface for expert versus novice also needs to take into account different characteristics of abilities and use.

Van Dijk (1995) investigated the requirements of CADs of conceptual designers in industry. There are several commonalities between the wishes of the conceptual designers he reports and those of the designers at Rolls-Royce. For example, easy data entry (such as 'drag and drop'), opportunities for sketching and retaining that data. A prototype, which addresses some of those issues, has been developed by Van Dijk called the fast shape designer (FSD). Although in its early stages of design, initial tests by designers using the FSD found that it could support aspects of early design, but it would depend on the object. Some features such as ease of data entry still did not meet with expectations. Other prototypes are referred to in the literature, for example where alternative input devices have been designed to "invoke production-like design operations through spatial and tactile manipulations" (Robertson et al, 1991, p.199).

As presented in chapter 3, section 3.4.1, Pugh (1993) suggests a variety of aids required to facilitate the design process. A report conducted by Spence (1994) which was based on interviews with some "visionary engineers" sought to elicit visions of engineering design for year 2020 AD. A number of 'wants' were highlighted as well as retaining some of the artefacts which have always been used, such as a pencil, paper and eraser. Some of the 'wants' are listed below under various headings taken from the report. Similarities between the unfulfilled support needs of the Rolls-Royce Aerospace (Bristol) engineer designers and the report are highlighted.

6.4.6.1 Creativity and advisory software

This type of software helps designers to be more innovative, think laterally and develop advantageous design concepts. They will include some of the following features:

- idea sounding board or mind explored with computers to be 'mind-opening' rather than 'mind-expanding'
- to facilitate the creative process by supporting brainstorming suggestions as divergent or convergent as required by user
- allow tentativeness to be expressed as well as "reflection in action"
- allow emergence of new concepts
- CAD software to allow suspension of judgement so decisions made at any time (reducing cognitive load)
- knowledge-based software accessed by designers via 'character software' where questions can be put to a human face on the screen
- automatic design supervision monitoring and critiquing of design taking into account company practice, previous designs and detailed design decisions

The designers in the Scoping Study had also suggested that programs which could stimulate them in terms of idea generation, presenting cues to possible solutions and alternatives and potential problems in their designs would be an asset to them. The ability to interact with the software by asking questions would support the face-to-face discussions so essential in design activities. They also wanted to be able to log decisions and designs which could be revisited in the future for further development.

6.4.6.2 Product specification and design

This type of software would bring technical criteria into play during creative design. It include the following features:

- communication with domain specialists via 'bridging' (or 'translation') software
- opportunity and availability to obtain off-the-shelf designs which may require slight redesign or innovation
- opportunity for all parties concerned (from client order through to design and production of the product) to see what effects each others decisions have on each other

Again these suggestions reported by Spence (1994) are similar to some of those put forward by Rolls-Royce engineer designers. For example, they require systems which are flexible and compatible and able to interface with other packages enhancing the whole design process for all involved. This is especially important to them as they interface with many companies on a national and international level.

6.4.6.3 Automated design

- some detailed design could be carried out automatically with the allowance of the designer's input

A similar suggestion was presented in the Scoping Study where it was felt that more automation would free up time for more creativity. This would need to be underpinned by faster and enhanced hardware capability though.

6.4.6.4 Parameter exploration

- support of two concurrent processes, that is problem formulation and problem solution
- use of large interactive displays representing all aspects of data in a variety of forms allowing for "interactive perceptualisation" collaboratively

The designers at Rolls-Royce had made a suggestion not unlike these where they would like an interactive real-time display of the impact on important design parameters as their designs changed and developed.

Spence's (1994) report forecasts that by 2020AD technology will have had to advance in terms of increased memory and processing power to keep abreast of the demands required of it. He suggests there will be greater facilitates for working collaboratively even though designers will be geographically dispersed across different countries. Certainly the designers at Rolls-Royce wanted computer programs with increased capability and finely-tuned tailored software packages built to reflect the conceptual design process. They also wanted expert and intelligent systems to support their information seeking and design activities. Some of these requirements have been met by new technologies and software packages such as stereolithography and Pro/ENGINEER™ (Bill, 1995) used by Rolls-Royce Aerospace (Bristol). However, these technologies are still some way from the networking, creative, collaborative and user friendly characteristics desired by designers described in chapter 4, section 4.4.6 and chapter 5, section 5.3.1.14.

Various other tools have been suggested as possibly supporting the creative user. For example, Candy and Edmonds (1997) propose that a criteria-based model can support the designer in his/her creativity. Also, through the solution-led process that occurs in design a number of constraints are imposed which Candy et al (1997) argue promotes the criteria for the current solution and sets the precedence for the next iteration thus narrowing the solution space. Imposing such constraints has been suggested as facilitating innovation and creativity (Boden, 1992). Thus having a computer system which presents criteria, which can be used to evaluate current designs, would also be beneficial to designers. Fischer (1993) has developed a program which has incorporated these very features (see chapter 3, section 3.6.3).

Oxman (1990) postulates a knowledge-based design system which can enhance creativity and design. She argues that "design has an analogous relationship to learning" where prior design knowledge is adapted and modified in view of newly acquired knowledge. This is achieved by implementing various strategies such as partial matching and reconstructing memory, explanation matching and analogical reasoning. Design systems which could support such strategies would be an asset to creative designers. Reference to other ways design can be supported by computational models are made by Gero and Maher (1993) and Ramierz (1995) (see chapter 3, sections 3.6.3 & 3.6.4 for more detail).

In the DGI Study better facilities for communication between computer systems and companies were desired. However the problem of security has always to be taken into account due to the nature of the work being undertaken in NPE. There was more emphasis on the need for computer applications training and the need for skills and learning packs to be developed as suggested in the DGI Study (chapter 5, section 5.3.1.14). These 'wants' had generally been stated in the interviews. There had been no direct question to prompt such data as had happened in the first study.

6.5 Perceived barriers to creativity

The data from the studies reported in the previous chapters (4 & 5) and reviewed in terms of the literature in this chapter have highlighted many issues relating to perceived barriers to creativity. Creativity is defined (see chapter 1, section 1.7.6 & chapter 3, section 3.6.3) in terms of when the designers believe themselves to be engaged in creative activities.

Problems associated with the sharing of access to knowledge, whether it is due to organisational or demographic change or access to electronic databases, was reported by the designers. Whilst this has not been identified as a barrier to creativity specifically in the literature, they can be mapped onto some characteristics and factors mentioned in studies reviewed in chapters 1 and 3. For example, Majaro (1992) identifies that "lack of slack" in a company means there is not enough people with 'spare' time to ponder and think creatively. Correspondingly "lack of slack" in terms of reduced manpower means less experience to draw upon and bounce creative ideas off. De Alencar and Bruono-Faria (1997) identified "lack of equipment and other material sources" as a characteristic which affects an organisation's creativity. The problems of accessing information could be mapped onto this, as not being able to obtain the correct information needed to progress with a design could be a barrier to creativity.

Recent changes in the procedures for managing projects (booking codes and key systems) at Rolls-Royce were seen to be too formalised, inflexible and perceived as barriers to creativity. The designers argued that demands of the new project management system were too prescriptive and militated against the unpredictable nature of creative design. Majaro argues that "bureaucracy and restructuring" are barriers to creativity in an organisation. Similarly De Alencar and Bruono-Faria identify "political and administrative influences" and "organisation structure" as being characteristics which affect creativity. West (1997) also argues that for a company to be innovative and generate a creative climate any changes introduced by the organisation could be resisted unless employees felt they were involved from the outset and saw a rationale for their implementation. This appears not to have been the case at Rolls-Royce hence the reluctance by the engineers to embrace the booking system completely.

The "physical environment" is another characteristic which De Alencar and Bruono-Faria (1997) proposed as affecting creativity in an organisation. The designers felt, to a certain extent, isolated in the NPE secure working area as they had reduced chances for opportune discussion with colleagues from other areas of the Bristol Rolls-Royce site who may have ordinarily walked through the department. The open plan office also meant a lot more interruptions to their work and this interfered with their thought processes.

Other major issues seen to be barriers to creativity were the tools and technology the designers worked with. For example, the CADs had replaced the drawing boards. CADs were not perceived to be user friendly nor the correct tool to facilitate conceptual design. Also this type of medium did not engage other designers unlike the drawing boards which, when used in the past (and was observed when used for another reason in the DGI Study), encouraged designers to spend time and discuss collaboratively individual designs and their development.

As discussed in chapter 3, section 3.6.4 recent developments in AI (e.g. Rentema et al, 1997) and knowledge-based systems (e.g. Gero & Maher, 1993; Gero, 1996) may offer a wider variety of new tools and technologies in the future to facilitate and support creative conceptual design.

As Eder (1995) proposes procedures, attitudes and the cultural/creative climate developed by organisations and management teams are important factors to consider when looking at barriers to creativity. Haim (1998) also adds that barriers to creativity can operate on an individual level as well.

Creativity in terms of the Geneplore (Finke et al, 1992) and Trinity model (Jarvis, 1997) in relation to new and experienced designers was discussed in section 6.4.4. Some of the new designers involved in the study inevitably had less experience of designing to draw upon and hence the social organisation of the company, for example, social connectivity and access to the transactive memory system (Wegner, 1987) would be of vital importance for these new designers. In addition a number of programs have been developed to stimulate creative ideas such as MacCrimmon and Wagner (1994), Hori (1997) and others (see chapter 3, section 3.6.3 for a brief review of these studies). These could help develop individual creativity and be an asset for the both groups of designers.

6.6 Summary of the chapter

The purpose of this chapter was to review the findings from Phase 1 of the research in terms of the literature reviewed in chapter 3. Many of the issues highlighted by the engineer designers correspond to those reported in various areas of the literature.

6.7 Summary of Phase 1

This phase of research used semi-structured interviews and allowed those interviewed to discuss various aspects of their roles and responsibilities in general terms during the period of data collection. At the end of Phase 1 the data analysis of the DGI Study identified 16 categories which had been developed from the original findings of the Scoping Study. This highlighted a number of general issues in relation to perceived barriers to creativity.

It is apparent from the data analysis in chapter 5, that some of the categories have more impact and influence on creative design than others although all categories are vital to be able to 'tell the story' adequately and completely. A number of interesting patterns and relationships between these categories have been developed to highlight where the phenomenon occurred under macro conditions. Triangulation of methods, sources, analysts

Phase 2

Chapter 7: Tracking Study

7.1 Introduction to Phase 2

Phase 1 provided a platform for this second phase of the research by identifying and highlighting the common themes and important categories relating to perceived barriers to creativity.

Phase 2 of the research involves two studies; the Tracking Study and the Shadowing Study. These studies allowed for the embellishment and verification of the categories elicited from the data in Phase 1 through progressive focusing and theoretical sampling (see chapter 2, figures 2.3 & 2.5). Progressive focusing and theoretical sampling allows the sampling of specific issues to provide more information to shed light on the emerging theory. It can help develop the emerging categories and make them better defined. It demands that data be compared with data from the fieldnotes to develop those categories that will ultimately explain the whole dataset in terms of the phenomenon under investigation. Further, the identification of new categories could take place.

The first study in this phase, the Tracking Study, focuses on specific issues being experienced by the design engineers in relation to perceived barriers to creativity. The Tracking Study examines 'real' instances of perceived barriers to creativity under micro conditions whereas in chapter 5 the focus was on broader and general issues under macro conditions. The interplay of how the phenomena can be explained between macro and micro conditions are presented in chapter 10.

The Tracking Study comprised weekly visits to the New Projects Engineering (NPE) department, Rolls-Royce Aerospace (Bristol) over an eight week period. This allowed for the salience, relevance, frequency and any commonalities of the instances of perceived barriers to creativity to be identified.

The second study, the Shadowing Study, was of one week's duration. Data from this study was used to confirm and identify any contradictions in the findings from the Tracking Study through negative case analysis and hypothesis testing. This was achieved by comparing instances of the phenomenon under micro conditions in the both sets of data. The findings from the Phase 2 studies are reviewed together with the studies from Phase 1 in relation to the literature. This is reported in chapter 9.

Phase 3, which provides a grounded theory and emergent relationship model in respect of the phenomenon, is reported in chapter 10.

7.2 Introduction to the chapter

In this chapter the Tracking Study, undertaken in the second phase of the research, is described. The Tracking Study was conducted partially as a validation exercise to confirm the validity of the categories which had been drawn from the previous studies in Phase 1. It also provided evidence of instances of perceived barriers to creativity, and how they were circumvented, under micro conditions, at a more detailed level of everyday practice.

Thirteen designers comprising one project manager (group 1), seven experienced designers (group 2) and five new designers and trainees (group 3) from Rolls-Royce Aerospace (Bristol) were involved. Interview diaries with the majority of the participants were conducted weekly over an eight week period. During this time a total of 44 interviews had took place. Interview diaries offered the best chance of a rigorous validation of the previous findings given the restrictions on the use of recording technology. Frequency and salience of the instances of the phenomenon was monitored using this methodology.

Comparisons were made between the raw data from this study and the Design Group Interviews (DGI) Study described in chapter 5. It was important to compare the categories from the two studies rather than comparing with a refined/overview analysis set. Grounded theory analysis of the interview diaries led to the confirmation of many of the categories highlighted in chapter 5, the drawing out of new ones and the embellishment of others.

The categories discussed in this chapter are as follows:

- organisational processes
- weltanschauung
- timescales of project
- integration with other companies

- working practices (changes in)
- project management
- management style
- experience of designers
- design process
- communication (social)
- technology with new sub-category communication (technological)
- creativity
- workload and time pressure

Evidence was taken from the transcripts to further explain and illustrate the thirteen categories in section 7.4. The data collected during the Shadowing Study, described in chapter 8, section 8.3 seeks to validate the findings from the Tracking Study.

In chapter 9, the findings from the Tracking Study are reviewed in terms of the findings from Phase 1 and the literature.

7.3 The Tracking Study

The purpose of this study was to provide a more in depth analysis of the instances of perceived barriers to creativity and how they were circumvented by a number of the team from NPE. Being able to track the same people, over an eight week period allowed for the identification of the common occurrence of instances between designers.

Since Phase 1 of the research, the members of NPE had changed. Several of the new graduates and trainees had moved on from the department. There had been several retirements as well. However four people who had participated in the DGI Study were still present. There were also new members of staff who had joined the department.

7.3.1 Participants

Thirteen people from NPE were interviewed. They were an opportunistic sample who offered a range of roles. The group mainly comprised experienced designers although a few interviews took place with some new designers and trainees. One team leader was also interviewed. Opportunistic sampling was not ideal, but it was necessary to interview who was available and willing to take part, due to their workloads and commitments to delivery dates. It was not always possible to interview the targeted designers on a weekly basis.

The participants were coded as follows (see appendix B for more detail):

- *Project manager and team leader (Group 1) coded*[1]*:*
  *I(1)**
- *Experienced designers (Group 2) .coded:*
  B(2), N(2)*, U(2)*, W(2)*, X(2)*, Y(2)*, DD(2)**
- *New designers and trainees (Group 3) coded:*
  V(3), T(3)*, AA(3)*, BB(3)*, CC(3)**
- *Meetings coded:*
  *Z**

7.3.2 Method

The interview diaries (see chapter 2, section 2.4.4.5) were recorded over eight weeks. It had been hoped that a set number of people would be available to be interviewed every week, but this proved to be too demanding on their time. Therefore the diary interviews took place as often as possible with the same contact over the eight weeks, but this was not always achievable as they often had other commitments. However all experienced designers were interviewed at least four times and a core of experienced design engineers were interviewed at least six times over the eight weeks.

There were 44 interviews and the total amount of time spent was approximately 40 hours. Due to the amount of time a given individual could spare for being interviewed, interviews ranged from 20 minutes to 1 ¼ hours. In addition to the interview diaries conducted, a further 8 hours approximately were spent in attendance at meetings.

1 Where A–is the individual
(1)–is the category
*–is the interview number

A schedule (see appendix G) was developed for the interview diaries so that comparisons could be made between the different people participating in the study. The basic questions asked each week were as follows:

1. What have you been involved with over the last week?
2. What have been the most significant problems you have encountered?
3. Have you been stuck and/or stopped by something external to you?
4. How have you acted to overcome this problem?
5. What was the outcome of this exercise?
6. In what context did this happen?

As issues arose so further questions could be used as prompts to elicit more information.

The interviews took place in a secure area and therefore video and voice recordings were prohibited for security reasons. Hand written notes (fieldnotes) both from the interview diaries and observations in meetings comprise the data collection from the time spent at Rolls-Royce Aerospace (Bristol) in this phase of the research.

7.4 The Tracking Study findings

The data collected were subjected to the coding procedures of grounded theory as described in chapter 2, section 2.4.4.3 to classify the topics which were articulated by the interviewees. The categories which had been drawn from the data by the end of Phase 1 were used as a basis for the analysis of this phase of the research in terms of theoretical sampling.

As in the DGI Study, the initial open coding produced a large number of conceptual labels. By conducting comparative analysis, that is comparing and contrasting the data from this study with the already defined categories (see chapter 5, section 5.3.1), categories could be embellished and validated. It also allowed for any new categories to be uncovered (see chapter 2, figure 2.2). This iterative approach to the analysis is represented in figure 2.5 in chapter 2. The outcome from the analysis of the Tracking Study resulted in thirteen categories which are discussed in the following sections.

7.4.1 Evidence from progressive focusing

As previously discussed the research in Phase 1 focused on the general issues relating to perceived barriers to creativity as experienced by three different groups of people working within NPE (see chapters 4 & 5). At the end of Phase 1, sixteen categories were drawn from the data, by virtue of frequency and perceived importance (see chapter 5, section 5.3).

As the studies in Phase 2 were looking at more specific examples of instances of perceived barriers to creativity it was necessary to draw upon the original categories. These were re-evaluated during the Tracking Study. The new category set, which was drawn from the data, is described in this chapter. Table 7.1 summarises the resultant categories and how they relate to those identified in Phase 1 of the research.

As can be seen from table 7.1, twelve categories remained the same, two categories were split and two were merged resulting in thirteen categories. The four categories that were not found in the data were *setting and context, role information, milestones and deliverables* and *wants.* The reason why they did not appear in the data was because these categories related to the phenomenon under macro conditions and the focus of the study was on perceived barriers to creativity and where they occurred under micro conditions. However as Strauss and Corbin (1998, p.185) argue, "The distinction between micro and macro is an artificial one as micro conditions often have their origins in macro conditions." The relationship between these two conditions is discussed in chapter 10. The thirteen categories required further definition and therefore examples from the data are presented in this chapter category by category. As the main categories have been defined in chapter 5, section 5.3.1 this is not repeated here, but the additional split categories are defined in the following sections.

	Categories from Phase 1	Result of analysis from Tracking Study	Categories from Tracking Study
I	▪ Setting and context	*not evident*	
II III	▪ Organisational processes	*split into two*	▪ Organisational processes ▪ Weltanschauung
IV	▪ Timescales of project	⇨	▪ Timescales of project
V	▪ Milestones and deliverables	*not evident*	
VI	▪ Integration with other companies	⇨	▪ Integration with other companies
VII	▪ Working practice (changes in)	⇨	▪ Working practice (changes in)
VIII IX	▪ Project management	*split into two*	▪ Project management ▪ Management style
X	▪ Communication (technological)	*merged with technology*	
XI	▪ Role information	*not evident*	
XII	▪ Experience of designers	⇨	▪ Experience of designers
XIII	▪ Design process	⇨	▪ Design process
XIV	▪ Communication (social)	⇨	▪ Communication (social)
XV	▪ Technology	⇨	▪ Technology with sub category Communication (technological)
XVI	▪ Wants	*not evident*	
XVII	▪ Creativity	⇨	▪ Creativity
XVIII	▪ Workload and time pressure	⇨	▪ Workload and time pressure

Table 7.1: Summary of categories from Phase 1 and the Tracking Study in Phase 2.

7.4.2 Category II: Organisational processes

7.4.2.1 Demarcation and connectivity

In recent years the company has been reorganised and decentralised. As a result demarcation and fragmentation of departments has ensued. This has led to a number of issues and problems which are perceived as barriers to creativity.

For example, there was restricted accesses to databases whereby the information had to be requested from others rather than the designer having direct access to it.

> "Demarcation blocks creativity. Cost engineering (CE) have access to the company database. [He] asked for the data, but they [CE] gave the information they wanted to give. It would have been better if the engineers had direct access to the information, but they are not allowed to because of the politics. It would make their job easy, but restricted access to database is set at a high level."
>
> U(2)1/wk1/bk2/pg8/ln204-213

This was supported by another experienced designer who stated:

> "Company reorganisation tends to work against creativity. There are self-contained functions and project groups which are very efficient in producing a product, but militates against creativity and innovation. It's [company] fragmented now. People can't feed off each other's ideas. We can't communicate now. The barriers to creativity is a general feeling and people are leaving."
>
> X(2)5/wk1/bk2/pg26/ln9-13;19-22

Here the experienced designer was highlighting the problems associated with projectisation and the disbanding of discipline specific groups into multidisciplinary teams engaged on a project.

NPE is a secure area and this has meant that the designers are isolated to a degree because other members of the company cannot enter the department unless they are invited. They feel as a result of this situation, there is less opportunity for the exchange of ideas and development of social connectivity seen as an important aspect of network building (Baird et al, 2000).

One of the main problems experienced by the design engineers appeared to be the bureaucracy of the organisation and the way it was "selling off" different functions for functional or economic efficiency rather than design and creative flexibility.

There was also frustration at loosing some of the in-house capability regarding the development of code for specific software programs. This had always been conducted in NPE with help from Rolls-Royce's own computing department. Now a specification had to be written for the ITSS which once developed is passed back to Rolls-Royce for testing. For example,

> **"Rolls-Royce sold computing operations to the [ITSS] So all hardware in the department [NPE] is owned by the [ITSS] and rented to Rolls-Royce. Software development is now mostly done by the [ITSS]. We provide the [ITSS] with specification for the computer software. There are no guarantees though about delivering it even though we have paid for it. There are some reluctant islands in Rolls-Royce where IT development is retained."**
>
> N(2)2/wk1/bk2/pg12/ln25-34

For complex code this appeared to the design engineers to be very inefficient due to the iterative nature of systems development. There was also a concern that Rolls-Royce was selling off the "crown jewels" and it would have been better to have some baseline provision with a longer term commitment from the ITSS.

7.4.2.2 Accounting systems' demands

The need to make a business case for new practices was still seen as unnecessary bureaucracy. For example a system was required to link the mainframe to UNIX, which senior management had already decided was needed. A major problem for the team was that there was only one licence for 600 people. However NPE was forced by accounting procedures to enter into a long-winded process of submitting a business case for a comparatively low cost piece of software. As NPE would benefit from having access to the software, they had found an alternative, but less efficient way, to using it during the time the business case was being considered. When the department was reorganised, that facility was lost. Thus they found themselves back at square one by being forced to begin again by presenting a new business case as the previous request had been rejected. The lack of access to this software meant the engineer in question had to use Microsoft Excel with even less functionality for this particular purpose. The consequence of this was that he had to accept a lower quality result which took a longer time to achieve. The alternative was to ask another department who had the licence for the required software to do the task, but his involved further delay because of the need to obtain booking codes for such requests. The engineer who experienced this felt this was a barrier to creativity as he was forced to work without the relevant software plus it was a distracting and inefficient use of his time to deal with such administration.

> "The cost of the licence is probably between £400-£500. I'm paid good wages and I waste a lot of my time trying to get access to the software whereby if I had the licence it would be much more cost effective."
>
> U(2)6/wk2/bk1/pg32/ln47-50

What could appear to be trivial and innocuous was the centralisation of the stationery. New items of stationery that were required by the design engineers had to be ordered and fetched from another department. Limited amounts of stationery were held and delays were often experienced causing frustration.

A major concern that the majority of the design engineers felt on a daily basis was the Software Application and Process (SAP) system recently implemented, at the time the research was undertaken, by the Rolls-Royce Aerospace and integrated with the resource management system. The SAP system is a software tool of Enterprise Resource Planning (ERP) that replaced the previously used electronic commerce/product planning system. The SAP system demands that an engineer can only work on a task if they have the appropriate number booked against that task. The rationale is that management can allocate resources to a job and progress can be monitored. It allows the resource manager to make sure the company and design engineers are not over committed and over stretched in terms of the resources. Whilst the rationale appears to be logical, it was felt by the design engineers of NPE to be too formalised. They also found that before they could think about how to progress with a project the business needs in terms of project planning had to be addressed first. They also felt informal support and interaction were inhibited due to this process being implemented. Also it constrained the amount of manpower leaving less room for creative thought on the periphery.

> "The SAP system is a controlled, formal and rigid structure. This has implications for creativity. SAP system is fine for routine production processes, but not so for areas where creative and lateral thought is needed. The seniors won't acknowledge or see that there is a downside to the system."
>
> X(2)8/wk2/bk2/Pg44/ln79-82

Another problem associated with this booking system was losing opportunities for impromptu discussions with colleagues because of the bureaucracy. For example, one engineer had experienced a problem which he felt he would solve if he could raise a meeting with some colleagues and discuss it. Because of deadlines, he needed it to be spontaneous, however in order to get the meeting arranged, the system demanded that he must contact the resource manager and arrange a booking code. This would take a lot of administrative effort and, in the end because of the time it took, the moment had passed and the engineer decided to shelve the idea. The converse of this was that those who had been asked to help out on another project had had to be told they could not help unless a booking code had been allocated. They felt guilty about following the system to the letter, but did so as they would be contravening the requirements of the system and the demands of the organisation.

It would appear the system needs to be more flexible to be able to cope with these types of situations. Valuable networks of contact, which have taken years to build, appear to be violated by systems too rigid to accommodate such communications. The design engineers reported how it was drummed into them "Don't do it unless you have a booking code". One way around this system was to book in "arisings". This provided some "spare" time for problems they did not know about in advance. The amount of time set aside for this was assessed by experience. However many agreed that what was required was a flexible system because of the very nature of the projects in NPE. Such a system was seen to militate against creativity. For example,

> "You don't work until you have a booking code. There is no incentive to allow your mind to wander and try and think of a solution to help the person who has been trying to solve a problem. If you did this, you would be told it's not your job as you are not booked on this and you are then pushed back on track."
>
> N(2)23/wk4/bk2/pg109/ln37-41

The SAP system should avoid the design engineers being over committed, but it was too rigid to support the collaborative and creative needs of the engineers as a specialist group of professionals. It could not account for the day to day pressures of working and the kinds of problems to be overcome.

The SAP system was designed to be able to cope with changes in deadlines and deliverables, but as one engineer stated,

> "Plan the number of people resources, milestones etc into the system. But this is not related to individual people. It is up to the control manager to see enough time has been allocated to meet the milestone. For example if a third of an engineer's time has been assessed to reach the milestone, but they haven't been able to allot that time, then the milestone is at risk. If the worst comes to worst, it could be shifted, but it depends on how crucial the milestone is. We might be given another task. The SAP system can't cope with that adequately. Either we ask for more people or we work longer hours and then ask for time off in lieu. Therefore something has to give. Should really negotiate through SAP, the control manager, resource manager and project managers. We should get all three to agree and then get on and do the job. It should be a rolling process with other jobs coming in. Then SAP should relate to what's available and adjust the timescales as the jobs come to fruition. But the way it is set up assumes you can plan the job sequentially, but it doesn't happen like that in reality. As you're given a new job, this has to be slotted in with the rest. It *should* be re-negotiated to be able to slot in, but SAP appears not to be able to cope with that. SAP is a good production tool for one product, but too many things are running in parallel in the company and therefore a conflict of needs and resources arise."
>
> X(2)22/wk4/bk2/pg107/ln60-79

It can be seen from this dialogue that there appeared to be many problems with the new SAP system 'fitting' in with the demands of NPE. The way the design engineers had learnt to circumvent this problem was to plug in a "dummy" task or operate a "slush fund" which would enable them to buy some time and have some hours free for panic jobs. However this was not ideal because it could not represent a true model of the project plan. In addition any performance indicators measured against the plan would be erroneous. Those involved in initiating a project saw it as having to "plan for a plan". That is thinking things through to see what man hours were needed and other resources before actually getting on with the job. Whilst on one hand this could be viewed as good practice, for the experienced designers in NPE they found it inhibitory and often irrelevant for the types of project and problems they worked on.

In week 6 of the Tracking Study an example where the SAP system was too rigid a system to be able to deal with a change in time scales due to the politics incurred on a project.

> "The major inhibition is timescales. They are not moveable as they are driven by politics. We will produce something outlining the problems, but there is no time to produce solutions. There are knock on effects for other projects. The SAP system should be able to handle this by re-jigging the milestones and deliverables of the task booked *but* if promised deliverables to the MOD or 'company X' are within certain timescales then the problem arises. People try their best to integrate the additional tasks at the risk of other tasks by either working harder or taking short cuts."
>
> X(2)30/wk6/bk2/pg134-135/ln59-65;88-95

Another engineer also agreed with such comments.

> "The implications are that we'll have to do more work which is unplanned for. Either we do extra or we slim down what we can do. We need to negotiate the depth of the study and it will end up being a lot shallower. Therefore the quality of the final product will suffer. Chances of missing things increases and it will have to be a minor study instead of a major one as the man hours are not there."
>
> B(2)38/wk8/bk2/pg165/ln25-29

It would appear that to alleviate the problems encountered with the SAP system, design engineers were using methods to circumvent them. Either by 'fooling' the system that adequate hours had been booked or the tasks were being compromised. The single project manager who was interviewed during this Tracking Study felt that the SAP system was useful, but it depended who you were and why you were using it. The main problem was that it was not flexible enough for the types of projects carried out in NPE. There was a "de-committing process" which involved contacting and negotiating with the control, resource and project manager. It could allow you to accommodate an unplanned project, but it was a rather long drawn out process and no one bothered. They just coped when such a project was slotted in for two weeks. The outcome of this was that other projects suffered. The project manager admitted though that this situation could not continue as eventually it could impact on the company's operational performance and market competitiveness.

7.4.2.3 Policy changes for design methods

Some felt that the introduction of committees were of limited benefit and stifled innovation. The committee system developed on the basis of formalising problem-solving and risk limitation would be called to help solve a problem. So rather than an individual taking responsibility for solving a problem a committee was invoked to sanction such decisions. In the past a respected senior engineer would make a decision as "they know best", but that decision making had been transferred to a committee now and the process took longer, slowed things down and may even have compromised the final decision. They felt this may be a money issue within the company as there was only enough money to look at one option now and probably the one with the lowest risk assessment.

As one engineer put it,

> "You wonder if same decision would have been made on the Harrier [Pegasus engine]. That was a brainwave and the engineer had conviction, knew it would work and went with it. Whereas today the committee may well talk themselves out of it."
>
> B(2)9/wk2/bk2/pg54/ln174-178

Such organisational changes can have an impact upon its culture and individual self perception of what it is to be a "professional creative design engineer" (West, 1997).

A recent notice from the company had this effect on one of the design engineers being interviewed.

> "We have had notification about a change of policy regarding IT equipment. It will be a PC base rather than a UNIX workstation. Another bright idea which will cost us no end of heartache. It is imposed from the company without knowing why people use workstations."
>
> N(2)31/wk6/bk2/pg140/ln115-119

This particular engineer had an example of where this attitude had affected his way of working. He commented on suffering from "initiative fatigue" as a result of so many initiatives and ideas being introduced by the company.

> "I used to have a printing facility where I could print to a plotter to scale the engines. The plotter broke and it was declared obsolete. I lost this capability. What used to be one step are lots of extra steps now. I work on the GENESIS system, save as CADs instruction file which then has to be transferred to a UNIX system, which in turn gets transferred to a CADs where I can execute a file to generate a picture. I don't bother now. Instead I take pictures off the screen and compare, but its tricky and you can't really compare due to the scales being different."
>
> N(2)31/wk6/bk2/pg140/ln119-125

Clearly organisational processes and changes in them affect the way people work. Some processes were seen to militate against creativity especially the SAP system. However, it should be remembered that this system had been introduced relatively recently and that acceptance might happen in response to later system adaptations.

7.4.3 Category III: Weltanschauung (world view) and cultures

The data pertaining to the attitude of the organisation, as experienced by the design engineers, forms this category. Originally such data would have been logged under the category organisational processes, but it was deemed necessary to split the category. It is not unusual as coding analysis continues to find data which no longer appears to 'fit' the original category definition. When it becomes too distinctly different, then the decision has to be made whether a new category has been found. This is what happened at this point on the research and analysis.

7.4.3.1 Information sharing

One of the 'messages' from the company was the value of "shared information". However it was felt that the company paid "lip service" to this statement as access to information from other departments was often blocked. This was seen to be a result of demarcation within the company. The company wanted information to flow between different departments freely, but in reality it was often blocked. The reason for the obstruction was described as being due to "internal politics and power". Heads of departments were concerned if other departments could access their information as it could put peoples' jobs at risk and they would lose an element of control over other departments.

It was often alluded to that the two UK sites of Bristol and Derby had different cultures and ways of working. For example Derby were viewed as defensive and guarded, working under more of a formal hierarchy whereas employees on at Bristol were more relaxed with a shallower and less formal hierarchy. According to one project manager the feelings went deeper than this and different cultures at the two locations led to some degree of rivalry.

> "Derby doesn't believe there is any talent in Bristol and despise the military work we do with the long timescales. Bristol is not recognised as a site with any capability. The communication is all one way with Bristol not being taken seriously. Derby has the ability to produce the Trent engine in three years. In fact Derby takes a disproportionate amount of money generated by Bristol who bring in large amounts of money."
>
> I(1)44/wk8/bk2/pg183/ln99-106

These differences appeared to have implications for the relaying of information and working together between the two sites.

> "Derby appears less adventurous in their ideas and has a narrower focus in finding solutions. Can't get them to think across company and across product. When working with them you need to keep reminding them not to forget the military."
>
> Y(2)27/wk5/bk2/pg124/ln72-76

> "One way traffic. NPE feed in, but they [Derby] won't feed back. You can never get access to them to share information. It all goes to the centre with nothing coming out."
>
> Y(2)36/wk7/bk2/pg157/9-11

This particular design engineer had experienced what he referred to as "closed minds". He had carried out a number of presentations, but there had been no feedback or sharing of information. He found this frustrating because people in Derby could be working on similar work and yet there is no way of knowing this or drawing on the benefits derived from the cross-fertilisation of ideas. This was also seen to be the case between NPE and its equivalent in Derby. There is limited communication between the sites and yet both have similar ideas and may well be working on the same things.

7.4.3.2 Management expectations and attitudes

It was suggested that senior level managers did not appreciate the nature of creative processes and viewed them as being akin to a mechanistic systemic approach that could be easily accommodated into the introduction of the SAP system. The use of the SAP system had meant they had become "slaves to the system" rather than it working to their advantage.

> "Senior management are now more programme orientated, but it is stifling for those who are creative. Creativity with systems appears to outstrip creativity with product."
>
> X(2)5/wk5/bk2/pg27/ln46-48

> "The senior level thinks if you have the technology in place and a bright engineer, creative design will follow. That's too mechanistic and the wrong attitude."
>
> X(2)5/wk1/bk2/pg30/ln115-117

One of the design engineers had grave concerns for the company. He felt that the company thought they were big enough to maintain power in their field. He used the IBM example where they thought they had a monopoly until the personal computer was taken up as the standard computing tool in business.

The company wants to encourage their employees to be involved in a continual learning process. However it was felt that due to the day to day pressures this was not achievable. An example was provided to support this.

> "Person puts their name down for a course, but because they have to fulfil their short term commitment to the job, they end up not going on the course."
>
> X(2)16/wk3/bk2/pg84/ln128-130

It was also felt that Rolls-Royce Aerospace was basically a mechanical company although it wanted to become an integrated power systems supplier. However it was thought the company had not fully understood what the implications of this were and were at risk of "missing the boat".

Another area for concern was the franchising out and outsourcing of various departments. For example all secretaries were employed through an agency. Comments were made by those interviewed who speculated that the company could be in a position where they made nothing, but just had the intellectual expertise. This concern had also been raised before by the Whole Engine Process Improvement Manager, Rolls-Royce Aerospace on a visit to the University of Plymouth where he stated, "Design is being franchised out—is it viable devolving the whole engine integration/concept? If so, we are giving away the crown jewels."

A number of engineers commented on the loss in manpower since 1985 when 14000 were employed and now it was less than 4500. A lot of this reduction in manpower was because of the automation of processes. This situation was thought to have major implications for knowledge sharing in the company. This was because a lot of the experience and wisdom relating to the success and failure of engines was held in their heads and not documented anywhere on paper. Such knowledge is an obvious asset to a company as without it is likely that the same mistakes would be made again that were made in the past.

7.4.4 Category IV: Timescales of project

The Tracking Study found only a small number of references to timescales *per se*. This confirmed the findings from the DGI Study (chapter 5, section 5.3.1.3). A few references to timescales were made in the meetings. For example, modifications to a proposed design were suggested, but it was pointed out that not much further refinement could be done within the timescales without first obtaining feedback from the customer and their thoughts about this. It was recognised how important timescales were in demonstrating that something had been achieved and in providing a framework against which decisions could be made on a particular project.

What was evident in the Tracking Study was the problem of fitting in all the tasks that had to be done, especially when additional tasks needed to be completed. This led to concerns about immediate problems militating against long-term problems and how they might be resolved. For example,

> "I had a panic job to do which had to be finished by Wednesday as a senior engineer had to have the information to take to France. Things were very 'hot' and this information may have helped to sort it. The original project has been left for two weeks."
>
> B(2)24/wk5/bk2/pg112/ln11-15

Timescales were important though and had to be worked to. The frustration occurred when the politics of working with other companies delayed progress.

> "The major inhibition is timescales. They are not moveable as they are driven by politics. We will produce something outlining the problems, but there is no time to produce solutions. There are knock on effects for other projects."
>
> X(2)30/wk6/bk2/pg134/ln59-65

Many of those interviewed remarked how working to tight timescales meant they had to cut corners and "thin" down studies to fit within the time frame. There is less finesse and maybe some approximation instead of a full analysis of the figures. For example, a small group of the engineers were working on preparing a package of software for another company. The timescales were getting very short and de-bugging and other features of the software were being viewed as less and less crucial as it had to meet the set deadline. One major concern was at one point there was consideration of the "time bomb" (protection codes installed to prevent pirate copies being made) feature being dropped. The company would be asked to agree not to copy the software, but the engineers did not feel this was sufficient. Fortunately their concerns were listened to and that particular feature was retained. However there were still concerns that bits of the programs would still require "workarounds" to be able to function properly and this would not meet the usual Rolls-Royce quality standards.

7.4.5 Category VI: Integration with other companies

7.4.5.1 Political environment

Many of the projects, with which some of the team members had an input, involved several different companies and countries. It was evident that company politics played an important part in these collaborations. Often when the engineers felt they were about to make progress, a stop would be put on the project. Meetings would be cancelled with no reasons given. They found this "blowing hot and cold" difficult and frustrating as they were not kept in the picture and could only speculate on what was happening.

> "Turbo-prop is a political scene. Last week it was almost full-steam ahead, but today the political climate has turned chilly. Unsure whether we will get any explanation. It would be nice to know why, but the wind may blow warm again. Never quite know what's going on at the higher level."
>
> N(2)42/wk8/bk2/pg177/ln81-85

They also felt at times there was nobody overseeing the bigger picture.

> "Collaboration of five nations on a project. We discussed what they have to produce. For example one may make the design and another make the parts. Each bit can be in charge of each module, but needs someone to be in charge of the whole engine and take that responsibility. We need to agree how bits will go together, that is we need to know what the dimensions are to meet other parts made elsewhere. We are in the early stages at present, a case of 'you show me yours and I'll show you mine'. We are scheduled to talk to today, but it has gone very political. We are constrained about what we can talk about at the moment. The meeting has been called off, but we are still working on the background data to draw upon once communications are re-established."
>
> X(2)39/wk8/bk2/pg168-169/ln10-23

The uncertainty as to whether collaborative projects would progress or not impeded their work and any creativity required in solving problems. The designers did not know how much effort to put into a project due to the instability of the situation. A lot of effort may be input and the project suspended infinitely, when that effort could be spent more productively elsewhere.

7.4.5.2 Coordination

A similar case was found with the team who were reviewing the software package before its supply to the client. The package comprised three elements each being prepared by different areas of Rolls-Royce. The concern with those interviewed was that there was nobody pulling it all together. For example, each group were writing their own user guides and no-one was overseeing what the format should look like to present a united front. They felt they needed a leader to make sure they were all pulling in the same direction.

The major concerns of working with other companies were the political issues and communication. Both factors tended to affect the progress of the projects.

7.4.6 Category VII: Working practices (changes in)

7.4.6.1 Secretarial support

One of the main comments, which came out of the Tracking Study, was that the design engineers had had to adopt and develop different skills. For example in order to present business cases they used PowerPoint to prepare their presentations. They referred to themselves as PowerPoint and spreadsheet engineers. As typing pools no longer exist, the design engineers had to type their own reports now. They are expected to do more administration and be proficient in Word, Excel and PowerPoint and they felt that this all distracted from central engineering and thinking time.

> "These days we have less time to do design work. Thinking time is dramatically reduced and therefore the quality of the end product is reduced too."
>
> B(2)9/wk2/bk2/pg55/ln208-210

One of the other changes in their way of working had been in the increase in telephones. They reported they spent a lot of time answering the phone often on behalf of others who were currently out of the office. This meant usually getting involved with the request themselves and spending anything from a few minutes to a lot longer on dealing with the telephone enquiry. In the past the section leader would only have access to a phone, they would have taken the message and only fetched you if it was urgent. Those interviewed thought that if they had more secretarial support, messages could be filtered and they would experience fewer interruptions.

7.4.6.2 Email

Most of the engineers had email and found the amount they had to deal with to be quite disruptive to their working day. The current practice was the secretary, who in the main was the Head of Department's personal assistant, forwarded every company bulletin. This cluttered the 'in-tray' and whilst interesting it was not always directly relevant. For example,

> "Email is a problem. Lots of stuff is forwarded onto you such as engineering reports. Ninety percent is not relevant to what you are doing although it can be useful background. So you try to use criteria to reduce the amount of email."
>
> U(2)6/wk2/bk2/pg37/ln140-144

When things were more paper based, then there was a 'natural' filtering process in operation whereby the first person who read it would either bin it if they felt it was not worth passing on or would take it to the person for whom it was most appropriate.

7.4.6.3 Formal procedures

Changes in the procedures of the organisation were perceived as more formal than before. They felt bombarded by initiatives, reviews and processing gates. This was something the Whole Engine Process Improvement Manager on a visit to the University of Plymouth had referred to as "change bombardment". The experienced designers also felt that too many engineer designers were doing non-engineer work such as servicing telephones and other administration, leaving little time to tackle 'real' problems.

7.4.6.4 Personal development

In previous years designers had been able to move around the company to broaden their experience. It was felt that people were now moved to meet the business needs of the company rather than for personal development needs. So it was perceived that "Investors in People" and staff development programmes were driven by the company's short-term needs with limited support for the longer-term staff development needs of employees and the organisation.

7.4.6.5 Opportunities for discussion of designs

In the "old days" (that is before Business Process Re-engineering) the design engineers presented their ideas to the same design group who understood what they said. They all had an input and could feed off each other. However things had changed and this practice had been replaced by seminars held on certain subjects from time to time. The emphasis had changed too in focusing on the deliverables rather than finding and exploring new and creative ideas or opportunities to problem-solve current issues.

7.4.6.6 CADs versus drawing boards

As mentioned in the earlier studies of Phase 1 (see chapter 4, section 4.4.3) and chapter 5, section 5.3.1.13) many changes in the way the design teams worked were articulated. For example,

> "Big design teams used drawing boards and you could see the design develop. As a young designer you could saturate yourself and see what was happening. Workstations are much more difficult. It's more difficult to see the screen, what the problem is etc."
>
> X(2)5/wk1/bk2/pg26-27/ln23-28

> "I'm frustrated as I am unable to go to a drawing board as I did in the past and draw things myself. Useful to have the skill of using CADs and Pro/ENGINEER™, but it's the time element associated with the training."
>
> X(2)16/wk3/bk2/pg81/ln67-70

Others reported how they could discuss more easily with the designer the 'whys and wherefores' of the design around a drawing board whereas computer screens are too small and low and the light is often a problem for everyone to see at once. Drawing boards were left at night and some reported using this opportunity to spend time looking at the design and familiarising themselves with it. Drawing boards offered a better place for interaction with designers about the design.

> "A couple of drawing boards are left in NPE and if a drawing is left on it somebody will go have a look and usually find someone else will join them and start a dialogue."
>
> N(2)23/wk4/bk2/pg111/ln72-74

This loss of using drawing boards appeared to be a major issue for the experienced designers. They felt this particular artefact enhanced the sharing of knowledge and understanding in a different more social way to that of a computer screen.

7.4.6.7 Inconsistencies in data tracking systems

A problem was highlighted with the departmental tracking of data. For example it was difficult to maintain an audit track of data transferred between the different designers working on engine performance, engine design, aircraft performance and evaluation. Data for the GENSIS[2] software program are stored in libraries with task numbers assigned to the reports. Working folders for task numbers identifies different projects. The performance engineers in NPE did not use this system as there were no set standards on handling data and this caused problems. What would be beneficial would be to assign a task number to a major piece of work and use that for each element as well. At one point there is a "transient book" where data from the performance engineers is placed on the mainframe for the GENSIS team to pick up. However as this "transient book" has a limited life on the mainframe the team need to access it quickly before it becomes deleted. Also the process for putting the data into this special space is complicated and depends on the expertise of the designer. Due to this issue, it was easier and quicker to manually pass the data in hard copy format to the GENSIS team.

Eventually the design dataset is returned to the mainframe and is logged in a "chapter and verse" format on the basis of how and when it was created. This provides an audit trail and makes it easier to archive material. The performance engineers did not follow this system and therefore it was harder to see what was new and what was old. Also they did not save their data. As a consequence no questions could be answered once these data had gone. A new model of performance would need to be generated again if this was the case. If it was saved then the performance engineers tended to save the model on their personal drives but they had no structured organisation of the saved

2 GENSIS is the name given to the whole engine model which has been developed to assist designers in preparation of proposals for new or derivative products.

files. Therefore if that person was away no one else was able to retrieve the data. To circumvent this problem they gleaned information from other sources and with an element of guesswork, recreated the model. This obviously had risks for the progress of a project and loss of work could potentially waste a large amount of the designer's time. People appeared to just make up their own way of working and this was not conducive to efficiency or creativity.

It would appear there are many issues relating to changes in working practices which could cause perceived barriers to creativity. These included changes in internal systems and procedures, technology and communication channels. Changes in the way of working have seen a greater expectation of skill development with less time for completion of projects.

7.4.7 Category VIII: Project management and the Derwent[3] "philosophy"

7.4.7.1 Reducing the space of alternative designs

The control of projects involved planning, estimating cost, timescales, task managing, deliverable and milestones. As those who were interviewed highlighted creativity cannot be planned for in terms of what problems might be encountered and need resolving, how long that will take and what expert knowledge might be required. In the past there had been flexibility to follow things up and for the designers to be more innovative. One reason for this was that there were more designers then. Nowadays, there is a process of project management to follow which does not allow time to think of alternative solutions and designs.

> "More things happen as a way of fulfilling a need. Not sure how it would fan out. We can't plan ahead here in NPE. Whereas now we are just given an objective and two weeks to meet it. There is no idea of realism for how things are created with a shift to a rigid planned system of project management."
>
> U(2)1/wk1/bk1/pg5/ln131-137

One of the concerns for the designers was that project management may get things done on time, but there was no opportunity to fit in newer and radical ideas. As a consequence they felt that the products were more derivative now.

3 Chapter 1, section 1.7.1 provides a brief outline of Project Derwent.

> "We first got our skills from first generation gas turbines. It is not so now. Aero-engines are much more derivative and evolutionary rather than having radical changes. Much like the auto industry."
>
> X(2)16/wk3/bk2/pg85/ln157-159

7.4.7.2 *External politics*

There appeared to be problems with the uncertainty of projects often related to the politics of working with other countries. For example,

> "We started in 1994 with an aircraft wanted for 2004. We only have 3½ years left and we are still running around like headless chickens. The political projects are kicked around different countries. You get problems with different levels of enthusiasm and motivations like a Mexican wave. Planning is stop-go-stop-go. It's difficult to get everyone working on it at one point. It's difficult to get people to make decisions. It's like Ping-Pong between business leaders and engineering groups. You get spurts of input until panic arises again. The trouble is you need to ensure a solution is settled on that doesn't allow companies to lose face. Therefore sometimes starting something completely new is best."
>
> N(2)/28/wk5/bk2/pg126/ln13-26

7.4.7.3 *Coping with 'rush' jobs*

One of the main administration duties of the project managers is to operate the SAP system. As mentioned under *organisational processes*, the system is supposed to facilitate the monitoring and resourcing of projects, but as has been already demonstrated for NPE it is not a flexible enough system to accommodate the 'rush' jobs expected to be covered.

7.4.8 Category IX: Management style

7.4.8.1 *'Efficiency' versus 'creativity'*

The *project management* category had to be split to provide an additional category of *management style*. It was evident from the transcripts that the manager of NPE had an influence on the way the design engineers worked. At the time of this research there was an imminent change to the Head of the Department (HoD). Prior to the current Head (HoD2), the HoD (HoD1) had been a mechanical engineer. It was suggested that this had meant there had been more emphasis on this discipline. For example there had been eight mechanical engineers working in the department at that time whereas that had now been reduced to two. There may well have been other factors as to why this had happened, but those interviewed saw that project engineers rather than mechanical had now been reduced to two. There may well have been other factors as to why this had happened, but those interviewed saw that project engineers rather than mechanical design engineers had replaced them. They had experienced a shift from the management style of HoD1, who had apparently been "very creative, technically orientated and involved in ideas", to one whose emphasis was that of project management (HoD2). HoD2 was viewed entirely differently to the previous HoD and labelled as "modern management".

> "Now the culture with this HoD [HoD2] is that of a 'bean counter'. Money and resources is the emphasis. Not as technically active or as good as the previous person. Previously the culture was much more creative."
>
> N(2)23/wk4/bk2/pg111/ln79-83

These comments may be expressing underlying concerns about the change and the new culture that had to become accustomed with HoD2 rather than direct individual criticism.

HoD2 was also seen as quite dynamic and as having a presence when in the department. The designers often experienced interruptions from the HoD with higher management input and felt they "had to jump and drop everything" and complete the work requested at short notice.

During the course of the Tracking Study the HoD was absent from the department for a week. Several of those interviewed expressed how there had been a significant reduction in interruptions and unplanned jobs to do.

> "Less interruptions this week as HoD is out. We are able to get on"
>
> U(2)6/wk2/bk2/pg37/ln145

Again, the HoD was in a difficult position. He had to work with pressures due to wider issues such as less resources and market conditions and run an efficient and effective department. He had to strike a balance with the employees in the department.

There was a little apprehension about the replacement (HoD3) for the current HoD (HoD2).

> "There is a new boss coming in [HoD3]. We need to teach them what the department is all about. Moving people around causes disruption. They come in, see what's happening and have their own ideas. They start to change things then realise it's not applicable necessarily in this department so we get a hybrid version of working. Start with a new person, chaos for a while and then it will evolve into something better."
>
> U(2)14/wk3/pg73/ln31-38

7.4.8.2 Reduction of reference to basic principles of design

A major concern for some of the designers was a change in management style they felt had left them vulnerable when preparing for a project. In the following example the project had been apparently ongoing for the last six years although the urgency for finding a solution had waxed and waned during that time. At the time of the research it had become prominent again.

> "The previous HoD of NPE (HoD1) would always map out the playing field first. That is run a parametric study looking at a range of studies using abstract parameters. For example what happens to fuel consumption, weight cost etc. when you vary the parameters. You end up with a grid which helps to identify what the optimum points are and see what the penalties are if you move from one optimum point to another. When this chap left, this approach died. Now we were told to consider two proposals using current hardware [engines], but they are no good. Where do we go from here? There is no map underneath so we have no idea what to do. There is pressure of time and it's like looking for a needle in a haystack with the light off! Nobody thought about starting from a clean sheet in the beginning and it's too late now. People think they are near the optimum, but don't really know. They are relying on a gut feeling. NPE will come up with some cobbled proposal to keep them at bay. Downside is the time pressure now. A parametric approach gives you thinking time. You need time (weeks) to do that, but they say 'It costs too much, you haven't got the time, make a guess'. It's a short-term attitude. Do the job, get it out of the way and get on with the next one."
>
> N(2)31/wk6/bk2/pg139/ln69-97

There was a feeling that general management should be more encouraging of ideas and be more receptive. However HoD2 had agreed to have a team of new graduates join the department and work on a specific project because they came with "new ideas and little baggage".

Near the end of the research the HoD2 moved to Derby and a replacement (HoD3) had joined the department. It was hoped the flow of information between the two sites might improve as a result of this change.

Although the new HoD had only started at the end of the Tracking Study, comments from those interviewed indicated that there appeared to be fewer interruptions from him. They felt HoD3 was more low key, but realised things might changed as he became more familiar with the department and its employees.

It would appear therefore that the management style of NPE had a fundamental impact on the workload of the designers. Such style changes were also tied to the wider business and market needs which inevitably leads to cultural and environmental changes for the company and its employees.

7.4.9 Category XII: Experience of designers

7.4.9.1 Perceived qualities

Many skills such as being pragmatic, patient, realistic, diplomatic, open-minded, analytical, having a good sense of judgement and knowing when to stop were highlighted by those interviewed as important for designers. What were also essential skills and qualities were having a wide knowledge base, good communications skills and the ability to think laterally and spatially.

7.4.9.2 Development of new graduates

It was felt that the training regime for the new graduates did not give them the opportunity to build a wide knowledge base, as had been the case in the past with the apprenticeship scheme. This was felt to be partly due to the departments in the company being more specialised and process/project orientated.

The new graduates also found difficulty with the in-house software and due to limited experience found it difficult to generate a number of different options. They also found their university experience did not necessarily prepare them for work in industry although they were highly numerate.

> "Universities [courses] have a very theoretical approach, but little on the practical element. So they [the graduates] know how to do the calculations but have little idea of how this falls in with the rest of the engine. It doesn't prepare you in how to use 'weapons' [tools]".
>
> CC(3)34/wk6/bk2/pg150/ln60-64

One of the new graduates interviewed had experienced problems with obtaining enough supervision and direction due to the pressures and demands of his supervisor.

> "There was a problem fitting in to meet for a progress review with my supervisor on Monday, so I had to meet up with him on Wednesday. I couldn't get on with anything until the supervisor returned and I felt bored."
>
> V(3)18/wk4/bk2/pg88/ln8-11

The next placement for this particular new graduate's training appeared to be better organised with a number of tasks outlined in advance.

> "There is more training development at the beginning of the placement. More than in NPE and more structured because they are better manned."
>
> V(3)18/wk4/bk2/pg90/ln74-76

It would appear workloads and time pressure impacted on the amount of time experienced designers could help new designers.

7.4.9.3 Loss of design experience

As had been expressed in Phase 1 of the research, throughout the Tracking Study concerns were also expressed about the loss of knowledge from the industry due to the retirement of experienced engineers.

> "Seniors are too busy looking at the bottom line. I have seen a large amount of people walk out with a vast amount of experience. Some come back as consultants, but that's only one attempt at addressing the issue."
>
> X(2)25/wk5/bk2/pg119/ln86-91

This comment was from an experienced designer in the department who wanted to pass on his experience, but commented they were only encouraged to do this locally within their own department. He felt frustrated about this situation and thought others in similar situations probably felt the same and that was why they sought to leave the company early.

> "I've got a contact now in compressors but it needs a designer to be assigned to the task. I don't know if he'll have the amount of experience needed."
>
> X(2)5/wk1/bk2/pg29/ln102-104

There were many concerns relating to this category. Less experienced employees meant that contacting the right person to assist them with information on the project was more difficult. The passing of knowledge was happening in some instances but to a smaller and smaller pool of people with less time to do it in.

7.4.10 Category XIII: Design process

As presented in chapter 5, section 5.3.1.11 this category refers to the processes experienced by the designers recorded during the Tracking Study. Some felt that to be able to solve a problem they needed to obtain a critical mass of understanding. This required access to the relevant knowledge information and resources and time, which was a rare commodity. If time constraints intervened or information was blocked it caused problems.

7.4.10.1 Expectations and attitudes

The design engineers were experiencing problems with their designs due to changes in attitude and time issues. For example,

> "The attitude is to meet the requirement according to the procedures. The problem is that there is no thinking time done around some of the design process."
>
> X(2)5/wk1/bk2/pg27/ln34-38

> "I would like more time. You need time for lateral and creative thought in NPE. It's not a production process. Human thought processes need an infinite amount of time. There are too many problems to think about and the total process suffers."
>
> X(2)39/wk8/bk2/pg172/ln111-112;117

Interruptions caused by 'panic' jobs meant that the designers had to keep changing their priorities and switch from one job to another. This upset their thought processes, ideas were lost and trains of thought evaporated.

7.4.10.2 Downside of software support

One experienced designer discussed the benefit of "making and breaking" something and what that can teach you. He felt that the company assumed that with the new technologies available this would no longer be necessary

> "Why make anything if you can simulate it on a PC? For example GE90 was the first 36 month engine. There was no rig testing, it was all done on computer. Delivered to the customer meeting their specification within 36 months. Lots of problems were encountered as analysis and assumptions were incorrect so they switched back to the Trent engine. Put crap in, get crap out. That was an example of not making and breaking things and learning from it. The new stretched 777 engine has had a series of developed or rig engines and it has been tested to death so they won't make the same mistakes again."
>
> B(2)9/wk2/bk2/pg51-52/ln96-109

The new technology had made an impact on the way they design. For example as they had more advanced software with greater facilities and capability, more analysis was undertaken perhaps unnecessarily.

> "There is a tendency to do more analysis on a screen. It is possible to analyse to death with too much detail in the early stages because we have all the tools there. This can waste a lot of time where previously you would have realised earlier in the simple sketches and equations at the beginning of design."
>
> B(2)9/wk2/bk2/pg54/ln180-185

With their high workloads and the need to compromise on outcomes this could be viewed more positively because they had to remain more focused on the job in hand. However it was easy to do more detail than was necessary which was referred to as "gilding the lily". They found they needed to draw a line under the problem if they felt they had answered the question. No longer did they have the time for fine-tuning.

7.4.10.3 Office environment

Many referred to the noisy open plan environment they worked in as interfering with their thought processes. For example, the telephone ringing constantly, email notifications bleeping on the computer and the general humdrum of the office (see also section 7.4.6.1). Problems were often solved when they were in a quieter environment where reflection was possible such as driving to and from work.

> "Emails and telephones interrupt. Most times it's OK if doing routine jobs, but not so if you are doing something more novel. You get a momentum up on an idea, get going and people ask for help. Then you come back to it and the idea is lost. I try to go off and hide."
>
> Y(2)11/wk2/bk2/pg63/ln85-88

7.4.10.4 Importance of social processes

During the meeting (Z2/wk4/bk2/pg95-98) with four design engineers three proposals in relation to engine mounts were presented. Extensive discussions and debates took place with evidence of experience of similar designs being drawn upon. Discussions of the "what ifs?" were evident which looked at different materials to keep costs down and the implications of this. Additional sketching took place and every feature of the options were discussed, problems highlighted with alternatives and solutions debated. Ultimately the customer would have to decide whether further refinement was undertaken because of the timescales involved. This evidence highlights the importance of social interaction in the design process. Such evidence of consultation to help solve problems was recorded. For example,

> "A consultation with [X] realised I needed to look at something in a different way. I drew up a structure and looked at how it would fit together. I knew that was where I wanted to get to, but I didn't know how. I discussed different aspects and this led to the solution. A good idea came out of this."
>
> Y(2)27/wk5/bk2/pg124/ln46-50

During the Tracking Study evidence of designers' approaches to design were recorded. In this particular instance a smaller project which was part of the FOAS project was to produce an expendable engine (unmanned). Such an engine would need to be cheap, as it is likely to be shot down in hostile environments. Therefore the engine cost needed to be reduced by 90%. The experienced designer involved in this project began by laying the groundwork by writing a paper on the issues involved. His report had a number of headings which he then passed to another experienced design engineer to add his thoughts to. The headings provided a route map looking at the major cost drivers. Once the report had been completed, existing engines would be considered to see what trade-offs could be made. For example, if the engine was a "clunker" (poor-performance engine) there may be a need to compromise and to add in costs to increase performance. A datum engine was chosen to make comparisons against any radical changes to the engine design which would be needed to be made in order to cut costs. A brainstorming session between a number of designers was organised to help stimulate ideas, again highlighting the social aspect of the design process.

It was felt there was a lack of understanding in the company as to what was really involved in the design process. Roll-Royce's answer was to invest in technology, but with little acknowledgement of those who used it.

7.4.11 Category XIV: Communication (social)

7.4.11.1 Individual and local versus team motives

Communication between departments was seen to be problematic at times. All of those interviewed highlighted the need for knowledge and information. This was fundamental to whatever they were involved in and yet there were obvious barriers in accessing it.

Knowledge was seen as power and some of those who have the knowledge were reluctant to share it as they felt their job was threatened. One interviewee expressed it this way.

> "NPE are specialists. The concern is that NPE will absorb their function and do them out of a job. So people are wary to give information to NPE up front."
>
> U(2)1/wk1/bk2/pg1/ln28-30

There was concern that being too creative, for example creating an automated system could mean you are doing yourself out of a job and this encouraged a "Luddite" attitude amongst some people.

> "The older section of the workforce are concerned with 'digging their own grave'. It's a 'young person's company if you look at the rate of changes on technology and computing."
>
> U(2)1/wk1/bk2/pg2/ln56-59

As perceived from the designers' perspective there also appeared to be a problem between the conflicts of interest between senior levels of management in the main corporate departments such as turbines and compressors. This was attributed to personal and career reasons. The problem and barrier was highlighted by this interviewee's statement.

> "Cost engineering are supposed to supply data—a naive thought. Cost engineering did assist but provided misinformation. So lip-service is paid to this idea of 'sharing information'. It's OK as long as nothing comes of it as it would do themselves out of a job."
>
> U(2)1/wk1/bk2/pg8/ln190-194

It was suggested that if NPE has the information from certain areas, and as a consequence then has the capability, people in other areas would no longer have a job. Before the advancements in the technology the flow of information was good. Information was supplied readily because the designers were mainly involved in drawing. This was seen as a non-efficient process but with access to new technology there was a fear that NPE could replace the work of other departments by not only completing the drawings using the technology but carrying out the analysis as well.

7.4.11.2 Importance of personal contact

Another problem regarding the communication between people was the location of the working groups. Although some designers were involved in collaborative projects, often other members of he project team were based on other sites. What the designers needed to do was to establish a line of contact and it helped if they knew that person beforehand. However even then they needed to be persistent in trying to make contact with the desired person.

> "I use my network of 'old' pals to find out who knows what. This can be a long-winded exercise—making phone calls and arrangements to meet—it could take weeks."
>
> X(2)5/wk5/bk2/pg29/ln96-99

This kind of situation was exacerbated by the reduction in manpower. Where there was one key person with whom to discuss issues with, and they were not available, answers were delayed.

In recent years there had been regular meetings of two main groups (Design headed by one team leader and Operational Analysis & Technical Design headed by another team leader) which had operated in NPE. These had worked well and had provided a forum for communication in raising and discussing issues relating to projects, the department and the company. More recently these meetings had been dissolved and instead somebody from the department went to weekly debriefing meetings with one of the senior managers and fed back to the 'shop floor'. This was seen as very much a one-way communication channel with limited opportunity for dialogue or discussion of the issues. It was hoped that someone would 're-invent' it again so the designers had a two-way communication flow.

The new graduates had a slightly different experience when it came to asking for information and help.

> "The graduate tag—you learn to use it to benefit yourself. Some are keen then to take you under their wing and provide the information or help you need."
>
> AA(3)32/wk6/bk2/pg142/ln17-21

However what the new graduates also experienced was problems in getting their ideas across and accepted. They did not feel they were listened too and taken seriously because of their position in the company.

7.4.11.3 Mismatched expectations

Several of those being interviewed in this phase of the research were working on a project which meant they needed to interface with colleagues in Derby. The project involved the sale of an in-house developed piece of software which comprised different packages. The packages were inefficient and needed some new development. Those involved in Bristol worked on these packages, but required further information from the turbine group in Derby. Many problems were encountered for a variety of reasons. One of the major barriers to progressing with this project was that Derby wanted to provide detailed information regarding noise estimation data. Bristol tried to get them to accept that approximate figures and parameters were all they needed because this software was used in the conceptual design phase and did not require absolute data. In this instance a breakdown in communication, due to misunderstandings and misconceptions about what was really required and what could be provided, impacted upon progress.

The sharing of information and the maintenance of communication sources is vital for designers. There needs to be an acknowledgement of others' conceptions and roles to enable the facilitation of good communication to take place across departments and company sites.

7.4.12 Category XV: Technology and sub category communication (technological)

It was decided to merge the previously separate category of *communication technological* to this category because of the overlap in the evidence from the data.

7.4.12.1 Access

The department had a number of different computers for the designers to use. Several had specific software set up on them and may or may not be networked. One engineer in particular, throughout the Tracking Study, had difficulty getting access to a computer with basic word processing functions as there were not enough in the department to use if all the people were present. If people were absent then he had to 'hot desk'. This situation caused him much frustration and angst.

> "I had problems this week getting on a computer to write a report. I need one of my own, but I haven't got this. It's frustrating. I need to wait until someone is out to use theirs."
>
> X(2)25/wk5/bk2/pg118/ln58-61

Access to the 'vaults' (networked storage space) and databases networked throughout the company was not easy. For example, there were a number of icons and windows which had to be navigated before entering the database. Each vault had a specific number to identify it and its contents. What the designers had to know was what that vault held and request a password for each. An example of how difficult the access was is illustrated below.

> "It's not very user friendly with lots of icons and windows. We want something that is more instantaneous for design. Each vault is identified by a number. You enter a query, go through the data browser and find the vault transfer report. That took me about half and hour and then the system crashed. I would like a single icon which is 'parts retrieval' with one window to type in the number and get the system to search *all* the data vaults in Bristol and Derby and come back stating where it is stored and then give options to modify it or read rather than having to sign onto different vaults to have a look. It shouldn't be this complicated. It is written by someone who hasn't a clue how engineers work. Different passwords for different vaults. I don't know why—we are all security cleared therefore no need."
>
> B(2)35/wk7/bk2/pg156/ln59-68

There were other features which could have enhanced the working with these systems. For example, once the file had been transferred from the vault to a local server and then opened in the CADs because it was in a different orientation it could not be viewed until it was rotated. A 'drag and drop' facility would help in these situations. Another problem the designers encountered was if they did not know the scheme number of an engine, only its name, then they would need to ring a person in Derby to find out. Knowing the person in Derby and the name of the engine is paramount to this being successful. This is another example, of "knowing who knows" and the designer's network of colleagues (transactive memory) which they can draw upon to access historical and relevant data.

Access to the library and the internet was very restricted. For example, there was no facility to browse for library books from computer terminals.

> "I needed to check for a book so I needed to physically go to the library. At university I could log onto any machine and see the library. That would be useful here."
>
> V(3)10/wk2/bk2/pg58/ln31-33

> "The way we gather information is laborious. The library is remote—you need to go over there and ask for a search. They are good at what they do, but they can't give an instantaneous answer. The internet can help, but only on unclassified material. There is a wealth of knowledge regarding classified material but you have to request a search by the MOD. That can take a month or so for a shallow search and sometimes you need things a lot quicker. We need a facility where we get quick access and capability—a quick look and see in an hour instead of things taking a week."
>
> B(2)38/wk8/bk2/pg167/ln120-130

Internet access was very limited as there was only one computer in the library which was networked to it. Engineers were allowed to book an hour on the machine for their use. This arrangement was frustrating to the engineers as they felt access to the internet was important.

> "NPE is looking at future possibilities—what the rest of the world are up to. Internet access would seem to be the forum where information is made available. Therefore it would seem sensible to have access to it."
>
> N(2)42/wk8/bk2/pg176/ln64-67

> "Internet access would enhance the job, but it is novel at Rolls-Royce at the moment."
>
> Y(2)13/wk3/bk2/pg69/ln39-40

Others felt that as most of the information they would want to access would be classified, it would not be published for about 20 years anyway.

7.4.12.2 Reliability

A major issue with the technology was its reliability. All interviewed experienced their machines crashing without any warning and it happened on a regular basis which was recorded throughout the Tracking Study. The main culprit was NTRIGUE[4], the PC emulator, on the UNIX workstations which meant re-booting the computer each time it crashed. People had various ways of coping with this from those who saved every few minutes so that a minimum of work was lost at any crash, to others who trusted to luck

4 NTRIGUE is the PC emulator software.

and consequently lost a lot of their work. It was reported that for a time it had appeared to improve, but recently it had become quite unreliable again. As suggested by the following quotes, reliability issues became most important in times of pressure or creative flow.

> "The NTRIGUE system failed again and I lost 3 hours work. I didn't save as I was so engrossed in my work. I was surprised 3 hours had gone by. I got back to where I was previously an hour later."
>
> W(2)20/wk4/bk2/pg101/ln45-49

> "Tuesday I had a panic job. I needed information for the meeting. I was doing the last few lines of entry and the system locked. I hadn't saved as I was in a hurry. Therefore I went to the meeting with scribbled notes and needed to go back to the beginning and start again."
>
> N(2)28/wk5/bk2/pg126/ln2-6

Working on shared drives was seen as useful but required common practices so that joint work could be organised. This did not always happen though and caused problems as described below.

> "We need more control/pattern for the directory structure for each job. It is left at the moment to individuals to organise the work which is fine on their own drive, but not so on a shared drive. It should be similar to a paper system where the same project number is associated with working files. It would help if all followed the same numbers as people need to be able to find things and pick up if people leave or are on holiday."
>
> N(2)2wk1/bk2/pg14/ln84-93

Some colleagues had developed identical directory structures which helped when working on each other's work. They tried to encourage others to work in a similar way, but really felt it should be operated department wide to be effective.

7.4.12.3 Information overload

As had been highlighted in the previous section access to the internet was limited although all had access to the intranet across the company site. Email was used to circulate information amongst colleagues, but it was felt by some that the content had not improved.

One interviewee's comment was:

> "Lots of words, but little meaning."
>
> N(2)2/wk1/bk2/pg15/ln111

Another interviewee found the amount of email intrusive.

> "Email is a problem. Lots of stuff is forwarded onto you such as engineering reports. Ninety percent is not relevant to what you are doing although it can be useful background. So you try to use criteria to reduce the amount of email."
>
> U(2)6/wk2/bk2/pg37/ln140-144

Email was seen as useful, but the amount of incoming mail was seen to demand attention.

> "We are slaves to the PC regarding demands on our time; reading email and responding to it."
>
> X(2)16/wk3/bk2/pg81/ln48-50

One of the problems encountered with the technology was looking at documents on the screen. It was not easy to read and so detail and information were copied down. Often documents had tables of figures in the appendices and the designers were frustrated when they had to scroll up and down to look at them.

Space on the servers had been an issue in the previous studies, but more space had been made available and was of less concern in this study and the problem was not raised.

7.4.12.4 Cross-platform problems

Transferring of data between different computers and countries still remained a problem despite continued attempts to resolve it over the last two years. The problem was that the files needed by other areas of the company were kept on a mainframe computer network. If a 'sister' company in another country did not have access to the mainframe, but could read text files from a workstation, the information had to be transferred to a UNIX workstation and made into a 'flat' file where it could then be accessed. Sometimes the mechanisms were in place, but access was blocked by protection codes which were not necessarily available.

Similar problems were encountered when specific software was not networked. This then involved the transferring of data between a number of computers using floppy disks. One of the designers commented that solutions to such situations had been requested, but resourcing it appeared to be problematic.

"The commercial area are considering via the [ITSS] to re-write some software so it is compatible to work with the LANs. The quote given by the [ITSS] was too high, but they suggested they could employ a smaller company to come up with the answer. Attempts to resolve this problem have been going on for a year or so. Something could be done. It's just the cost of upgrading. The old system doesn't print properly. You have to 'tease' out the printed pages by switching the printer off and on to empty the buffer. We want these situations sorted, but it just carries on."

U(2)6/wk2/bk2/pg36/ln111-122

"It would be better if information is transferred electronically, but it takes time to explain. So I am happy to accept a lower standard, that is paper form and type in [the data]. Errors can be made though with a misplaced decimal point. We used to check this by plotting the data, but we use different software now and don't have that facility."

N(2)17/wk3/bk2/pg87/ln49-53

Where the relevant software was not available or inaccessible the designers had to work around this problem. However this could be time consuming and possibly detrimental to the outcome.

7.4.12.5 Security

As high security is a major issue in NPE, some computers had to be isolated and not networked ensuring no transfer of data could take place. Consequently communication between computers was hampered. Also numerous protection codes were in place making access to database records difficult which in turn could delay the work from progressing.

"You can't access a person's computer due to security. There is a security block on sharing information, but we should be sharing but it is not happening due to security barriers between areas. Managers are prompting the sharing of information, but computer systems block this. OK in some instances, but there are areas where it would be useful. There is a conflict between the idea of sharing information and the reality that it is blocked. I encountered a problem this week. I haven't been able to use the spreadsheet so I had to go back to the Commercial department to ask them to do it for me. It goes against what we are trying to do long term."

U(2)6/wk2/bk2/pg34/ln68-82

As a result of this situation, the designer could not progress with his own work and had to pass it back. There was a communication block between the two departments in the company and a difficulty for the individual who had to find a solution to the problem.

7.4.12.6 Changes of emphasis in design roles

Having access to many different software packages did have a downside in the sense of creating cultural expectations for the presentation of information which distracts from productive design activities.

> "We are a nation of PowerPoint and spreadsheet engineers. There is a tendency to do more analysis on a screen. It is possible to analyse to death with too much detail in the early stages because we have all the tools there. This can waste a lot of time where previously you would have realised earlier in the simple sketches and equations at the beginning of design."
>
> B(2)9/wk2/bk2/pg54/ln179-185

Other forms of technology such as the CADs used in the company were used when detailed design took place. As had been mentioned in the studies in Phase 1, using CADs in the drafting stage was not ideal as it took a long time construct drawings from scratch. Also this package was not easy to learn and takes time to master.

> "CADDs5 needs lots of code inputs. To become proficient, it's a big learning curve and it takes about a year to get to know your way around. Pro/ENGINEER™ is a much more friendly tool—takes about 4 months to get to know."
>
> B(2)35/wk7/bk2/pg155/ln35-38

One of the new graduates preferred to use the drawing facilities in Microsoft Word where elements could be cut and pasted as required. Familiarity with the software made it easier and more versatile for him to use.

7.4.12.7 Usability

Some in-house software was not user friendly and quite unwieldy. One in particular, GENSIS, was written over 25 years ago. Therefore the interface was very old and a number of changes had been made to the programme over the years. The new graduates found problems with using such systems.

> "Radical ideas—there are problems modelling these due to the systems being old and inflexible. You need to do it by hand. There is a lack of resources to fix the incompatibility between the systems. It's frustrating having to wait for something to run. In-house software doesn't take advantage of the progress re computers."
>
> BB(3)33/wk6/bk2/pg146/ln27-33

One positive benefit from the new graduates having problems with this old software was to highlight this very issue. It was felt by some that the more who complained the better in the long run. There appeared to be a reluctance in the company to resource some of the software adequately. For example,

> "Cost development of engine costs was started in 1987-88. It was realised they could improve methods, but couldn't find the money. There is a problem with spending money on the mainframe. So we use Excel and 'add-ons' with little costing programs. It's used around the office and each person tweaks it a bit. Then need to pull back to the correct model. This takes time to run through whereas it would have been minimal cost to change the program in the first place."
>
> N(2)42/wk8/bk2/pg175/ln40-47

Communication with other companies using tele-conferencing was satisfactory as long as the visual material was distributed in advance of the meeting. Video links were not used very often, as the designers did not think the technology was up to it.

This category was another major one which highlighted many issues relating to the technology used in the department. Again issues of communication, operation, and access were highlighted as had been in the studies undertaken in Phase 1.

7.4.13 Category XVII: Creativity

7.4.13.1 Perceived qualities

There were various instances where the designers identified that they were being creative. For example the in-house software GENSIS had been continually developed over the last 25 years. It was not necessarily planned this way though.

> "More things happen as a way of fulfilling a need. Not sure how it would fan out. We can't plan ahead here in NPE."
>
> U(2)1/wk1/bk2/pg5/ln131-132

Where information was not readily available, data had to be created to bridge the gap between the two parts of the software design tools they used.

Those interviewed felt that to be innovative, you needed to be a lateral thinker, able to "challenge the norm" and "break the circle", in helping to solve and overcome problems in the conceptual design phase. Specialists may be able to provide accurate precise analysis based on information, but in NPE synthesising of design was based on very little information. For example, the design engineers created engine performance cycles and produced data relating to engine cost modelling that were based on conjecture about the future requirements and possibilities for engine design.

7.4.13.2 Interruptions

Whilst many of the experienced designers complained about the interruptions they experienced, it was seen that sometimes an interruption enhanced the creative process by changing the focus and allowing a period of incubation to take place. This would depend on the creative activity, the point at which the designer was at, and the nature of the interruption. However for many, interruptions broke the train of thought and impeded their progress.

> "A major impact on creativity is the fact we start things and begin to think things through, then we have to stop and lose the whole thing. Therefore we spend the morning refreshing our memory as to where you were and what had already been written. It takes a few days to get into the swing of things again."
>
> B(2)24/wk5/bk2/pg114/ln59-65

> "A panic arises and you are told to stop one job and do another. A change in priorities, especially if you are in the middle of something, upsets the train of thought. It is the nature of NPE though. Some people get upset and won't stop as they think that is more important."
>
> B(2)9/wk2/bk2/pg52/ln120-126

7.4.13.3 Supporting creativity

One possible measure of creativity suggested by the interviewees was the number of patents they had. Financial rewards from Rolls-Royce were available to those who achieved them. However they had diminished possibly through lack of encouragement and the company not really understanding what was required to foster creativity. For example,

> "New grads are operating within the standard business system. Is this conducive to lateral thinking? Too much system might well stifle creativity, that is a procedural system through a particular route given a number of steps regarding decision points. It may generate too much concentration to meet the needs of the system, but you have met the real requirement of the project or product which you're trying to produce—gone through the steps. Have you accorded with the system rather than concentrate on the actual output—is it the optimum output? Rolls-Royce may say –yes it is a direct result, but I'm not convinced about this. There is not much opportunity for lateral thinking—all getting around a table and thrashing out the issues. But because we are more proceduralised we end up homing in on a solution rather than giving an opportunity to have things better at an earlier stage to make the product better and cheaper."
>
> X(2)16/wk3/bk2/pg84/ln135-151

> "Company re-organisation tends to work against creativity because they are self contained functions and project groups which are very efficient in producing a product, but it militates against creativity and innovation."
>
> X(2)5/wk1/bk2/pg26/ln9-13

Those interviewed felt the company could be more supportive of creativity. One interviewee suggested setting aside some time each day/week for exploring new ideas.

> "There is no such policy here, but it could be useful. A lot may think it is a waste of time, but something may come out of it. The message from Rolls-Royce is that 'you can be creative', but the reality is different. At the working level the mindset and culture isn't present, that is it doesn't foster ideas in a creative way. NPE is slightly different. Most engineers are working on projects working to tight timescales. Chief Engineer will say 'You haven't got time to look at that, we haven't got the money to look at that—just fix the problem.' You can try to be creative within this, but it is difficult to do so. So we fall back on tried and tested ways of doing it due to pressures. People are not encouraged to be innovative—just asked to solve problems today quickly and cheaply."
>
> Y(2)21/wk4/bk2/pg102/ln16-34

As many of the projects are short-term with fixed constraints they found it harder to be creative and saw it as quite a challenge. The engineering designers tended to approach problems in the same by asking themselves, "What is the problem I want to fix?" Different ideas and strategies then develop to tackle the problem and find a solution. For example, some started with researching the area, looking at something similar which has been done before, then initiating a working document to put thoughts and ideas into words.

Those interviewed felt the company supported creativity in some direct ways, but that also through more indirect ways had actually created obstacles to creativity.

7.4.14 Category XVIII: Workload and time pressure

The pattern of work in NPE was fairly erratic and the engineers found it difficult to plan ahead. Whilst most of them had specific projects they were working on, 'panic' jobs and other projects were fitted in as well. Other things, which impinged upon their time, were meetings called at short notice, sometimes in Europe, and impromptu training sessions for up to three days. Every week throughout the Tracking Study those interviewed expressed how busy they were, how many jobs they were juggling, how they were having to undertake and fit in rush jobs and how much time was taken running about and chasing key people. For example, "The workload has been erratic in the last 6 months. It's the nature of NPE. Can't plan everything—try, but can't foresee changes in customer requirements."

Y(2)13/wk3/bk2/pg69/ln30-32

"Series of panic jobs since January—very disruptive."

B(2)24/wk5/bk2/pg112/ln27-28

"The week was planned—then thrown into disarray. Two and a half days out of five for something completely different. Then I was asked why I haven't done what I should be doing. This is project life. It was Thursday before I could file things away and get back to normal."

N(2)23/wk4/bk2/pg108/ln8-12

"I'm continuing to work on [engine] cost modelling. No time to pursue new costing method because working on a job now which has a deadline of March—external customer contract in place. The other job doesn't have a fixed deadline."

U(2)14/wk3/bk2/pg72/ln7-11

"I'm fire-fighting at the moment as each deadline approaches. It's like spinning plates in the air and trying not to let any fall off. This seems to be the position in NPE at the present. I was asked to join another meeting—didn't as I was already booked. The Head of Department told them we didn't have enough people with the right experience."

X(2)22/wk4/bk2/pg106/ln32-36

Many felt they were juggling several jobs at once. The SAP system was supposed to allow them to book the hours needed, but the reality was that they knew something else would suffer. There was an element of frustration and feeling under pressure in that they were not able to do as much as they wanted on the different projects and progress was therefore impeded.

"Brainstorming exercise outcomes were passed to trainee to put into word processing format. We will work together to get it into a draft report. Preferable to do this sooner rather than later in case of last minute glitches or unplanned project rush jobs. Haven't touched base with other project since meeting last week. I had planned to talk to a specialist but had hoped to get something done this week for the customer. Therefore it doesn't stand in good stead—continuous 'spinning of plates'. Enjoyable in some sense, but there is a risk of a 'plate' coming down. It would appear the XX project is the one to have suffered this week. Can't see into the future, but there are plans to reduce numbers overall so I can't see it getting any better."

X(2)25/wk5/bk2/pg118/ln62-77

Similar experiences are recorded for others working in NPE. For example,

"I was dragged off this project to do other things. The people who he [HoD] needs to do things are dragged off to do other things. It has slowed my progress."

T(3)37/wk7/bk2/pg161/ln19-23

"Getting better at having several things on the go at one time, but would prefer to have one. Two to three major things are doable—over that you begin to lose the thread. A couple of weeks ago I had three to four things all of equal importance—got worried. Have to have self discipline and prioritise—need to do this. If found to be stuffed [i.e. overloaded] you need to persuade people to help you."

T(3)37/wk7/bk2/pg162/ln42-49

As mentioned in the DGI Study, chapter 5, there had been some attempts to develop the idea of skill owners and focal points. However this had not come to fruition in NPE. At the time of the Tracking Study a number of new graduates had been brought into the department on a particular project. The engineers had mixed feelings about them being there. Whilst they accepted that part of their role was to train people and help them to become accustomed to the way the department worked, the software, design principles and methods and generally give advice, the continuous interruptions from them meant that the work they were involved in suffered.

> "Three to four years ago Rolls-Royce had the idea of people in the department being skills owners and focal points who would write worked examples in books for new trainees. This unfortunately died a death as there was no time to get it off the ground. Had it worked it would have helped to reduce the interruptions. We weren't given any time to develop these and as we couldn't show a pay back, we couldn't do a business case. We are paying the penalty now for not doing this as we carry on getting more interruptions and it goes into a downward spiral."
>
> N(2)28/wk5/bk2/pg127/ln46-51

The majority of the engineers in the department were working well in excess of the 37 hour week and working at maximum capacity. There was a feeling that the workforce could not continue to operate at this level and many felt it had implications for the outcomes of the various projects they were involved in.

> "Most of the workforce are working at 110% all the time. All have more than one job on the go. Ten to fifteen years ago this was not the case."
>
> B(2)24/wk5/bk2/pg114/ln74-76

Not having enough time to concentrate on a particular job had implications for their workload.

> "Lots of running about which is par for the course at the moment. I spent a week on another project out of the blue, which came from the Controls group. We are under-booking on controls at the moment. There should be five people and they have just one. The problem is I am unable to sit down and concentrate on one thing at a time. There is a constant breaking of the train of thought. This has implications on my work—I won't get as far as hoped. I have deliverables so I concentrate on that at the moment and push other stuff down the list."
>
> Y(2)13/wk3/bk2/pg68/ln12-21

All of the interviewees frequently stated they did not have enough time in the day.

> "No space or quiet on your own to get on with your work."
>
> CC(3)34/wk6/bk2/pg152/ln124-125

There were constant interruptions from a number of sources for example from the new designers and trainees (team of 12) in the office who were making demands on the experienced designers' time.

> "About six times a day I am interrupted with questions. The majority I can answer within a few moments. Two or three times a week though the questions are more involved, for example helping them to recover data they have lost—they need the information, but can't access it or know where it is so you try and get it back for them. It stops the train of thought as working through something. When you return, you need to engage your thoughts again as to where you are in the work."
>
> W(2)7/wk2/bk2/pg39/ln42-49

> "A local and transient problem is the number of new graduates in the department which are a great source of interruption. You're almost afraid to walk past them as you know you'll be stopped. I accept that we need to pass on our expertise but all these interruptions are not scheduled in the SAP system. You can't very well tell them you can't answer unless they raise a booking code."
>
> N(2)28/wk5/bk2/pg127/ln35-41

In addition to this the demands of the new designers and trainees were getting greater as they progressed up the learning curve.

From the evidence, clearly the design engineers had a high workload and were working under a lot of pressure at times. Procedures introduced by the company to account for their time spent on projects was misleading as it could not account for the interruptions they experienced due to helping the new designers and trainees in the department. There was a need to find a better way to bring the trainees up to speed and develop their contribution to the work of the department.

7.5 Example of perceived barriers to creativity under micro conditions

In chapter 5, section 5.4.2.3 a number of 'paradigm'/models (as described in detail in chapter 2, section 2.4.4.3) were developed to represent the phenomena under macro conditions. Data from the Tracking Study were used to provide an insight into specific occurrences of where perceived barriers to creativity under micro conditions were experienced on a day-to-day basis.

The previous sections have described the categories which were drawn from the data in the Tracking Study and used evidence from the transcripts to explain and illustrate them. There are many overlaps and inter-relationships between the categories. Thus making it hard to disentangle and separate the different issues. The following 'paradigm'/model, figure 7.1, attempts to demonstrate a common instance of a barrier to creativity under micro conditions.

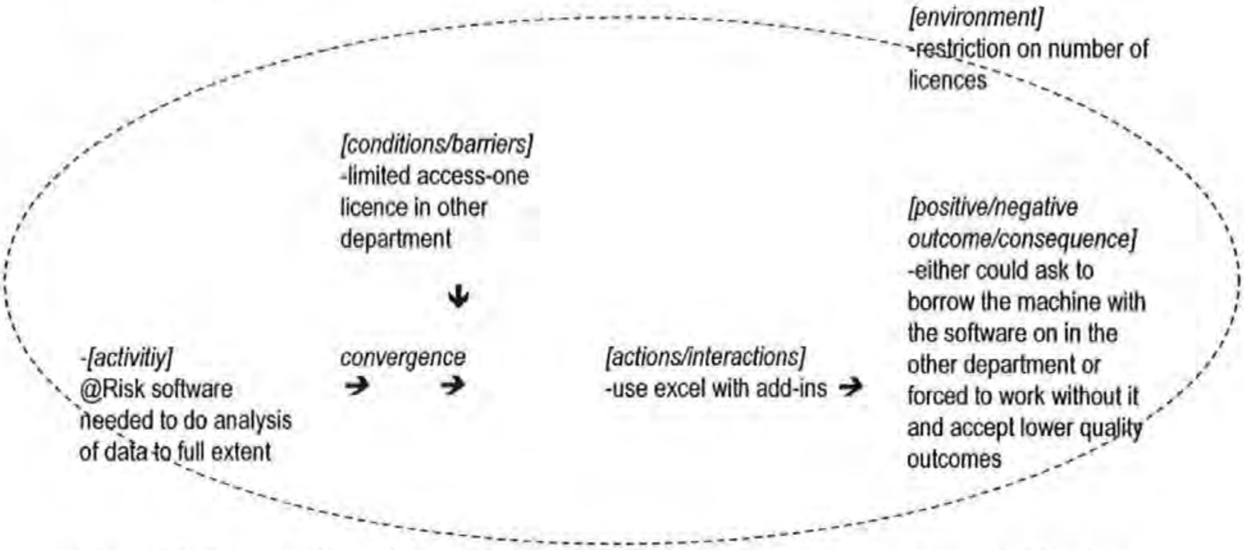

Figure 7.1: 'Paradigm'/model representing the occurrence of the phenomenon: perceived barriers to creativity under micro conditions.

This particular example highlights the problems that some of the design engineers experience through lack of access to the appropriate software due to the restricted number of licences (see section 7.4.12.4). The experienced design engineer in question had been endeavouring to obtain a copy of the software for the last two years, but to no avail. As it was an essential program for his work he was frustrated that the only way to circumvent this issue was to either request to borrow the computer with software on it from the another department or use Microsoft Excel with add-ins. Neither outcome was satisfactory. Access to the computer was very difficult and using Excel meant accepting that the quality of any output would be lower. The other option was to hand the work back to the Commercial Department, but as they were overloaded and had handed the work out in the first place to NPE this was not a viable solution either.

Macro and micro conditions where the phenomena occur are not independent. Macro conditions and micro conditions often intersect and interact with each other highlighting paths of connectivity (Strauss & Corbin, 1998). The 'paradigm'/models can help explain relationships between structure and the process of the phenomenon emerging from the data. However, these 'paradigm'/models suggest there is a linear relationship where under condition 'A', certain actions/interactions 'B' occur which result in consequences 'C'.

However the models are somewhat simplistic and not a true representation of what was really going on in relation to perceived barriers to creativity in NPE under macro and micro conditions. Therefore the 'paradigm'/models have limited value.

In order to understand the phenomenon completely there needs to be a way of looking at the interplay between macro and micro conditions under which the phenomena occur as both conditions are important to the analysis. In 'real life' there are multiple conditions (past, present and future) which influence the actions/interactions taken which can then set off a chain reaction. In these circumstances it is hard to identify the relationships between different events. A rich picture diagram of what is going on provides a greater overview of this highly complex situation and this is presented and discussed in chapter 10.

7.6 Summary of the chapter

The Tracking Study recorded instances, over an eight week period, of perceived barriers to creativity under micro conditions and how they were circumvented by those interviewed. Data from the Tracking Study identified thirteen categories:

- organisational processes
- weltanschauung
- timescales of project
- integration with other companies
- working practices (changes in)
- project management
- management style
- experience of designers
- design process
- communication (social)
- technology with new sub category communication (technological)
- creativity
- workload and time pressure

Twelve of these categories mapped onto those identified in the DGI Study, two categories were split, two had merged and four were no longer present (see section 7.4.1, table 7.1). The similarities and differences between the categories in these studies could be due to a number of reasons as listed below.

1. Not exactly the same people were interviewed in the Tracking Study as had been in the DGI Study.
2. The department had changed in structure.
3. The department comprised of new and different members of staff.
4. The Head of the Department (HoD2) was about to move on.
5. There had been the introduction and establishment of new procedures.
6. The projects they were involved in had progressed and in many cases changed.
7. The aims and objectives of the two studies were different.

Whilst the interview diaries had given an indication of the frequency and the perceived importance of problems and barriers to creativity as experienced by the interviewees, it was necessary to validate their retrospective accounts. Therefore following on from the Tracking Study a one week Shadowing Study was undertaken in this phase of the research. Data from this study will be used to inform the richer picture of what is happening in NPE in relation to perceived barriers to creativity. It will also be used to conduct a negative case analysis with the data collected from the Phase 1 studies and the Tracking Study. This is reported in chapter 9.

Chapter 8: Shadowing Study

8.1 Introduction to the chapter

The Shadowing Study described in this chapter is the final study of the research project (see chapter 2, figures 2.2 & 2.5). It was conducted to observe the frequency and the salience of the categories and instances of the perceived barriers to creativity identified in previous studies over the period of a week. This primarily involved work shadowing two experienced designers although incidental observations and inputs of many of the designers previously involved in the research are included in the data.

The Shadowing Study was a validation exercise to confirm and identify any contradictions in the data generated from informal interviews with design engineers during the Tracking Study (see chapter 7). This exercise fulfils the requirements of negative case analysis and hypothesis testing as described by Strauss and Corbin (1998) (see chapter 2, section 2.4.4). It also adds to the triangulation of the data.

The study lasted for five full working days following on from the Tracking Study. Data collected from this study comprised of observations with supporting input from those being shadowed.

Grounded theory analysis of the direct observations led to the verification of the categories (see chapter 7, section 7.4) and many instances of the phenomenon of the perceived barriers to creativity, under micro conditions. However, as the Shadowing Study was only for a limited period of time inevitably not all the instances which had been previously reported were observed. The thirteen categories were:

- organisational processes
- weltanschauung
- timescales of project
- integration with other companies
- working practices (changes in)
- project management

- management style
- experience of designers
- design process
- communication (social)
- technology with new sub category communication (technological)
- creativity
- workload and time pressure

The observed categories in view of the observation are reported below in section 8.3 category by category.

The findings from Phase 2, incorporating all the major findings from the two studies conducted in Phase 1, are reviewed together in relation to the literature in chapter 9. Conclusions focusing on the findings from Phases 1 and 2 are reported in chapter 10 and lead into suggestions for future research.

8.2 The Shadowing Study

The main purpose of the Shadowing Study was to observe instances of perceived barriers to creativity to perform negative case analysis by comparing the findings reported in the Tracking Study (see chapter 7). As the studies from Phase 1 of the research provided a platform for the studies in Phase 2, it also confirmed those findings to some extent. The Tracking Study elicited many of the concerns and issues prevalent at the time of the research and originally raised as macro conditions in Phase 1. The Shadowing Study allowed for observations to be made to record whether the issues and concerns were as salient and frequent as suggested in the Tracking Study.

The design engineers were involved in a number of tasks associated with their own project and other projects as well. The types of activities which were observed included, engineering design, creative problem-solving, working with different software packages, gathering information, administrative tasks, assisting the trainees and interactions in discussions and meetings.

8.2.1 Participants

The participants had all been involved in the Tracking Study. The main two participants were design engineers who were shadowed as closely as was possible. Less frequent observations of activities of several of the experienced designers, a project manager and new designers and trainees were also noted during the study.

The coding for those shadowed and observed is as follows (see appendix B for more detail):

- *Project manager and team leader (Group 1) coded[1]:*
  *I(1)**
- *Experienced designers (Group 2) coded:*
  B(2), N(2)*, U(2)*, X(2)*
- *Meetings coded:*
  *Z**

8.2.2 Method

The direct observations (see chapter 2, section 2.4.4.2) took place over 40 hours across five consecutive working days following the Tracking Study. Those observed were closely followed through as many design activities as possible. Observations of their work, use of technology, communication with others in the department and elsewhere and attendance in meetings were recorded. Supporting explanations and discussions were also recorded.

Data from the observations were recorded as hand written notes because video and audio recordings were not permitted in the NPE department.

The data were then analysed using grounded theory and the findings are reported in the following sections.

1 Where A--is the individual
(1)--is the category
*--is the interview number

8.3 Shadowing Study findings

Thirteen categories had emerged from the data of the Tracking Study. Data from the Shadowing Study provided evidence of the extent to which the problems and issues raised in relation to perceived barriers to creativity during the Tracking Study, could be confirmed by observed behaviour and activities. Each category is discussed in turn using the same headings and sub-headings as used in chapter 7, section 7.4. The Shadowing Study is a brief snapshot in time and is therefore a small window on the complexity of the problems encountered in NPE, but it both confirms and enriches the studies from Phases 1 and 2.

As described in chapter 7, section 7.4.1 the thirteen categories from the Tracking Study were mapped against the sixteen which had emerged from Phase 1. As a result twelve have remained the same, two have split, two have merged and four were not found in the data. Therefore the numbering of the categories in the headings of the sections relate to those in chapter 7, table 7.1.

8.3.1 Category II: Organisational processes

8.3.1.1 Demarcation and connectivity

It was reported in the Tracking Study that demarcation and fragmentation of the company was perceived to be a barrier to creativity as access to information and loss of capability was experienced. These concerns were observed during the Shadowing Study. For example, reorganisation of the Compressors Department had meant they were relocated to Derby. This had resulted in a loss of capability in this area on the Bristol site. Therefore when a specialist was required from Compressors in Derby they had to communicate via teleconference. A teleconference was observed with X (2) from Bristol conferring with the specialist in Derby (day1/bk3/pg4-6/ln97-128). The content of the teleconference centred on the need for data and information. Confirmation of the current status of the project being discussed took place with a negotiation about timescales as key people were absent until the following week. Also some confirmation and establishing of where responsibilities lay between NPE, Bristol and the Compressors Operating Business Unit (OBU) were discussed.

Comments after the teleconference provided evidence for the cultural differences alluded to between Bristol and Derby in the previous studies.

> "Any input regarding compressors has to come from Derby. Due to their focus on detail and culture regarding the very slight evolutionary change from Trent engine to Trent engine means they have a different focus. We need to keep reminding them that in the conceptual stage of design you don't need too much detail. We want them to think laterally more. They will change I presume over time–inbred."
>
> X(2)/day1/bk3/pg6/ln131-138

> "They haven't got the experience in Derby. They have the technical knowledge but not on special features regarding military aircraft so they have to be educated on this."
>
> X(2)/day2/bk3/pg12/ln26-28

8.3.1.2 Accounting system's demands

A lack of access to relevant software as highlighted in the Tracking Study was evident. One of the experienced designers being shadowed required two computers to be able to work more efficiently. Obtaining two computers posed a problem for him (more detail on this issue in sections 8.3.9.1 & 8.3.11.1).

As mentioned often in the DGI Study and Tracking Study the recently implemented SAP system did have its observed shortfalls. At the time of the Shadowing Study experienced designer B(2) had used up all the booking time on the SAP system in relation to a particular project. Unfortunately due to the hours having been spent, there was no time to complete the report. It was stated that there was a need to write the reports for future reference, but in this case it would be left (day1/bk3/pg4/ln7-79). Here was evidence to support the comments previously that the SAP system was inflexible and that due to time constraints project outputs had to be slimmed down.

Booking into the SAP system to update the record for each project needed to be done weekly. The system did not appear to be very user friendly as the password demanded a mix of upper and lower case letters together with a set number of digits. The designer who was observed getting into the system took about 10 minutes after navigating a series of windows and menus. One example of a problem encountered was that one designer had found himself 'locked' into the system. In order to 'get out' again he had to ring the helpline in Derby. Such examples whilst involving limited time per project also accounted for a significant degree of frustration and distraction.

Whilst in the Tracking Study comments had been mainly negative towards this system being introduced as one designer commented,

> "It has replaced in the region of 1600 separate systems and therefore will help the information flow. We have to adapt procedures to fit SAP. Previous systems supported 'chieftains' in small empires. SAP is supposed to break those 'castles' down so no 'walls' are in place and the information can get through. They now all interface and are compatible with each other. There needs to be a cultural and attitude change though."
>
> B(2)/day1/bk3/pg10/ln234-240

Another issue observed was the relationship with the IT services supplier (ITSS). Telephones were rented from them and there was only one telephone between four people. This caused some logistical problems due to the arrangement of the desks. Designers were interrupted as they passed the phone to colleagues when the call was for them. NPE had no ownership of the hardware or software used as this was also rented from the ITSS. As had been noted in the Tracking Study, software specifications should be passed to the ITSS for them to write the software. However, in NPE's experience they were not getting value for money especially when experienced programmers in NPE had done most of the work (day3/bk3/pg34/ln163-170). The ITSS did not appear to understand the engineering aspects adequately and therefore NPE were reverting back to writing their own programs. One of the designers who had been part of the Tracking Study was involved in this project involving the development of new software and whilst capable needed the time and space to get on with it.

Observations from the Shadowing Study did appear to provide evidence to confirm the perceived barriers to creativity the designers were experiencing. The fragmentation of the company had meant networks were disparate, harder to maintain and with the reduction in the workforce hard to find adequate replacements. Evidence of the impact of the SAP system affecting the quality of the outcomes of some projects was also observed. Problems associated with the use of specific software was not observed during the Shadowing Study as those who had recorded such problems when interviewed in the Tracking Study were not being observed.

In chapter 7, section 7.4.2.3 other organisational policy changes for design methods had been discussed such as the committee structures which make decisions on new designs and other new initiatives. Direct observation of these issues did not take place during the time of the Shadowing Study.

8.3.2 Category III: Weltanschauungs (world view) and cultures

8.3.2.1 Information sharing

In the Tracking Study problems with the sharing of information was often reported. It was perceived that channels were blocked although the company policy to was "value shared information between departments". It was also reported that the flow of information between Derby and Bristol sites could be improved, but different cultures and ways of working prevented this from happening. Evidence of this breakdown in communication between the two sites was observed during the Shadowing Study.

One of the projects some of the members of NPE were involved in was the revamping of some in-house software. This was in preparation for selling it to another company. Derby was also preparing different aspects of the software. As mentioned in section 8.3.1.1, a teleconference was set up to revisit the goals of the project between Bristol and Derby. Introductions were offered by Derby and the minutes read from the previous meeting. It became evident from the meeting that the people in Derby had little understanding of the requirements of the people in Bristol regarding the project. Frustration with the people from Bristol became evident as the lack of understanding and compromise from Derby continued. For example, Derby was reluctant to provide figures for the developers to work with unless they were precise ones. However what the group in Bristol had difficulty in getting Derby to understand was that precise figures were unnecessary and what they required were some "ball park" figures in relation to certain parameters (Z3/day4/bk3/pg47-50).

The meeting went on to review the set objectives in terms of red, amber or green priorities. Derby appeared to be all green at this point whereas the Bristol team were under pressure as they had a Exit Review Gate to meet the following week. There appeared to be reluctance from Derby to accept some of the responsibility in assisting the Bristol group to meet the issues although they had been raised three weeks previously. Therefore things had come to head at this meeting. What appeared to be the main problem was that there was no overall person in charge of the project between the two sites. The project manager in Bristol was annoyed that his counterpart was unavailable in Derby. As the teleconference continued so the animosity grew with cutting remarks made by the people in Derby and someone losing their temper in Bristol. The problem appeared that the teams were working in isolation and each group had little or no experience of each others' project requirements (Z1/day4/bk3/pg46-50/ln121-228).

The project manager summed it up by saying,

> "There is a big barrier between us and them not knowing how they work. We need someone to look over their shoulder and see how they work."
>
> I(1)/day4/bk3/pg50/ln229-231

It has to be noted that the person in Derby was an IT specialist and had limited knowledge of the methods referred to and found it difficult to make any comments. The person who needed to give the technical input was not available.

The observation of this incident not only highlighted the underlying difficulty in comprehending the different cultures between the two sites, but also again emphasised the problem of the availability of the 'right' person to talk to, obtaining the relevant data and the problems and frustrations this caused.

It has been discussed in chapter 7 that there was reluctance from other departments to share information. However B(2) did have a more positive experience at a later meeting he attended. A meeting with turbines had not been as negative as he had expected and an agreement on their involvement was made (day1/bk3/pg2/ln31-34).

It would appear that there is evidence to support the perceived blocking of information at least between Derby and Bristol and sometimes between departments. The extent to which individuals obtain the information they need is dependent on the strength of the network of personal acquaintances and contacts they have in place and whether the information needs are understood on each side of the discussion and can be provided in the desired format.

8.3.2.2 Management expectation and attitudes

During the time spent on the Shadowing Study it was possible to read the Designer's Terms of Reference manual which is an internal publication developed through generations of design practice (day1/bk3/pg16-19/ln121-205). It stated, "A good designer is one who knows his skill and can relay that knowledge to others who must then take it forward to manufacture". It also stated that designers must keep abreast of new developments, be kept informed by others and on that basis make the correct decisions so as not to cost the company. It was interesting to see how the company acknowledged in this book that evolutionary design may result in a lot of drawing, but less time was needed to think whereas novel ideas would require a lot of thinking time and produce scant drawings and sketches.

The manual also described the attributes of designers where experience was gained from the "cradle to the grave" through courses and practical training from time spent in the company. It mentioned that the creative ability "was variable from a thirst for knowledge and the ability to draw upon their own experience to enable the production of sound and novel ideas. Less gifted designers have the above characteristics but are less pronounced and this shows in the quality of their work."

The company design manual suggested that to be creative the designer needed to use a technique for solving problems by sometimes consciously working on the problem and often sub-consciously and "rather loosely" (i.e. allowing the development of ideas and solutions informally). It also suggested the less gifted person should be aware of the technique and practice using it.

Two types of problems that designers have to solve were proposed in the manual: synthesis and analysis. Synthesis it stated. "...is the drawing upon past problems which develop into elemental ideas resulting eventually in satisfactory solutions". Recognition of the process not necessarily being sequential was noted and that many solutions could be generated, but decisions based on experience and judgement needed to be made at different junctures. The manual continued to state how a designer in the first phase of design should begin solving a problem by undertaking a thorough investigation into the company's earlier designs and documentation, drawing on the specialist knowledge from different departments and researching in the company's library. Whilst the company appeared to recognise it was not a step by step process, it did expect a methodical approach to the task. For example it stated in the manual, "Designers need to put their minds to work [second phase] methodically like a computer running through the stores of basic materials in the brain to come to a satisfactory solution."

The manual went on to suggest that thoughts, ideas and sketches were to be encouraged and if no solution was forthcoming then putting the problem to one side may elicit an answer from the sub-conscious. However the company reminded the designers that time set aside was not infinite (profits of the company were mentioned) and a designer should seek help from a colleague. There was also recognition that creative people did not like working in groups or to any rules and systems and stated the need to "effectively gear engineers to work with the whole organisation".

Once the solution has been critically evaluated it needs to be developed into a detailed, sound and practical engineering proposition. This, the manual stated, was the third phase of design. The fundamentals of good design were noted as:

- Design disposes of chance and disorder
- Vision in design is invaluable
- Materials cannot comprehend man (be sure design is coherent and logical)
- Directness of action and smoothness of shape ensure the minimum of stresses and strains
- Efficient function and manufacturing limits are reconciled by good design
- Safety is no accident
- Quality in the product does not happen by chance
- Communications control efficiency—many lines begin at design
- The customers' contribution to design is indispensable
- Design determines dividends

The manual provided some very clearly stated directives on creativity and design, but what this research has shown was that it was not necessarily supported adequately. For example as highlighted in the Tracking Study, documentation was not readily available, it was not always completed due to the hours on a project having been depleted, access to library and records was not easy, and obtaining specialist knowledge could be problematic due to a reduction in the workforce and consequently brainpower.

Notable were the number of posters observed during the study publicising retirement parties and presentations posted around the company. When asked one designer commented,

> "Something will break. We are creaking at the seams already. We are driven by stakeholders and shareholders interests in profit. Knowledge and training skills of individuals cannot be replaced easily. The company needs profits to increase and as we can't take on any more projects so they cut wages. We're up the spout if something goes wrong."
>
> B(2)/day3/bk3/pg38-39/ln227-282

As discussed in the corresponding section in chapter 7 the franchising out and out-sourcing of various departments was a concern. This was expressed again during this study by one of the project managers who felt the company was becoming too lean as people were continually taking their knowledge base with them.

> "I can see Rolls-Royce becoming an intellectual company which produces nothing. We are becoming very lean."
>
> I(1)/day5/bk3/pg58/ln98-99

One of the company's initiatives had been to encourage a paperless office. So files and folders were cleared off desks at the end of the day. However the designers felt they could not work in this way as the creative mind was not something that worked in a tidy manner. To get around this problem the designers had piles and even some had bookshelves under their desks to keep the documents and files they drew upon close by. This provided a valuable resource which could be easily drawn upon when needed as was observed. The problem with this system was only the owner really knew what he had available and it was not easily accessible to anyone else.

Some barriers to creativity were perceived because of the different cultures and preconceptions held by the designers in Derby and Bristol. The consequence of this situation had led to misunderstandings in relation to the information being exchanged between groups involved in the same project but located on different sites. Delays on the project had ensued.

The company, as stated in the Designer's Terms of Reference manual, was obviously aware of the important aspects of creative design and outlined the process and suggested ways of supporting designers involved in such activities. This was perceived by one experienced designer to be very comprehensive, but he felt it was not referred to enough by new designers, and the evidence from these studies was that the advice of the manual was in some cases thwarted by the issues identified above.

8.3.3 Category IV: Timescales of project

As discussed in chapter 7 under this heading, timescales were important as meeting them often meant less detail and fewer alternative solutions could be considered. Negotiations on extending deadlines did not always appear to be an option. However, the timescales on a particular project were discussed and re-negotiated in a teleconference meeting which was discussed in the previous section. For this particular project it meant less time to achieve what was necessary and there were concerns about the level of quality of the end product as indicated by this comment during the teleconference.

> "It looks like we are giving them something which is unreliable. We'll have to give them the tools to manage it."
>
> N(2)/day4/bk3/pg48/ln197-198

As had been stated in the DGI and Tracking Studies "workarounds" were being used as there was not enough time left on the project to iron out the bugs in the software (day4/bk3/pg47/ln146).

Some of the designers were involved in developing software. Depending on the task it could take a long time to find a solution to a problem, or it could be solved relatively quickly. Thus they found it impossible to assign timescales although this was what was required through the SAP system. As had been discussed in the Tracking Study it was the inflexibility of the SAP system to accommodate the creative and variable elements of design which they found so frustrating and perceived to be a barrier to creativity.

8.3.4 Category VI: Integration with other companies

8.3.4.1 Political environment

The Shadowing Study highlighted how the political climate affected the work of the conceptual designers. One of the experienced designers had a unique project where he had to reduce the cost of an engine by 90%. This called for him to have some radical thinking on the design because it was an unmanned aircraft and the criteria usually set when designing engines were in many ways irrelevant in this case (see chapter 1, section 1.7.4). Discussing this situation with him he commented,

> "The MOD pays so they call the tune. Ten years ago we operated cost+ where we came up with the best solution and we told them how much and they paid up. Nowadays the MOD say how much they have to spend. We have to compromise on everything—usually the performance and sometimes the mechanical aspects. We used to design an engine for the most advanced materials around taking the mechanical design to the limit. Now we have to take cost into account from day one and compromise on everything: performance, architecture and materials. Studies from the operational analysis look at the fleet size and the operation of the aircraft. They work out the usage and total life cycle costs. If it's unaffordable the customer says no so Rolls-Royce have to modify until it's acceptable. It comes down to the unit cost the customer is prepared to pay. I haven't gone through this yet [for the unmanned project] so I don't know the maximum unit cost the customer is prepared to pay. If I knew this it would help to decide how radical I can be."
>
> B(2)day1/bk3/pg2-3/ln45-65

The other experienced designer shadowed had to prepare and write a report for a project with an international collaborator. However the meeting had been cancelled due to changes in the market and projected requirements for engines in the future. Political climates and international relations affect much of this uncertainty. This lack of knowing the current state of some of the projects, whilst being an inherent aspect of the conceptual design process, was frustrating and unsettling as the design engineers were unsure how much time and effort to spend on each project.

8.3.4.2 Coordination

As mentioned in chapter 7, section 7.5.4.2, there appeared to be a lack of coordination with some projects. This was observed in the teleconference reported in section 8.3.2.1 where problems were experienced between the two sites as no one person had direct responsibility for pulling the project together. Lack of understanding between the two groups and misconceptions about the information to be shared in order for the project to be completed had led to delays and a poorer quality deliverable.

Therefore lack of access to the relevant information was perceived by the designers to be a barrier to creativity and inhibited progress on various design activities. This in turn had caused a certain amount of angst and frustration amongst those engineers involved.

8.3.5 Category VII: Working practice (changes in)

8.3.5.1 Secretarial support

Throughout the studies the designers had referred to themselves as PowerPoint designers and found they had to become multi-skilled communicators in order to make good presentations and word process reports and documents. This was very evident during the Shadowing Study where designers prepared PowerPoint presentations and documents using their IT skills. A lot of time was spent tidying up the view foils and checking all the text and layout.

Many interruptions were observed regarding phone calls throughout the week. This supported what the designers had reported throughout the Tracking Study. Employees in the department were often absent for a variety of reasons. As they had to share one telephone between four it was evident that taking the telephone call for someone else disrupted their work. Usually the person became involved in answering the query even though the call was for another person.

8.3.5.2 Email

Daily reports were circulated via the email providing information about aerospace type events. Emails were checked a couple of times a day and whilst it did not appear to cause too much distraction as had been reported in the Tracking Study, those observed spent some time scanning them but found there was too much information to take in (B(2)/day1/bk3/pg6/ln147-150).

8.3.5.3 Formal procedures

As discussed previously in chapters 5 and 7, procedures for booking project time had become more formalised. In the Tracking Study it had been highlighted that less time meant that projects were "thinner" or the reports were not written fully. One designer made sure that the presentation and report were done as the project progressed in case the hours were stopped and then there would no time to write up the report B(2)/day1/bk3/pg9/ln218-220. However there was evidence of reports not being finished due to the spent hours on the project (day1/bk3/pg4/ln7-79).

8.3.5.4 Personal development

Personal development was perceived by those interviewed in the Tracking Study as wholly focused upon meeting the company's needs and related to short term skill needs. Evidence was found in the Shadowing Study to support this. For example one of the key designers was requested at very short notice to attend some training during the Tracking Study. Again during the Shadowing Study one of the main designers in the group was told he would need to attend a training day in Coventry later that week (day3/bk3/pg33/ln149-150). The training was in conjunction with a new system being introduced into the department. There was little evidence of any professional or career advice in any of the four studies.

8.3.5.5 Opportunities for discussion of designs

One of the benefits of working in an open plan office was that other conversations could be tuned into quite easily. This could obviously cause a distraction, but such an opportunity was observed as having a positive outcome whereby a discussion about active magnetic bearings (AMBs) in marine engineering was overheard by other designers. This sparked off a conversation about the potential use of AMBs in certain military aircraft. So whilst some formal opportunities for discussions had been dropped as reported in the Tracking Study there was evidence to suggest informal stimulating discussions still took place.

8.3.5.6 CADs versus drawing boards

Many of the designers interviewed in previous studies had highlighted the disadvantages of CADs for conceptual design. They felt many important aspects of their working practice had been lost when CADs replaced the drawing boards. For example the social interaction which occurred around drawing boards was much lamented by the experienced designers. Fortunately there were still a couple drawing boards left in NPE and during the Shadowing Study they were used to lay out a large general arrangement (GA) of an engine. Almost immediately this happened it sparked an interest and other designers came to see and be involved in what was being discussed. This provided evidence of the types of constructive social activity these artefacts generated that CADs did not and confirmed the issues raised in chapter 5, section 5.3.3.1 and chapter 7, section 7.4.6.6.

Those interviewed throughout the research had also mentioned the cognitive demands required to operate a CADs. Several hours of CADs work were observed during the Shadowing Study. The designer using the CADs was the only competent user within the department at that time. Although the user appeared to operate the CADs seamlessly it did take numerous actions to enable him to zoom in and out, tidy up lines, make modifications and then view the model in different perspectives. At one point he put a ruler to the screen to obtain some sort of perspective (B(2)day3/bk3/pg26/ln7-13). This lack of perspective had been noted as barrier before when using this type of technology. However, many of these activities could not be carried out on a drawing board so there were some advantages to using CADs.

8.3.5.7 Inconsistencies in data tracking systems

During the Shadowing Study no problems with data tracking systems, as noted during the Tracking Study, were observed. However this could be mainly due to the fact that the group for which this was particularly important were not being directly observed.

Many perceived barriers to creativity related to changes in working practices as noted in this section. Whilst working in an open plan office had its advantages, there was a downside as well. The designers were constantly interrupted by a variety of sources and this impeded their thought processes. They often found it difficult to remember at what stage they had reached in their particular task. Another major change that the designers perceived to be a barrier to creativity in some aspects was the exclusive use of computers for creative design activity. Some important features of the design process had been lost when the drawing boards were removed from the office.

8.3.6 Category VII: Project management and the Derwent "philosophy"

8.3.6.1 Reducing the space of alternative designs

Concerns had been expressed in the Tracking Study that the current project management philosophy was to reduce costs and lead-time to an absolute minimum rather than focusing on the optimisation of design solutions. This had an impact on the creative output, the ability to seek alternative solutions and the overall quality of the design process. Evidence of this situation was found during the Shadowing Study.

As has been recorded in other sections of this chapter (see sections 8.3.1.2 & 8.3.5.3), reports were left unfinished due to the booking time on the SAP system having lapsed. Many had mentioned that less time meant they had less time to think through ideas because of the amount of work demanded of them. For example one experienced designer, who was trying to write a new program, stated he had some ideas, but needed space and time to get on with it.

> "You need a good amount of time to get focused and think things through. It may take a week and not move too far as you go up a blind alley. It's the nature of NPE—lots of interruptions means you don't get this opportunity. All you can do is deal with short quick requests as they are easier and leave the more detailed work to later."
>
> U(2)/day3/bk3/pg34/ln171-175

Given the short duration of the Shadowing Study it would be hard to provide evidence for the "thinning" down of projects. As already mentioned though in section 8.3.2.1, timescales had been discussed in meetings about the development of a software program and it was evident from the conversations that a less reliable program would be the ultimate result due to the time constraints imposed.

8.3.6.2 External politics

The uncertainty of the current status of some collaborative projects was associated with the politics between the companies involved as discussed in section 8.4.3.1. The implication of the politics was that designers were confused as to whether a project would continue or not. Frustration ensued because of these issues as the designers did not know how much time to assign to them. This was noted several times during the Shadowing Study.

8.3.6.3 Coping with 'rush' jobs

What were perceived to be barriers to creativity in this section were the instability and uncertainty associated with some of the projects due to the unplanned 'rush' jobs they were asked to complete.

As said in section 8.4.5.1 above, there were a number of unplanned tasks which had to be responded to quickly during the week's Shadowing Study. For example one of the experienced designers had to drop everything he was doing and locate two pictures of engines in order to make a comparison to respond to a request. It required drawing on his experience of where to find these images and his skills in using the software to produce the final composite picture. In total the unplanned 'rush' job took 1½ hours. As he returned to the work he had been doing he commented,

> "Where was I? What was I doing?"
>
> B(2)day1/bk3/pg9/ln200

As the task took a relatively short time it was not entered into the SAP system and therefore was not accounted for. However, it had taken the experienced designer 1½ hours, time which he should have spent on the main project in hand. It would not take too many of these 'rush' jobs to fill a day's work. This supports the comments made in chapter 7, section 7.4.14.

8.3.7 Category IX: Management style

8.3.7.1 'Efficiency' versus 'creativity'

At the end of the Tracking Study a new Head of Department (HoD3) had been appointed. The designers perceived the new style of management as more "middle of the road" rather than the "boom and bust" of the previous Head of Department (HoD2) (U(2)day1/bk3/pg4/ln73-74). HoD3, as perceived by the experienced designers, did not command the same presence whereas the previous Head of Department had been referred to as having an "aura" about him. As he was not available to participate in the Shadowing Study, it was difficult to find evidence to support these comments.

8.3.7.2 Reduction of reference to basic principles of design

In the Tracking Study reference had been made to the background of HoDs1 and 2 who had run NPE in the past. As the background on HoD3 was unknown, no comparisons or conclusions can be drawn.

8.3.8 Category XII: Experience of designers

8.3.8.1 Perceived qualities

During the Tracking Study and the studies in Phase 1 many of those interviewed had a clear perception of the qualities necessary for a good designer. Many of these qualities were observed during the Shadowing Study. For example, one of the experienced designers being shadowed commented that after 30 years experience he could easily visualise a general arrangement (GA) in 3D. He had always had an interest in car engines and looking at diagrams which were cut-aways of models (B(2)/day3/bk3/pg 51/ln267-269).

An interesting fact was pointed out during the Shadowing Study by (B(2)), who had been working in the department for some time and in the design halls prior to the introduction of projectisation. He had noted that in those days 70% of the designers were left handed in the department. He observed there were many more right handers employed now and speculated that perhaps they were less creative and innovative although highly numerate (B(2)day1/bk3/pg11/ln265-267).

8.3.8.2 *Development of new graduates*

As highlighted in the DGI Study (Phase 1) and the Tracking Study new graduates had a different training and educational history compared to many of the older experienced engineers who had completed 'traditional' apprenticeships in past years. The current model was to expose them to a broad knowledge base by locating them in different departments for relatively short periods of time. During the Tracking Study and Shadowing Study a small cohort of new trainees were involved in a different model of learning. The twelve new trainees had been set a small project within NPE which they had to manage themselves. They sought assistance from the experienced designers in NPE regarding any problems they encountered. Throughout the Shadowing Study it was observed that the new trainees in the department on a regular basis interrupted the experienced designers.

Additional training on software was organised for this group of new trainees by B(2) who spent various amounts of time throughout the week getting it organised. B(2)'s expertise enabled him to identify what they needed to know at this point on their development.

The department also had some slightly more experienced graduates (new designers) and whilst it was evident that they had many skills to draw upon, they lacked the experience and knowledge base of previous designs which could help them overcome some of the problems they were encountering. For example one of them had been asked to provide some comments about an engine which had been sent to him from a colleague in the US division of Rolls-Royce. The new graduate had struggled with this and asked one of the experienced designers, X(2) if there were any problems with the design. Immediately the limitations of the design were spotted and articulated. He added that this was a classic design by a "bright young thing", but experience and intuition informed X(2) that many aspects of the design would just not work. For example he could see risks in the mechanical design with the possibility of a component getting too hot and causing internal components to shear off. This could result in the HP turbine breaking up and further adverse consequences if engine debris hit the plane unless built in safety measures took this into account. The criticisms were based on years of experience and knowledge of how the engineer and company had designed their engines (X(2)day4/bk3/pg51/ln247-274). By articulating his thoughts about the engine the following day, further problems about the design emerged. Confirmation of X(2)'s thoughts about the structure of this proposed design came from him looking at a GA of a similar design. Another experienced designer (B(2)) looked over his shoulder and immediately noticed that this design would not work either (B(2)day5/bk3/pg56/ln40-42).

This evidence provides a clear example of the value of experience, the social aspects of design and effective transactive memory systems (Wegner, 1987).

8.3.8.3 Loss of design experience

Throughout all the studies in Phase 1 and 2, concerns were expressed about the reduction in manpower and the consequent loss in experience. There was a lot of evidence to support the impact this had on the designers as there were less people they could draw upon to help them answer specialist problems. A lot of time was wasted waiting for the relevant person to be available to answer any problems. This in turn meant delays in finding solutions to problems causing further frustrations to be built up. For example,

> "We need to gather information from people. We need to go through this process of tracking them down and so on. We have to liaise with different project teams and as the organisation has disbanded any capability for HP compressors in Bristol we have to rely on them at Derby."
> X(2)day2/bk3/pg12/ln21-25

The lack of key personnel who needed to be drawn upon to provide specialist help were being reduced in numbers due to company polices. For example, within NPE at the time of the Shadowing Study there was only one experienced designer left who could operate the CADs proficiently. Therefore all problems which required the use of this technology landed on his desk. Many of the people in NPE were crucial lynch pins because they had specialist skills and knowledge. If they were to lose any more people, they would lose some capability. For example during the Shadowing Study one of the designers with specialist knowledge on running the GENISIS programme was absent for a few days and a request that only he could deal with had to be left until he returned (day2/bk3/pg15/ln84-85).

It would appear there is ample evidence, as highlighted by those interviewed during the Tracking Study, of the consequences as a result of the loss in manpower. Many of these were perceived to be barriers to creativity whether it was because of inadequate training, support or human and other resources.

8.3.9 Category XIII: Design process

Evidence of the design process was observed during the Shadowing Study. A fairly detailed account of the observations of the design process undertaken by the two main participants of this study who were shadowed throughout the week is presented in the following sub-sections. It provides evidence of the steps and stages of design that different designers take (see chapter 7, section 7.4.10.4) and some instances of their perceived barriers to creativity.

8.3.9.1 Account of B(2)

The experienced designer B(2) was at the time of the Tracking Study and Shadowing Study, involved in designing an expendable engine. This was to be an unmanned aircraft (UAV) and therefore it did not have to meet the usual design characteristics and safety requirements. However it needed to be cheap, as it was less likely to be used time and time again. The criteria for designing such an engine were very different to those which would normally constrain a design of an aero-engine.

Before B(2) could begin to explore the concepts for designing the expendable engine he wanted to check through a problem about a design which he had been thinking about over the week-end. He commented that he had became too focused by looking at the screen all day (from the previous week) and needed to be away from the workstation as this helped him to think about the broader issues (day1/bk3/pg1/ln16-18). In view of his thoughts over the week-end he made some amendments to the presentation foils (overhead transparencies). A lot of tinkering to get the text and diagrams 'just right' was observed and provided evidence of "gilding the lily" (see chapter 7, section 7.4.10.2). It was not until mid-afternoon (on day 1) that he was able to start looking at the document that reported on various aspects of the expendable engine.

To be able to work on this project B(2) stated he needed two computer terminals on his desk: one aerospace and one secure. It was thought that the project manager had this request in hand. The reason for the two computers was that the FOAS work was held on the secure network and therefore the expendable engine data should also be on the secure LAN. However information from the turbines database was needed and this was not on the secure LAN.

Problems were encountered with working with two different computers at different ends of the office, as he had to keep returning to his desk to answer the phone when he was working on the other computer. This happened several times whilst he was working on the drawings and he found it very disruptive. He commented,

> "The calls are very disruptive. I'm just in the middle of sorting something out and I want to get it sorted before I go home."
>
> B(2)day2/bk3/pg21/ln244-246

Evidence of having to think about the hours needed to design the engine was noted as B(2) had worked out in advance that 25 hours were needed. This was based on previous experience. Some agreed time was also booked out to the Turbine Department (day1/bk3/pg9/ln205-208). This provided evidence of the demands of the SAP system (see chapter 7, sections 7.4.3.2 and 7.4.14).

B(2) began with what he referred to as his first "brain dump". He chose a datum[2] engine to begin with. A lot of the initial design was done on the CADs as the project involved developing the design from a datum engine rather than starting from scratch. At this point in time the focus was on one engine, seeking to manipulate different aspects of the turbines in that engine. He would have liked to have had a GA drawn to represent the modifications, but the person who could supply them was absent (day2/bk3/pg15/75-85).

2 A datum engine is a basic engine with fundamental stages. It forms a baseline from which to develop a new engine.

He started on the HP turbine and support bearing as this was the most expensive bit where parts could be reduced. As the re-design developed though he noted that he will need to work towards the back of the engine which is hotter and has the shortest length of life.

Each aspect of the turbine considered was debated either with himself or colleagues as to what was the most cost-effective. For example should the seals be "labyrinth", "carbon" or "brush?" During this debate around cost-benefit and trade off issues another experienced designer suggested using piston rings. To be able to take the discussion further they went to the drawing boards, displayed the relevant GA and discussed the design of the engine flows drawing on other peoples' ideas (day2/bk3/pg15/ln86-103). This was evidence of a time where they needed to communicate with someone else and bounce ideas around. All of this was necessary before B(2) could start designing the expendable engine.

Working back in front of the computer screen B(2) looked at the drawings and talked to himself about how things may be changed. As he talked checking the drawings, he used manipulations of his hands to see if changes were feasible. Quite a lot of time was spent looking at the screen thinking and pondering on the drawings and seeing what modifications could be made. Each change needed to be thought through because of the knock on effects further down the line. Also changes to parts needed to be considered as they might not be possible to manufacture. Any potential problems that were missed would be picked up at the review meetings later on. Discussions with the transmissions people (Bristol) were necessary to see if the basic architecture would 'fit' with the modifications made. He visualised the changes he made in 3D but the CADs he operated did not have the facility where you could see the changes updated in 3D as they were made. He constantly used the zoom facility to make any changes and then zoomed out to see how the whole engine looked. The diagrams were coloured where he had made changes in different layers. Interestingly at one point it was observed he needed to sketch as he could not envisage how the lock nuts would fit in. Taking a scrap of paper he sketched components relating to where the oil came in and flowed through. He talked through his drawings and reached a solution within minutes. The sketch was then transposed onto the CADs where designing continued (day2/bk3/pg23/ln294-300).

With this particular project the engine could afford to lose some performance as the engine was expendable unlike any other military aircraft. Discussion with others appeared vital. A small meeting of three designers enabled their thoughts to be pooled and identified what the effects on performance would be regarding the proposed changes in the design (day1/bk3/pg7/161-162). Later another chance hearing of a conversation about AMBs was taken on board by B(2) as a possibility for his expendable engine (day2/bk3/pg24/ln314).

At the end of day two it was interesting that this comment was made,

> "At the beginning I didn't think it would end up as it [the drawing] has, but I'm happy with the outcome and it is meeting the criteria of reducing costs with parts, couplings and machinery. All is following a logical path. At this point I can leave it and not have to think, where am I?"
> B(2)day2/bk3/pg25/ln346-350

B(2) decided to use a split disc and after locating a previous design on microfiche he began to replicate it using the CADs. During this process he was looking to take the best from one engine and integrate it into the one he was designing. He managed to do this but had a "gut" feeling that it would not work. He asked himself questions such as, "Why won't this work? Oil flow problems perhaps?" Some changes were made to modify and improve the initial concept.

One facility the CADs technology they were using did not have was access to a history of changes made. Pro/ENGINEER™ has the facility and it was useful for a designer and others who worked on a project to see what the thought patterns were in relation to the changes made. When B(2) finished drawing the split disc and "worked up the picture" he copied it to the secure network in readiness to do the modelling in Pro/ENGINEER™. He was unaware whether the split disc had been stressed or not but it needed to be done. The mainframe system did have a package to allow him to do some preliminary stressing, but he was unsure of the criteria for the unmanned aircraft which it would need to be stressed to, and its speed requirements (day3/bk3/pg26/ln19-25).

At this point he thought about the method of attaching the turbine blade to the disc and how to remove the seal plates. He called this a "blisc". The next step in this design was to model the blade and disc. He did not think this had been done before and thought there maybe a patent in this part of the design (day3/bk3/pg35/ln181-187). This idea had come about by working through various drawings, discussing with colleagues, thinking about them and challenging the possibilities and finding solutions to them.

However some ideas did not always work out. For example, B(2) focused on a part of the gas turbine to make some modifications, but realised what he had done was a waste of time so he had to start again (day3/bk3/pg37/ln232-233).

At one point in the design B(2) needed to find an example of a 5mm bolt of appropriate material and head shape. The current technology had no standards directory, which he expressed would be a useful facility to have on-line. He commented that Pro/ENGINEER™ was working on this, but the extra catalogues of standards would need to be bought in. He eventually obtained a copy of a 5mm bolt and transferred it to the file he was working on. However this ended up in a different orientation and he needed to manipulate the system to be able to view it. The new bolt then had to be readjusted to fit in with the rest of the model (day3bk/3/pg37/ln242-249). One concern was that he may have simplified things too much.

Returning to the report and checking some of the comments made by X(2), B(2) realised that the design of the air flow would need to be modified as it would have implications in other areas of the engine.

Not much more progress could be made at this point as B(2) needed to talk to a specific person from turbines about more detail of the blade. He was unavailable until the following day and as no one else could help he had to wait. Thus providing evidence of needing to draw on specialist knowledge that appeared to be in short supply.

By 4.30pm on day three his concentration had gone and he felt he could no longer be productive. His original objective was to have completed the turbine by the end of the week, but then he had not anticipated being out for a day on a training course (day 4) (day3/bk3/pg40/ln318-319). The course, on day 4 (see section 8.3.5.4), interrupted his chain of thought when he had been making steady progress. His intention was to write down what he had achieved so far at the end of the week, but this did not happen.

By the end of the Shadowing Study B(2) needed to talk to someone in compressors. As there was no actual compressors department in Bristol anymore he would have to contact someone in Derby. He rang them, but they were unavailable until the following week. In readiness for his discussion with them he printed off part of the engine in A3 size large enough to doodle on as they talked through the design.

Evidence of using analogies is noted when B(2) comments that he has had some thoughts about the expendable engine.

> "Thoughts come unexpectedly to me. For example I came up with the zimmer frame option for supporting the engine in an airframe without having to make any modifications. The idea came from looking at my mother-in-law using her zimmer frame."
>
> B(2)day5/bk3/pg57/ln71-74

8.3.9.2 Account of X(2)

At the start of the Shadowing Study X(2) was involved in writing a report on long-term storage of engines. He began by writing headings on a screen and then working from there. If he was "cold" he found it difficult to write directly onto the screen and so began to write down some scribbles whilst gathering his thoughts together. He felt closer to the problem using pen and paper rather than using the computer. He commented that,

> "Writing on screen is more the embroidering of words and then reassembling them to make more sense. By re-reading it you come up with further thoughts on the paper. I know what I want to say—its how do you put it together."
>
> X(2)/day2/bk3/pg14/ln63-66

X(2) preferred to be left on his own to get his initial ideas down. Then he began by thinking laterally. What he did recognise was that total introspection was not necessarily good and there was a need to talk to someone about his ideas. What hampered his progress was that he did not have a designated computer to work on.

He continued to write the report throughout the week picking it up and dealing with other issues as well. At times X(2) was in "embroidery" mode, as he putted it, adding detail and changing words to his report.

However he had to attend a one-day conference mid-week and returned to follow a lead regarding long-term storage. A chance flicking through a classic car magazine had brought to his attention a "cocoon" bag each with an individual air-filter and humidifier for storing classic cars. He considered this might be a feasible solution to long-term storage for aircraft engines. X(2) was in the process of making contact with the suppliers and arranging a demonstration of the bags. At this point Customer Logistic support should follow up the cost-benefits of this idea, but at the time they were too busy, so X(2) decided to do it for himself. However he did need them on board and they would have to agree between the two departments how to divide the workload. Whilst at the conference X(2) met with a colleague who he worked with years ago and who has experience of long-term storage. The colleague gave him a network of people who had experience in this area. X(2) endeavoured to follow up the links (day4/bk3/pg42/ln41-49). He also needed to write up his notes from the conference.

B(2), who was out on a training day on day 4, asked X(2) to look at the document relating to the expendable engine. His approach was to set himself some questions. For example,

> "What if I make the 'cold' end out of plastic type materials. OK if it is flown straight away, but may need to consider 20 years of storage until flown in anger. Therefore I need to think about the degenerative aspects of plastics and whether 20 years later they would be too brittle to use."
> X(2)day4/bk3/pg43/ln68-73

X(2) needed to jot down the thoughts using pen and paper before returning to the computer and adding to the report. He considered making changes to the turbine blade to an integrally bladed disc, but this had implications for machining, that is what could be forged and cast and whether any new methods would need to be developed. The report documented the continual assessment of the trade-offs down to very finite detail for example whether to weld, bolt or use some other type of seal on the expendable engine. One could be cheaper than the other could, but compromises in other aspects would have to be made. Therefore there was a need to converse with the manufacturing people to establish who would supply the parts, that is whether it could be manufactured in-house or whether other suppliers needed to be brought in. It was necessary to look at the wider picture at the outset to ensure people could put together what you designed and for it to be reliable and repeatable (day4/bk3/pg45/ln104-117). B(2) followed up the feasibility of the suggestions made by X(2) when he returned from his one-day course.

These accounts relate to different creative design activities. The first account relates to an example of direct creative design involving the radical modifications required to design an expendable engine. It highlights some of the barriers to creativity experienced and perceived by the designer B(2). For example, the mental drain due to the demands of the software system he used, administrative demands, the limited software facilities to support conceptual design, the accessing of information, as well as interruptions and the working environment.

The second account relates more to a creative thought activity, essentially a personal brainstorm in support of design. X(2) experienced fewer perceived barriers to creativity which were mainly access to information and interruptions.

These accounts are discussed in view of the literature on models of design in chapter 9. The perceived barriers to creativity have been highlighted elsewhere in this chapter under the relevant category headings and are discussed in more detail in chapters 9 and 10.

8.3.9.3 Expectations and attitudes

In chapter 7, section 7.4.10.1, those interviewed had mentioned about greater expectations required of the experienced designers. This was very evident in the Shadowing Study. For example, not only did B(2) have to continue with his design of the expendable engine, but he was also being asked to organise the training for the new trainees and participate in further training for himself. He was often asked to attend impromptu meetings. His work was constantly being interrupted and he had to pick up where he left off time and time again.

8.3.9.4 Downside of software support

The downside of software support was alluded in chapter 7 where, because the current technology offered a greater capability, designers could easily follow blind alleys and introduce more iterations into the design than were necessary. This could waste time. Therefore they have to maintain a balance between exploration of alternatives whilst focusing on the design specification.

8.3.9.5 Office environment

There was ample evidence of the telephone ringing and designers being interrupted in their work and thought processes to support the statements made in the Tracking Study. However, chance hearing of conversations going on between different designers in this open area also led to the cross fertilisation of ideas on different projects as discussed in chapter 7, section 7.4.3.1 and this chapter in section 8.3.5.5.

8.3.9.6 Importance of social processes

Observations of the social processes which took place in meetings were recorded in chapter 7, section 7.4.10.4. Further evidence to substantiate these findings was found during the Shadowing Study.

Throughout the week whilst observing the two experienced designers a lot of interaction was taking place between them as problems were discussed, debated and possible solutions offered which in turn raised new problems to consider. This in turn generated ideas of previous engines which had particular characteristics. New ideas were triggered when the designers conversed with each other. They talked their own language referring to past engines by name but both understood what the other was saying. For example, at various points in the design process B(2) checked with X(2) about particular problems he was encountering. X(2) provided some examples and suggested B(2) looked at another engine which happened to be a helicopter engine. Talking through the issues helped identify other issues and possible solutions (day2/bk3/pg22/ln276-278). Once again, to see the design of the helicopter engine better, they moved to the drawing board to display the GA and both interacted with the drawing and themselves. This episode also illustrated the importance of shared history and common experience of earlier design as a necessary precondition to economical discussion. In this way it also related to the issues of experience (category XII).

8.3.10 Category XIV: Communication (social)

8.3.10.1 Individual and local verses team motives

Many of those interviewed in the Tracking Study stated that communications between NPE and the other Operating Business Units (OBU) was poor. This was attributed to underlying motives and 'hidden' agendas. As the Shadowing Study concentrated on observing two experienced designers, there was little evidence of this occurring. Indeed B(2) had been pleasantly surprised that a meeting with a specialist in turbines had proved useful. He was surprised because often in his experience they were negative to discussions about long-term problems that more often than not do not come to fruition. This was apparently due to the fact that people in turbines tend to be focused on short term manufacturing problems and find it hard to think in terms of the same time horizons as NPE (day1/bk3/pg2/ln31-33). Such examples are probably indicative of cultural differences and differing working priorities rather than conflict or competition.

8.3.10.2 Importance of personal contact

The interviewees of the Tracking Study stressed the importance of establishing a line of contact at the outset of a project with required specialists and yet this proved to be quite difficult as times. Evidence of the difficulty in trying to get hold of the 'right' person was observed many times in this study. Problems had to be put on hold until the person they needed to talk to was available.

For example, in one case the first two days were spent by one of the observed X(2) trying at various times to get hold of a contact who had been suggested to him (day1/bk3/pg6/ln139-140). B(2) needed to contact the specialist in turbines (as noted in the previous section), but found that he was in a meeting and unavailable until the following day (day2/bk3/pg15/75-85). Contact also needed to be made with transmissions by B(2) to discuss the basic architecture of the engine and take this into consideration when making changes (day2/bk3/pg25/ln336-337).

These examples identify the complexity of the problems and the range of people to be considered in the process of design.

There was further evidence of experienced designers thinking about who may be able to supply the relevant information or provide some ideas based on their experience (day4/bk3/pg41/ln10). For example, X(2) had a request for some information from another engineer outside the NPE department about an engine X(2) had worked on some time ago. X(2) was not sure where the papers relating to the engine were, but felt sure they were somewhere (day4/bk3/pg41/ln10-12).

The value of having personal networks to draw upon was also evident in the Shadowing Study. For example, a new graduate asked one of the experienced designers about a particular problem he was experiencing with his design. The experienced designer referred to information and tests undertaken in the 50s and 60s. He informed the new graduate about the details on properties that was available and suggested he spoke to someone in transmissions who could help. Apparently the new graduate had already tried this, but the person had appeared a bit suspicious. This appeared to be evidence that personal networks can work, but there needs to be a history between the two contacts. Passing on a name of someone else is not adequate (day3/bk3/pg38/ln257-261).

Observations during the course of the Shadowing Study provided evidence to support the idea that a lot of time and effort was expended trying to track people down to help on different projects. This also reinforces the need to talk to others whilst involved in the design process and the benefit of networks of contacts built up over many years.

8.3.10.3 Mismatched expectations

As already discussed in sections 8.3.1.1 and 8.3.2.1 of this chapter, there was evidence of misunderstandings between Derby and Bristol. These were observed in two different teleconferences which took place during the week between the two sites.

Under this category it was evident that there were perceived barriers to creativity relating to the lack of ease of communication between people in different departments and sites involved in collaborative projects. Specific instances of where this occurred were observed during this study and have been reported throughout this chapter.

8.3.11 Category XV: Technology and sub category communication (technology)

8.3.11.1 Access

In the Tracking Study, concern relating to the availability of hardware had been an issue for one designer in particular who did not have a designated computer at that time. To resolve this he had to hot desk and this continued during the Shadowing Study. The other experienced designer being shadowed (B(2)) was also experiencing problems with access to the appropriate technology.

B(2) had expected a second computer to be set up for him by the end of the week, but the mediator between NPE and the ITSS did not want to set up a precedent by letting people have two computers. B(2) needed the second computer to reduce the time spent trying to locate a free computer and GSL workstation. Much discussion took place over this situation. The project manager had agreed it, but the mediator continued to be reluctant in letting someone have two computers on their desk.

In the Tracking Study it had been reported that access to network databases and vaults was quite difficult. This was partially because of the procedures demanded for security purposes and that the systems were not user friendly. For example observations were made during this study of one of the experienced designers trying to attain some information. Some relevant information was held on the secure LAN and access to it was hindered not only because the system demanded passwords but also UNIX code commands were needed to find the correct directories where the information was stored (day3/bk3/pg26/ln14-16).

Rolls-Royce does not have access to MOD 'classified' documents and so in the case of X(2) developing his report on storage engines a literature search was requested to be carried out by the Defence Research Information Centre (DRIC) in Glasgow. Rolls-

Royce were charged for this search which took three months to do (prior to the Shadowing Study) and provided little information suggesting that there was little experience regarding this issue of long-term storage of engines.

As reported previously in the Scoping Study (see chapter 4, section 4.4.1.4) accessing information from the library was not always very productive. However other means were more effective such as the transactive memory system so clearly evidenced throughout all the studies (Wegner, 1987). For example the experienced designer B(2) had reached a point where he needed to check a plan of a split disc (part of the turbine on a particular engine). He knew of its existence as he had known the designer who had designed it in 1974 although he had now retired. The library did a search for the split disc, but not did find any reference to this component. However, B(2) managed to locate a GA of the engine eventually (day2/bk3/pg21/ln251-255).

The designers often needed to contact key people and they used their network of contacts if possible. However, with the reduction in manpower across the company finding the 'right' person with the required knowledge and expertise was not always easy. Although they had an electronic phone book they could only search by name and not by department or expertise. What they seemed to require was a facility to search by department to enable them to ring that department and enquire who the best person would be to advise and talk to about a particular problem. The system they currently had access to was highly criticised especially as it provided no indication of what each person's expertise and responsibilities were.

The Shadowing Study confirmed that there was plenty of evidence to support the concerns expressed by those interviewed in the Tracking Study in that access to information with regard to the technology was problematic.

8.3.11.2 Reliability

Throughout the studies conducted in Phase 1 and 2, reliability of the software and hardware had been highlighted. Some of the issues had been resolved during the period of this study as new systems and software were made available. However other problems continued. For example, at various times throughout the Shadowing Study it was observed that NTRIGUE either crashed or was very slow and caused problems for the designers (day1/bk3/pg7/ln159; day2/bk3/pg13/ln38,58; day2/bk3/pg22/ln272). Although the designers were obviously aware of the unreliability of the system, long periods where they did not save their work on the computer were noted. This was usually when they were engrossed in their work as had been reported in chapter 7, section 7.4.12.2.

8.3.11.3 Information overload

During the Shadowing Study it was observed that emails were checked a couple times throughout the day. They did not appear to be as obtrusive as had been described in the Tracking Study (see chapter 7, section 7.4.12.3) although the company reports were long and were only scanned and skim read, if at all, as there was too much to take in (day1/bk3/pg6/ln147-150).

8.3.11.4 Cross-platform problems

Interview diaries conducted during the Tracking Study highlighted the problems of transferring data between different countries and across different platforms (see chapter 7, section 7.4.12.4. As this was a frequent exercise, the problem was observed during the Shadowing Study.

What some of the designers were experiencing was the loss of functionality when having to translate information into neutral formats. For example in the FOAS project incompatible software was being used and therefore they had to translate it using IGES-STEP[3] and then re-translate and accept and overcome the problems that those actions caused. At the time of the study they were considering some new software to get over this issue. The software would have an information manager facility where the data would be stored centrally. The idea being that anyone involved in the project (even different companies across the world) would be able to request this information (day3/bk3/pg29-30/ln46-58). At present what was happening (as described by B(2)/day3/bk3/pg31/ln80-90) was that any request for access to restricted information

3 IGES-STEP is the Standard for the Exchange of Product Model Data in CADs offering conversion capability.

required a system administrator to book out the request. Then one of the six approvers who could sign the request had to be located. This was then passed to a key person who transferred the data from the GSL (Government Secure LAN) by burning a CD ROM. All this could take up to a day to arrange whereas the ITSS could see this could be done more efficiently and save time. The computers still had to be isolated and not networked as demanded by the MOD. Another company would be responsible for setting up the shared data environment. It would be the hub of the network with dedicated links to all certified partners in the alliance. In theory the partners would all be able to communicate with each other and have access to the information through the central hub of this company which would incorporate a CD reader and writer. It would speed up the design process and make interaction with the customer easier. What needed to be established was whether this was acceptable to the MOD who were financing the FOAS project (day3/bk3/pg31-32/ln76-106). The current contract stated deliverables had to be on a CD so the designers would need to have things checked out by a legal representative in case there were any loop holes in this arrangement (day3/bk3/pg31/ln92-110).

The ITSS would be able to supply the infrastructure for such a system, but a commitment from NPE in providing manpower would need to be addressed. B(2) was finding out more about this proposal and had attended a foundation course. Further days were to be attended in the period following the research (day3/bk3/pg32/ln117-124). His concern was that if the system required a high level of commitment then he would have to stop doing something else to make time for the new initiative.

> "I need to talk to several people to find out the remit expected of me. I need to talk to XX [HoD3] who probably has no idea about this at all."
>
> B(2)day3/bk3/pg33/ln139-140

There were lots of questions to be asked in terms of responsibilities and ownership between this company, the ITSS and FOAS. For example, it was needed to be determined who would be responsible for upgrades of computers, technical support and training etc.

A concern for responsibility and delegation was expressed by B(2) as he was involved in so many different things the question he had to ask was,

> "What happens when I'm on holiday?"
>
> B(2)day3/bk3/pg33/ln143

8.3.11.5 Security

NPE being a secure area required the designers to have passwords for accessing many of the software systems. Whilst this was a necessity it did cause problems as they had to be updated quite regularly. This was observed during the study (day1/bk3/pg10/ln224-232). Time was wasted either trying different passwords and combinations or finding help to get out of a system which they had been inadvertently locked into (day3/bk3/pg26/ln14-15).

8.3.11.6 Changes in emphasis in design roles

In the DGI and Tracking Studies (see chapter 7, section 7.4.12.6) the designers had mentioned that having access to many more software packages had its disadvantages. They referred to themselves as PowerPoint designers and this was evident in this study where they spent time making presentations and modifying slides (day1/bk3/pg9/ln212-215).

At several points in the thesis, CADs have been suggested as being a better tool for the detailed aspect of design rather than the conceptual stages. The experienced designers were aware that new versions of Pro/ENGINEER™ were available with enhanced functionality and starting to become more like a conceptual designer's tool. For example it offered a sketching tool driven by the mouse. Although both Pro/ENGINEER™ and CADs incorporated icons, one of the main differences between the two was that with the former there is a 'drag and drop' facility. CADDs5 works by modifying the geometry whereas Pro/ENGINEER™ allows modifications to dimensions to be made and the package then adjusts and modifies the complex 3D shapes accordingly. Pro/DESKTOP™ is a new package which would run off NTRIGUE and link into Microsoft office. The designers viewed this software as a very powerful tool with features and facilities more aligned to drafting rather than detailing. It was also felt that Rolls-Royce needed to "bite the bullet" and purchase the software. The problem was that Rolls-Royce was still supporting CADDs5 and it was unlikely there would be any enhancements. A few key people in NPE had compiled a report and business case making a recommendation for the upgrade. However the decision had to come from the top management level (day5/bk3/pg56-57/ln46-68).

8.3.11.7 Usability

Observations of the use of a range of software during this Shadowing Study provided evidence (see section 8.3.1.2) that some of them were not very user friendly. This had been highlighted in the Tracking Study.

The experienced designer B(2) spent quite a lot of time using the CADs during the week's study. This particular designer stated he could visualise in 3D which was an advantage as the system he was using did not have this facility (day2/bk3/pg16/ln113-114). Observing the experienced designer using this system it was evident that a lot of thinking time was required. It also was very laborious to drive a system requiring several clicks of the mouse and keyboard commands just to draw a straight line. These observations supported the comments made in the studies conducted in Phase 1 and Phase 2 of the research.

The designers stated that using CADs was a large drain on mental activity. This was evident when towards the end of the day B(2) would lose his concentration after having spent a couple of hours using this software. As discussed in section 8.3.1.2 there were other features lacking in the CADs which would have aided the thinking process the designers were going through. For example, some software provided a trail of the changes made to the design through its development which illustrated the thought patterns of the designers and could also serve as a provenance audit trail of ideas considered, modified and rejected.

Throughout both the phases of the research it was apparent that there were many issues and concerns relating to the hardware and software that the designers use. Many instances of the phenomenon under investigation have been highlighted in the above section.

8.3.12 Category XVII: Creativity

8.3.12.1 Perceived qualities

In the Tracking Study one of the interviewees referred to the need to be a lateral thinker. This was observed when the experienced designer X(2) had come across the cocoon storage bag for classic cars and thought about the feasibility of using similar bags shaped like that for the long-term storage of engines (day4/bk3/pg41/ln20-21). Lateral thinking had also been observed when B(2) commented on the construction of a zimmer frame providing the idea for an engine frame (day5/bk3/pg57/ln71-74).

In the design of the UAV B(2) was constantly having to think about how components would work, be re-engineered to operate reliably during a shorter life expectancy at a substantially reduced manufacturing cost and maintenance costs to the end user (day5/bk3/pg59/ln117-118).

8.3.12.2 Interruptions

Interruptions had been reported in the Tracking Study as often stopping the designers' thought processes and impacting on their creative ideas. A lot of interruptions coming from all sorts of sources were observed during the study. For example, the new trainees often needed help with using the software and interpreting datasets (day2/bk3/pg23/ln287-288). The enquiries took anything from 5 minutes to over an hour (day1/bk3/pg8/ln184; day3/bk3/pg36/ln229-231; day3/bk3/pg39/ln289).

The experienced designer B(2) who was arranging some training for the new trainees had numerous phone calls to deal with regarding this exercise. As he was often working at another computer away from his own desk and phone extension not only did the calls interrupt his chain of thought, but he also had to walk half way down the office to take the call. Each time he returned to his computer screen he asked himself what he was doing (e.g.day2/bk3/pg21/ln232,233,241,244; day3/bk3/pg39/ln292; day3/bk3/pg40/ln320; day5/bk3/pg57/ln75; day5/bk3/pg61/ln139).

Similarly X(2) received quite a few telephone calls in relation to the project he was involved with (e.g.day4/bk3/pg41/ln15) which distracted him and took him away from writing his working paper.

Throughout the week lots of calls were fielded by many of the engineers in NPE. This was often in respect of the people absent from the department during the week of the Shadowing Study. These interruptions were usually perceived as barriers to creativity although it did allow for some divergent thinking to take place at times. The experienced designers also felt that it could feel rewarding as they needed to often think quickly to solve a problem, but they worried as their other jobs were being neglected.

8.3.12.3 Supporting creativity

There was little evidence to suggest that creativity was being supported in the company although the Designer's Terms of Reference Manual outlined attributes and ways to enhance creativity as presented under section 8.3.1.2 of this chapter.

8.3.13 Category XVI: Workload and time pressure

Throughout the studies in Phase 1 and 2 of the research, it was evident that the engineers were working very hard at what they do but have the opportunity to discuss things and be involved in friendly banter. During the observation though it was evident that people were frustrated with systems and the difficulties in accessing the specialists. This resulted in wasting time. There was also frustration expressed where lack of understanding between Derby and Bristol was experienced. A couple of designers did feel that morale was low. One of the reasons suggested for this was that their pay was not comparable with what designers were paid on the continent. In addition they felt the company did not offer any perks (day2/bk3/pg23/ln283-284). There was also concern over the impending job losses in the company.

There was plenty of evidence to support what had been reported in the Tracking Study regarding aspects of this category. There were many indications of pressure where people were working to tight deadlines, attending meetings and conferences, covering for people absent from the office, working on long-term projects and yet they were still expected to 'fit' in unplanned projects and deal with many interruptions throughout their working day. A visit from some Austrians had to be postponed as the only relevant person to talk to them was too busy to entertain them. The engineers in NPE appeared to be left to manage their own time although ultimately their time was accountable through the SAP system.

8.4 Summary of the chapter

Data collected from the direct observations conducted during the week of the Shadowing Study provided observable instances of the phenomenon, perceived barriers to creativity, occurring under micro conditions. Two design engineers were observed although other observations of activities in the department were also recorded. Following grounded theory analysis, no further categories were identified and none were dropped from the thirteen discussed in chapter 7, and section 8.1 of this chapter. The extent to which the instances supported the findings from the Tracking Study was stated indicating the frequency and salience of the perceived barriers to creativity and thus validating the findings.

8.5 Summary of Phase 2

Phase 2 of research used interview diaries in the Tracking Study and direct observation in the Shadowing Study. These studies were necessary to highlight specific examples of perceived barriers to creativity whereas Phase 1 had considered the phenomenon under the macro conditions. The interview diaries tracked a core number of experienced designers over an eight week period. This had provided an insight to the types of difficulties and perceived barriers to creativity they were experiencing on a week-to-week basis. Thirteen categories emerged and whilst many of these mapped onto those identified and verified at the end of Phase 1 (see chapter 5, section 5.5 & chapter 7, section 7.4.1), two merged, two split and four were not found.

The Shadowing Study enabled the process of negative case analysis to be conducted by comparing data from the Shadowing Study against the findings from the Tracking Study in terms of the perceived barriers to creativity of those involved in the research. These were discussed in light of the thirteen major categories that emerged. A model indicating how perceived barriers to creativity can be explained under macro and micro conditions and how these interact is presented in chapter 10. The findings from Phase 2 and the extent to which there are commonalities across the phases of the research are interpreted in terms of the literature and presented in the next chapter.

Chapter 9: Review of Phases 1 and 2

9.1 Introduction to the chapter

This chapter reviews the outcomes of the Scoping Study, the Design Group Interviews (DGI) Study (Phase 1), the Tracking Study, and the Shadowing Study (Phase 2). The findings are interpreted and reviewed in terms of the literature documented in chapters 3 and 6 and augmented in this chapter under the six themes identified in the Scoping Study. Any commonalities or differences found in the data from across the two phases are highlighted. Evidence of 'perceived barriers to creativity' is identified and discussed. The final section of this chapter outlines the final phase of the research.

9.2 Summary of findings from Phases 1 and 2

Phase 1 comprised the Scoping Study and the DGI Study (see chapters 4 & 5 respectively). The six themes which were drawn from the data in the first study formed the basis of the DGI Study which culminated in sixteen categories grouping the perceived barriers to creativity and how they were circumvented by the engineers. The semi-structured interviews in the first phase had elicited the perceived barriers to creativity at a macro level (as described in chapter 2, section 2.4.4.3). During a validation exercise of the findings to date, it was evident instances of the phenomenon, perceived barriers to creativity, needed to be recorded and observed under micro conditions. To achieve this, Phase 2 comprised the Tracking and Shadowing Studies (see chapters 7 & 8).

Grounded theory analysis of the Tracking Study data identified thirteen categories, many of which mapped directly onto those developed from the DGI Study (see chapter 7, section 7.4.1). These categories were confirmed in the Shadowing Study analysis where specific instances of barriers to creativity were observed. The instances were compared to the findings from the Tracking Study and the extent to which the findings were validated and confirmed was discussed in chapter 8.

9.3 Interpreting the findings from Phases 1 and 2 in terms of the literature

As outlined in the above section the general themes and subsequent categories led to thirteen micro level themes and these are described below in terms of the literature. Links between Phase 1 and 2 are described where appropriate. The categories are grouped under the themes which had been drawn from the Scoping Study to illustrate the relationships between them thus following the same order as used in chapter 6.

9.3.1 Knowledge sharing covering: communication (social) (XIV[1])

What was clearly evident in all the studies was the importance of the establishment of networks of people who could be drawn upon for their knowledge, expertise and specialist advice when needed by the designers. They provided informal support and communication, access to wider internal and external networks than otherwise would not be available, experience of similar problems in the same domain or analogous areas of work, expertise in engineering solutions and organisational issues. As found by Baird et al (2000), these networks of social connectivity were developed over time as an individual's expertise grew and others trusted that knowledge. Examples of this knowledge sharing between experts has been reported in the Phase 2 studies (see chapter 7, section 7.4.2.1 & chapter 8, section 8.3.1.1) and has provided clear evidence of a transactive memory system (Wegner, 1987) being in place in Rolls-Royce. For example (as described in chapter 8, section 8.3.11.1) a search for a blueprint of a particular engine proved fruitless when carried out by the librarians, but a fellow designer knew of the design and was able to provide a copy for his colleague. Other examples have been reported in previous chapters (e.g. chapter 6, section 6.4.1).

However, what was impacting on this invaluable resource were constraints imposed by the company's working practices. For example, the SAP system which demanded booking codes to be used for any input/advice given on a project (see chapter 7, section 7.4.2.2 & chapter 8, section 8.3.1.2). This was perceived to be a barrier to creativity as it was inflexible and did not allow for the fluidity of creative design. Another factor affecting the maintenance of the personal networks were cost cutting activities where a continual

1 This relates to the category numbers used in table 7.1 & subsequently in the category headings in chapters 7 & 8.

number of personnel were being made redundant or taking early retirement. This was leading to a reduction in manpower and brainpower which had been mentioned in Phase 1 and was substantiated through the Phase 2 studies. For example, often there was only one 'key' person who could advise the designers on a particular aspect and if they were unavailable, delays to the project ensued. What was also perceived as a barrier, was finding out who the 'key' person was if they were not part of the designer's personal network. As highlighted in chapter 6, section 6.4.1, Olsen et al (1993) present a tool for the retrieval of documents and information employing a visual technique where data can be explored and located. Such a system may serve many uses in Rolls-Royce such as facilitating the search for significant personnel and important documents.

Other aspects of sharing knowledge appeared less productive. For example, the poor information flow between departments and the two major Rolls-Royce sites sometimes proved difficult. Perceived barriers and obstacles related to different cultural expectations and work ethics and may have also been due to the relative paucity of personal networks between sites. These difficulties had been reported by many of the participants throughout the phases of the research and examples of such problems had been observed during the Shadowing Study. This finding is supported by De Alencar and Bruono-Faria (1997) who identified organisational culture as one of the eleven characteristics they suggest inhibits creativity (see chapter 1, section 1.3.2). Cultural barriers are also seen as blocks to creative thinking and inspiration according to Davis (1999).

As discussed in chapters 7 and 8 "shared information" between departments was not always apparent. Majaro (1992) argues that poor lateral communication can be an indicator of "hidden agendas" within an organisation. Participants in the Tracking Study had referred to the "people factor" as a perceived barrier to information they needed from other departments to progress with their design activities. The engineering designers felt this may be due to concerns about their jobs, loss of control and demarcation issues. These findings fit well with Majaro's suggestion that "suspicious and insecure individuals" can affect communication flows. Similarly, Raudsepp (1982) suggests "personal security" to be an important factor when considering organisational barriers to creativity.

Majaro (1992) also suggests that "walls of silence" can be developed through a competitive "divide and rule" policy adopted in a company. However, Rolls-Royces' message, according to the designers, was acknowledging the value of shared information, but it was felt that many in the company only paid lip service to this company value. West (1997) states that to enhance an organisation's creativity and innovation, interdepartmental communication should be valued and encouraged allowing for constructive conflicts rather than power struggles.

9.3.2 Social mechanisms covering: communication (social) (XIV)

As mentioned in the previous section, the transactive memory system that operates in Rolls-Royce is a vital resource that the designers both exhibited and used. Numerous examples identified in the data from the studies have been documented throughout the thesis to support this.

Various aspects of social interaction relating to the design activity were seen as important in the Tracking and Shadowing Studies. For example, during the Shadowing Study one of the designers, who was observed, often bounced ideas off his colleague (see chapter 8, section 8.3.9.1 & 8.3.9.6). Discussions were observed around the drawing boards when a GA was laid out to consider aspects of a particular design. The easy visibility afforded by a drawing board provided a social focus to enable discussion. They often sought confirmation on aspects of the design from each other when thinking about a new idea in terms of the design activities they were engaged in.

The demise of the drawing boards meant that the social interaction and the opportunistic discussions, which had taken place around them, were lost to the much more solitary activity of design using a computer. Some social interactions did occur, but only as a result of the drawing boards being used to display a GA of an engine as observed during the Shadowing Study. As the social aspect of design was deemed an important one, the loss of such an artefact, which enhanced this, was lamented frequently by those interviewed (see chapter 5, section 5.3.1.13, chapter 7, section 7.4.6.6 & chapter 8, section 8.3.5.6).

The social aspects of design were highlighted throughout the studies as an important element of the design process. This supports the findings of Baird et al (2000) who reported on the relevance of social connectivity she found in her study of engineer design teams. Similarly, Bucciarelli (1988) argues that many social processes (both individual and collaborative) are involved in design. Cross and Cross (1996) also highlight the importance of communication between teams engaged in design activities. As the participants of this study identified (see chapter 5, section 5.4.2.2), communication is a major influence on many other activities the designers were involved with such as accessing information. Issues and barriers affecting communication could therefore impact on the creative design activities of the designers.

9.3.3 Management structures and organisational constraints covering: organisational processes (II), weltanschauung (III), timescales (IV), integration with other companies (VI), working practices (VII), project management (VIII); management style (IX)

Many of the categories discussed in chapters 7 and 8 belong in this theme developed from the Scoping Study and demonstrate the overlap and interconnections that the categories have.

One of the major changes in recent years, which had had an impact on the designers, was projectisation. It had been necessary to implement Project Derwent, as discussed in chapter 1, to remain competitive in the aerospace industry (Moore, 1997). However, projectisation had meant that projects and the people involved in them are co-located in multi-skilled and multi-disciplinary teams rather than in functional departments which previously were home to specialists of a common discipline. This arrangement has had an impact on the social networks tending to weaken the maintenance of the specialist knowledge required and in reducing informal contact that sustains the transactive memory system and allows it to flourish.

Fragmentation and the demarcation of the company were perceived by the design engineers to result from projectisation and this appeared to cause problems with communication between departments and sites as noted in section 9.3.1. For example, restrictions were in place so access to other departments' databases was not possible. The reduction in manpower across Rolls-Royce aerospace business meant getting hold of the 'right' person to help was more problematic. Indeed the whole issue relating to the reduction in manpower and "brainpower" in the company was of a major concern, expressed by all those interviewed in the studies. Majaro (1992) argues that the decentralising of companies can foster creativity, however unless clear communication lines are in place the cross-fertilisation of ideas across departments can be problematic. This issue had certainly been evidenced in the Tracking Study (see chapter 7, section 7.4.3.1).

Another recent change affecting the organisational processes and IT systems was the introduction of the SAP system. Throughout all the studies this issue had gradually grown in significance to the design engineers as its implementation into the company progressed. In the earlier studies in Phase 1, relevance to its use in NPE was questioned by many of those interviewed. They thought it was too formal a system, unable to be flexible enough for the demands in NPE. It was evident by the time it was implemented (at the time of the Phase 2 research taking place) that some of their concerns were confirmed as noted in the analyses (chapter 7, section 7.4.3.2. & chapter 8, section 8.3.2.2). Project time had to be booked with people in advance and there was a reluctance for people to offer advice unless they were booked out, and thus budgeted, to the project. The impact of this was a loss in obtaining quick short yes/no answers to many problems and questions. Instead often inappropriate responses were offered providing more detail than was required. The use of this system was also seen by the designers as another factor which was undermining the personal networks built up over many years as contacts had to be maintained through this formal system.

Many of those interviewed had viewed the SAP system as militating against creativity, by placing increased demands on the designer in terms of project management for instance. There appeared to be a reluctance in embracing this system and strategies had been developed to circumvent the problems it caused such as using "dummy codes" (see chapter 7, section 7.4.2.2). As De Alencar and Bruono-Faria (1997) suggest administrative influences can inhibit creativity and arguably this was happening in Rolls-Royce Aerospace (Bristol). However, there were possible benefits with reference to traceability and accountability on any project although awareness of the strategies used to alleviate the problems associated with its inflexibility for NPE projects would need to be taken into account.

Other organisational constraints, which affected the way the designers worked, were in terms of resources for software and hardware. Hardware such as computers and telephones were rented from the ITSS. This situation caused problems for the designers regarding access as there were too few computers with the relevant software and not enough telephones for them to have their own telephone lines. This appeared to be due to budgetary constraints. What was evident was how the designers in NPE used different strategies to overcome the lack of appropriate software. For example, in the case of relevant software not being available, it had either been accessed from other departments or 'add-ons' were developed. Lack of equipment and other material resources are further characteristics identified by De Alencar and Bruono-Faria (1997) as inhibitors of creativity. There was a sense of frustration in those interviewed toward the organisation for not recognising the importance of having the appropriate software for creative design and other associated activities (see chapter 7, section 7.4.2.2).

In the competitive aero-engine industry working to timescales has become an important requirement. Concerns had been expressed throughout the studies of the impact this had had on the outcome of many of the projects undertaken in NPE. For example the designers reported they were unable to follow alternative solutions, studies were shallower and "workarounds" had to be incorporated into software developments in order to meet the required deadlines. Thus the designers found they were having to "satisfice on their designs" (Ball et al, 1997). The introduction of the SAP system had not made this any easier as the calculation of man hours needed for some of the projects undertaken in NPE was not easy to determine at the outset. Often they had to be manipulated to accommodate the extra hours required. Timescales and deadlines though remained the same unless they were re-negotiated which was a rare occurrence. This indicates that the focus leans towards creative administration rather than creative design at the early stage in a project.

Politics appeared to play a major part in the capacity to work with other companies. For example, progression with projects was often unpredictable due to the current political climate between the collaborating companies. The fact that the designers were not readily kept informed of policy or project change and progress meant they encountered problems with how much time and energy to assign to projects competing for man hours.

It is interesting to note that other characteristics highlighted by De Alencar and Bruono-Faria (1997) such as organisation structure and political and administrative influences mirror quite closely the categories and factors which were recognised as barriers to creativity in this company.

The interviews conducted throughout the phases of the research highlighted many changes in working practices for the designers. They had to be multi-skilled in terms of the software available both for design and administrative purposes. There was a feeling amongst those interviewed that the organisation had become a "service provider", driven by what the customer wanted with perhaps less concern with meeting the needs of the conceptual designer practice as a forward looking and long term developmental activity. The engineers operated in project based design teams rather than in design halls. Drawing boards had been replaced by CADs and other engineering software. Accountability appeared to be at the forefront of the company's ethos and had led to systems such as the SAP system being introduced.

These factors had had an impact on the way they worked. For example, projectisation had meant a loss of social connectivity due to isolation and the breakdown in communication between personal networks. The expectation of being multi-skilled and the availability of more sophisticated software had led to a lot more time being spent preparing reports and documents for formal presentations. The problem here was that having the additional capability to enhance design presentations or conduct analyses on the designs meant sometimes a disproportionate amount of time was spent "gilding the lily" (see chapter 7, section 7.4.10.2 & chapter 8, section 8.3.9.1). Therefore there appeared to be a conflict between the ability to do more detailed work and yet not having enough time to do deeper studies looking at alternatives due to time constraints.

At the time of the research the FOAS project was one of the longer term development projects being undertaken in NPE (see chapter 1, section 1.7.4). However, the very nature of NPE meant that many smaller tasks and projects that demanded attention almost immediately came their way. This caused problems for the designers as they were removed from other longer term projects with no forethought to the impact that would have on their thought and creativity processes. Many situations were recorded where lack of continuity and resource issues had left the project managers in a compromising position regarding deadlines and timescales of bigger projects (see chapter 7, section 7.4.2.2). The SAP system was designed to alleviate this scenario, but the designers appeared to have little faith in the exercise as the outcome of the project still had to be fulfilled. The unplanned projects were just not built into the system. This situation is akin to what Majaro (1992) refers to as a "lack of slack" which can be a barrier to creativity where too lean a company can impact on their creative output.

De Alencar and Bruono-Faria (1997) propose another characteristic, as an inhibitor of creativity, is "boss characteristics". Support for the effect of this characteristic can be found throughout most of the studies where the Head of Department (HoD2) whose management style was described as "modern management" and "boom and bust". Those interviewed felt they had to "jump" and respond instantaneously to his demands for additional tasks to be completed. Majaro (1992) argues that it is important for managers to have a range of skills to be effective and encourage creativity.

9.3.4 Individual/personal resource and design processes covering: experience of designers (XII), design process (XIII), creativity (XVII), workload and time pressure (XVIII)

This section identifies several categories that overlap in this particular theme.

A number of perceived qualities for design engineers had been mentioned by several of the participants involved in the studies reported in chapter 7, section 7.4.9.1 and chapter 8, section 8.3.12.1.

One of the designers had been involved in all of the studies of the research. He clearly demonstrated many of the behaviours which Guilford (1950) suggests indicate a creative personality, such as inventing (he had many patents) and design and planning. B(2) also had a number of characteristics said to be personality attributes of a creative person such as self-confidence, intrinsic motivation, a willingness to develop and a commitment to work through problems and obstacles (Sternberg, 1988; West, 1997). Many of these attributes and characteristics were observed and can be mapped onto the account recording his creative design activities (on an engine for the UAV) during the Shadowing Study (see chapter 8, section 8.3.9.1). For example, problems were not solved instantly, they were arrived at by a series of approximations such as with the split disc idea which then developed into a "blisc" (a novel combination of turbine blade and disc). During the observation of this particular design many problems and obstacles had to be overcome in order to take the design forward and achieve the outcome required. At one point he wasted some time developing an idea which proved to be unfeasible. The designer displayed an internal desire to be creative, to employ innovative ideas into the design and deliver the best design he could develop given the constraints.

De Bono (1994) suggests that creative people are lateral thinkers. X(2) demonstrated this quality in his creative activities described in chapter 8, section 8.3.9.2 where the idea of a "cocoon" designed for storing classic cars could be used to store engines long-term.

As reported earlier in chapter 8, section 8.3.8.2 a small group of new trainees were engaged on a project within NPE. They called upon the designers' time and expertise quite considerably. This was felt by the designers to be detrimental, in the main, to their own creative thought processes although some had welcomed the opportunity to think about other things and felt it could enhance their creativity. This situation is described as "incubation" in the creative process where it is argued the subconscious continues working on a problem often resulting in the solution at the point of "illumination" (Poincaré, 1952; Wallas, 1970).

Earlier in the research the team leaders had been seeking to develop training packages for new designers and trainees to work through. This had not materialised and yet would have been a vital resource for these particular graduates in getting them accustomed with the in-house software systems. This would have allowed them to eliminate basic questions. Whilst the interruptions by these new trainees were perceived to be disruptive to the experienced designers, it could be seen as the continuation of the development of the new trainees' transactive memory system. Also it provided a type of apprenticeship model which could be expanded upon to provide an opportunity for learning in the social context of their environment (Lave & Wenger, 1995).

The importance of apprenticeships is discussed by Collins et al (1989) and traditional apprenticeship schemes appear to be valued at Rolls-Royce and had recently been reinstated. It may be that additional benefits could arise from following the Cognitive Apprenticeship Model (CAM) as a way of enhancing the teaching and learning of problem-solving skills required of designers. This would perhaps be especially beneficial for new trainees/graduate engineers who do not undergo a traditional apprenticeship as it would help to broaden their knowledge-base, which many of the experienced designers thought was lacking. It could also provide a more comprehensive library of possible preventive structures to explore in terms of the Geneplore model of creative cognition (Finke et al, 1992).

One of the major concerns of those participants involved in the studies was the loss of experience due to the reduction in manpower of the company. Many different people had expressed this through the interviews throughout all the studies. One of the designers in the Tracking Study highlighted an article by William B. Scott in the international journal, *Aviation Week and Space Technology (2000).* The article looked at the demography of the aerospace industry in the USA and the concerns regarding "gaps in expertise". The authors discuss the outcomes from a Rand study which reported a two-peak bimodal age distribution in the aircraft industry of 30-39 and 50-59 years old. The dip between the two peaks is reportedly due to the industry's downturn in the 1970's. Not only does this highlight a gap in the knowledge base, but as the 50-59 year olds are now beginning to retire, the wealth of experience departs with them. In addition the study demonstrates how the older engineers had access to a wider and more varied repertoire of engineering design due to the larger number of designs generated during the 50's, 60's and 70's compared to the 80's, 90's and the beginning of the 21st century. The experienced designer who identified this article believed that it also reflected what was happening in the UK aerospace industry as well.

Models of design were outlined in chapter 3, section 3.2.2 and as highlighted in chapter 6, section 6.4.4, a more iterative and less systematic and prescriptive model of design were preferred. For example, in the detailed account of B(2)'s creative design activity (see chapter 8, section 8.3.9.1), there was evidence of a number of iterative cycles exploring the "what ifs?" of the design. In addition there was evidence of "reflection-in-action" and "reflection-on-action" (Schön & Wiggins, 1992) as the designer talked to himself and asked himself questions as new features and ideas were incorporated into the ill-defined design.

At one stage in his creative design activity he referred back to pen and paper, finding this an easier medium to externalise his thoughts and ideas as suggested by Reisberg (1987) and Ullman et al (1987). Another important aspect of this particular designer's approach to design was his dialogue with an experienced colleague. This provides evidence for the "social permissions" (Baird et al, 2000) which acknowledge the working relationship that has been developed over time so the knowledge shared is known to be valuable and pertinent. Whilst shadowing this experienced designer and observing him designing, it could be argued that evidence of "combinational play" (Finke, 1990) took place. For example, he examined in detail different components and manipulated them until he had developed what he referred to as a "blisc". As the design developed and took on different features the boundaries of the design state space incorporating the innovations were extended as described by Gero (1996). This process of creating a new component to meet the requirements of the task could also be argued in terms of Ramirez's (1994) idea of "semantic adaptivity" where the product has emerged through a process of disassembling and reassembling the knowledge within an area. It may also account for the combination of two searches to find solutions when designers seek alternative ways to reinterpret the current design state and new emergent sub-structures are formed (Liu, 1996).

From the description of B(2)'s design activities, it is clear there are some elements which map onto the initial stages of Pugh's (1993) model of total design (see chapter 3, section 3.2.2 & chapter 6, section 6.4.4), for example where information is sought and received from other departments (OBUs). Also, as discussed in chapter 6, section 6.4.4 there are similarities with Rechtin's (1997) proposed model of design, albeit for the development of software, for example the iteration which is represented by a model of an outward spiral. At certain points it reaches stages where a stable version of the design is attained with a review of progress before progressing to further development. It could also be argued that observations of the design process reflected the Geneplore model of creativity (Finke et al, 1992), and its modified version, the "Trinity model" (Jarvis, 1997).

The other designer who was shadowed (X(2)) was not directly involved in the conceptual design of a component or engine although he provided a sounding board for ideas and suggestions to the other designer (B(2)). However what he did demonstrate was the benefits of lateral thinking allowing him to produce a possible solution to the problem he was resolving. He also demonstrated how experienced designers can have a "feel for design" based on intuition and experience (Hubka, 1995) when he critiqued a plan of an engine for a new designer (see chapter 8, section 8.3.8.2). His comments were based on a sound knowledge base developed through apprenticeship and experiential learning and illustrated how they cannot be totally replaced by the extended education route. This provides evidence of "situated learning" (Lave & Wenger, 1995).

It is argued in the literature that creativity in individuals can be enhanced by employing a number of techniques (e.g. Fischer, 1993). Cross (1989) categorises them as either rational or creative methods. Evidence of a number of creative techniques was observed, for example, synectics, combinations, checklists and lateral thinking as discussed in chapter 8, sections 8.3.9.1 and 8.3.9.2. Pugh (1993) suggests that to maximise the level of quality in the conceptual design phase that "gut feelings" should not be relied upon when making decisions and that a "method of controlled convergence" should be employed. However, it was apparent in the study that "gut feelings" were taken into account (see chapter 8, section 8.3.9.1) although not everybody agreed with this approach (see chapter 7, section 7.4.8.2). Without researching it further, it is not possible to make any judgements about this practice in relation to the literature.

Throughout the studies, various drawings had been employed for a variety of reasons in the course of their activities. For example, sketches and drawings had been used on an individual level to help explore and conceptualise ideas. This is what Ferguson (1993) refers to as the "thinking" sketch. Some of those sketches were discarded, others elaborated and annotated and then "worked-up" into a CADs. Such drawings Ferguson calls "prescriptive" sketches. Other drawings were used in groups to discuss and extrapolate ideas. This "talking" sketch was observed being used in meetings.

What was not observed throughout the studies was the phenomenon of "functional fixedness" (Luchins, 1942; Duncker, 1945). Purcell and Gero (1996) found mechanical designers had their creativity blocked or fixed when they had to solve a problem which incorporated typical principles and characteristics of their domain knowledge base. In fact evidence in this study was found to the contrary, where the experienced designers reported using analogical and/or lateral thinking to move their design creations forward.

Chapter 3, section 3.6 discussed various aspects of creativity. In particular sections 3.6.3 and 3.6.4 presented a number of ways to support creativity both at an individual and organisational level. As already suggested, many techniques were employed by the designers at an individual level to enhance their creative performance. The company's Designers' Terms of Reference manual also provided an outline of the creative process and some advice on how to enhance that process. Recommendations as to how creativity could be enhanced from an organisational stance are discussed in chapter 10, section 10.3.11.

The participants involved in both phases of the research commented on the workload and time pressure that they were experiencing. This problem was partiality associated with the resource issues in terms of manpower and the nature of the department in which they operated. For example, fewer people meant greater workloads and many unplanned projects had to be completed over and above the work designers were tasked with on the SAP system. Such changes from one job to another caused disruption to their thought processes and was perceived to be a barrier to creativity. Extreme workload pressure has been found by Amabile et al (1992) to undermine creativity. This relates to another of the characteristics identified by De Alencar and Bruono-Faria (1997) who argue "volume of task" can inhibit creativity due to the increased workload and intense time pressure leaving little time for creative activity.

All those interviewed often referred to the lack of time throughout the studies. It was often in the context of not having enough time to complete a job, and therefore having to make compromises, and not having enough time to think creatively. Many alluded to the past when they could "wander about thinking and having incidental discussions with colleagues". Majaro (1992) argues that companies such as the 3M (Minnesota Mining and Manufacturing Corporation) have benefited from allowing their employees to devote 15% of their time to the generation of ideas and management of innovation.

9.3.5 Technical issues covering: technology, communication (technological) (XV)

Many of the issues expressed about the technical issues in the studies of Phase 1 were mirrored in the two studies of Phase 2. For example, the issues relating to the provision of adequate technology in terms of both hardware and software were evident in all studies. Whilst the company had updated the hardware between Phase 1 of the research and Phase 2, the number of computers available posed a problem (see section 9.3.3).

Other aspects of the technology caused problems as well. For example, certain restrictions were in place due to NPE being a secure area. Therefore set procedures had to be followed in terms of accessing and sharing information. At times this appeared to be inhibitory to the design engineer's creative activities, as they tended to end up being preoccupied with the administration of their work rather than the development of it.

With drawing boards no longer in use for mainstream design activities, Pro/ENGINEER™ and CADs technology was used. As discussed in chapter 6, section 6.4.5 using CADs was problematic in terms of the mental power it required in order operate it and its inappropriateness for the conceptual stage of design (Robertson et al, 1991). During the Shadowing Study it had been observed that after several hours of using the CADs software, the designer B(2) had stated he was too tired to continue due to the cognitive demands imposed by using it. This was perceived to be a barrier to creativity as simple modifications to a drawing took several keyboard commands/mouse clicks. For example, to draw a straight line demanded several keyboard entries/clicks which can be laborious, time consuming and interfere with the flow of thought. As noted in chapter 8, section 8.3.9.1 at one point he reverted to a quick drawing using pencil and paper to help clarify the design change he was making as sketching was not supported by the technology he was using. This need to sketch spontaneously supports Verstijnen and Hennessey (1998) who argue that the mental processes of restructuring and combining are used in this activity. Fish and Scrivener (1990) also argue that drawing and sketching assists the internal cognitive processes by allowing thoughts to be externalised in a visual format. What is illustrated in this example, is how the designer found a way to minimise the cognitive load of the technology and maximise the capacity for creativity.

B(2)'s command of the software indicated how features of CADs such as zooming and visual manipulation enhanced the development of the engine he was designing thus providing evidence of the advantages of using this technology (Ertas & Jones, 1996). However, B(2) was CADs literate and it may be beneficial to extend those literacy skills through the group and integrate their use with collaborative technologies such as whiteboards.

The introduction of new software, Pro/ENGINEER™, to the department had provided something a step closer to the conceptual design software desired by the engineers. Pro/ENGINEER™ is part of a suite of software for different steps in the design process. For example, the Pro/MECHANICA™ software includes a facility for stressing components and Pro/DESKTOP™ offers, amongst other features, 2D sketching. Additional packages such as catalogues of standard components to assist in the modelling process are also available. It was hoped (at the time of the study) some of these options would be purchased. However, as with all requests in Rolls-Royce a business-case would need to be compiled and presented before any decisions could be made.

Whilst the technology was more versatile and could provide 3D models and simulations it was felt there was no compensation for building a "mock-up". Stereolithography, a rapid prototyping technique which produces a physical model of a component, was used to help "illuminate" concepts and ideas (see chapter 4, section 4.4.5). It was only then by having something tangible did potential problems come to the fore and were better understood. One of the experienced designers had referred to a situation in Derby where the IT technology had been wholly relied upon and an engine had been manufactured without any rig testing. Small changes had been made to a previous engine design and assumptions had been made on the basis "we've done this before so we know what we are doing". The engine was completed within 36 months to the customer's specification and tests were done using computer software. Unfortunately lots of problems ensued as assumptions had been made based on calculations which were erroneous. What had failed to be taken into account were the mechanical design changes such as vibration rates due to the modifications made. The new design was abandoned, but it had cost the company dearly and provides a good example of the need for, what one designer referred to as, "making and breaking" things to find out potential and otherwise unforeseen problems of designs.

9.4 Summary of the chapter

The purpose of this chapter was to review the findings from Phases 1 and 2 of the research in terms of the literature reviewed in chapters 3 and 6. There were many common issues and examples of perceived barriers to creativity, which were apparent through all the studies of the research project. These were discussed and confirmed in terms of the literature reviewed in chapter 3.

9.5 Summary of Phases 1 and 2

The purpose of Phase 2 in the research was to seek whether evidence elicited through the Tracking and Shadowing Studies regarding perceived barriers to creativity focusing at the micro level would be found to support or invalidate (through negative case analysis) the results from Phase 1. This was documented in chapters 7 and 8. The synthesising of the findings from both phases of the research in terms of the literature was discussed taking into account the more detailed review in chapter 6.

The next chapter comprises Phase 3 of the research. It includes a model demonstrating the interplay between the macro and micro conditions of the phenomena, barriers to creativity, as perceived by the engineer designers working in NPE, together with the development of the theory, which is grounded in the data. This is presented and discussed in the chapter 10.

Phase 3

Chapter 10: A Model of Perceived Barriers to Creativity, Conclusions and Recommendations

10.1 Introduction to Phase 3 and the chapter

In Phase 1 of this research participants were interviewed to gain an understanding of the general issues relating to perceived barriers to creativity within the NPE department. These issues related to the culture, values and opinions of the project managers, team leaders, experienced designers, new designers and trainees working in NPE. This culture is in turn affected by the environmental influences of Rolls-Royce and wider influences of the aeronautical and defence industries. In Strauss and Corbin's (1998) methodological terms of grounded theory this is identifying where the phenomenon occurs under macro conditions.

The premise of the research was that the values, attitudes, beliefs, relationships and artefacts which the members of NPE adopt and synthesise create dispositions, motivations and decisions that prompt activity. As Rolls-Royce wanted to know about NPE and its activities, it was important to understand these cultural constructs in order to understand the creative working practices and the perceived barriers to creativity exhibited in everyday working practices.

Phase 2 of the research focused on the investigation of the phenomenon under micro conditions. These were the day-to-day, minute-to-minute circumstances that sustained, evolved and affected the creative processes in NPE. They were understood through discussions of issues via information recorded in interview diaries and observations of activities and tasks. This revealed problems and practical barriers to creativity, built up through history and cultural activities (e.g. organisational, learning and socialisation) and the current operational activities. This work has found a strong interconnectivity between the macro and micro conditions as Strauss and Corbin (1998) suggest, but a simple cause and effect cannot explain the phenomenon of perceived barriers to creativity.

Rolls-Royce is a large and complex organisation. It operates within a highly competitive global market and has to be able to respond to the nature of that market for it to continue to be a key player in the aerospace industry. This research has identified and investigated the perceived barriers to creativity many of which occurred under micro conditions. However, seemingly distant and irrelevant influences relating to macro conditions can ultimately affect the individual or team and their perceived barriers to creativity as also identified in this research.

Through Phases 1 and 2 of the research, thirteen categories were drawn from the data as important in articulating what was going on in NPE. Simple diagrams and techniques were developed to represent the relationships between the categories. However, it was found that they could not easily represent problems associated with this real and highly complex organisation. For example, the development of the Interrelationship Digraph (see chapter 5, section 5.4.4.2) was intended to illustrate the interplay between the different categories in relation to the phenomenon. However it became apparent that this technique could not achieve this in full. This was due to the highly complex interplay between the categories and issues raised in relation to the perceived barriers to creativity articulated by the participants when working with this tool. A similar problem was found in the development of the 'paradigm'/models in chapter 5, section 5.4 and chapter 7, section 7.5. These models could really only begin to demonstrate the relationships between categories either under macro or micro conditions again failing to represent the complicated interconnectivity that really existed between them.

The interplay of the phenomena under macro and micro conditions leads to questions of change for the future. For example, how do NPE members adapt to meet change and retain creative ethos whilst meeting the aims of Rolls-Royce Aerospace? What are the implications of this in terms of human resources? There is also a need to research into the wider macro conditions (e.g. environmental) to better understand the vision of the company and organisation so that it may be possible to understand how wider environmental and global issues influence creativity in NPE and vice versa. The important question is to establish how the company will balance the creative and sometimes speculative endeavours of the members of NPE against the need to remain financially competitive in the aerospace industry.

The purpose of this final phase of the research was to draw upon the findings and outcomes from Phases 1 and 2 to help explain the perceived barriers to creativity in the context of what is happening at NPE, Rolls-Royce Aerospace (Bristol). The development of a conditional/consequential matrix/model (see chapter 2, section 2.4.4.3) and theory helps to represent and describe the interplay between the macro and micro conditions where perceived barriers to creativity were found to occur.

The major conclusions and recommendations from the research are discussed in section 10.3. Examples of how Rolls-Royce may want to consider the recommendations as possible solutions/ways forward is illustrated in terms of a 2x2 grid in section 10.4. It is inappropriate to suggest there is a simple answer to the outcomes of the research. The issues span a broad spectrum and suggesting simple solutions to the issues raised would be naïve. Therefore the outcome of the research has culminated in a number of conclusions and possible recommendations none of which can be or should be considered without further investigation.

Validation and the generalisability of the findings and ideas for future research are discussed. Finally a critique of the approach and methods used in the research brings this chapter and thesis to a close.

10.2 Conditions and consequences: a matrix explanation

A rich picture of the occurrence of the phenomena probably cannot be ever fully articulated, but the use of a number of models can provide frameworks that help to promote thought and begin to structure the understanding of how, why, when and where perceived barriers to creativity were experienced.

As discussed in chapter 7, section 7.5, a full representation of the interplay of macro and micro conditions of where perceived barriers to creativity occurred could not be drawn from the simple macro and micro 'paradigm'/models as depicted in chapters 5 and 7. They were useful for developing the relationships between categories as axial coding progressed, but to a certain extent were incomplete. The simple cause and effect 'paradigm'/models do not convey the richness needed to help explain the highly interconnected complex problem of barriers to creativity as perceived by the design engineers in NPE, Rolls-Royce Aerospace (Bristol).

Strauss and Corbin (1998) describe the conditional/consequential matrix (see chapter 2, section 2.4.4.3) as an analytical tool for helping to demonstrate and explain "the dynamic ways in which conditions, actions/interactions and consequences can coexist and influence each other. It can also account for different perceptions, constructions and standpoints from the various participants involved thus presenting an overall picture of what is going on" (p.183). Thus it can assist in the tracing of the paths of connectivity in relation to when the phenomenon occurred, why it occurred, what actions/interactions took place and what were the resulting consequences or outcomes. The matrix then is a diagrammatic representation and is used as a conceptual guide. Figure 10.1a is adapted from the conditional/consequential matrix described by Strauss and Corbin and is used in this thesis to help explain the "intricate web of connections that exists between contextual factors and actions/interactions" (p.191).

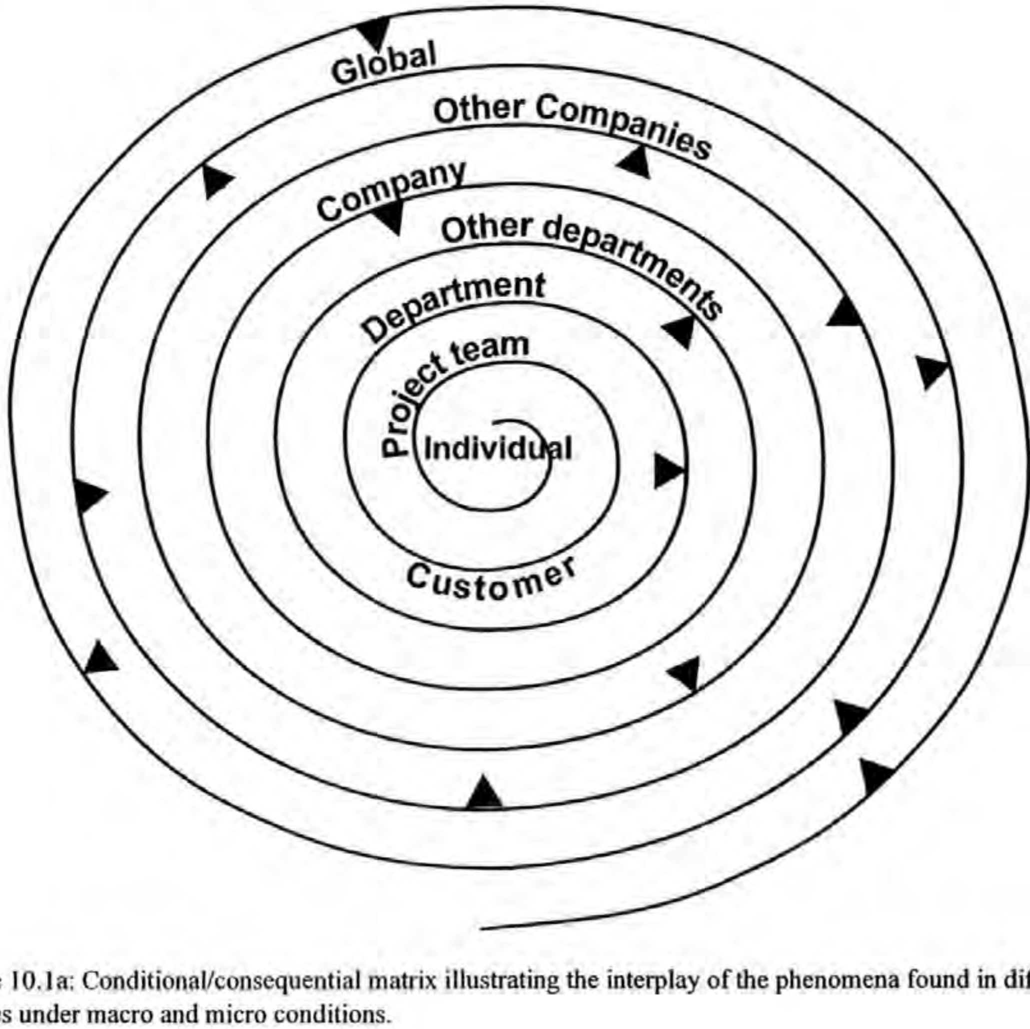

Figure 10.1a: Conditional/consequential matrix illustrating the interplay of the phenomena found in different sources under macro and micro conditions.

To explain the matrix, each concentric circle represents a different source of the potential conditions/consequences where the phenomenon was found to occur. Thus the conditions/consequences represent the structural context in which the actions/interactions around them occurred which could evolve over time and place. The actions/interactions can and did take many forms such as policies, regulations, plans of action and these depended on the source in which it was found. For example in figure 10.1a, a perceived barrier to creativity occurred under the micro condition in **project team** and another under the macro condition **global**. Depending on where it occurred, the subsequent consequences were be different. The arrows in figure 10.1a represent the intersection of the conditions/consequences and the resulting chain of events. However as Strauss and Corbin state, the relationship between conditions and consequences and subsequent activities rarely follow a linear path.

In complex 'real life' situations actions/interactions occur in response to multiple conditions some of which may have happened in the past, some which could be happening now and others which can be anticipated to influence future outcomes. The arrows moving away from the centre represent this situation. As Strauss and Corbin (1998) state, "multiple and diverse patterns of connectivity can occur with discernible shifting patterns of action/interaction over time" (p.188).

It must be remembered that the distinction between the macro and micro areas are dependent upon the circumstances and viewpoint taken in the research. In this research the focus was mainly on the inner most circles of the micro conditions although it was evident from the data that the broader macro conditions and consequences were still important. For example, the main focus of this research has been to identify the perceived barriers to creativity as experienced by designers in their daily creative activities in NPE. However, the broader conditions in terms of the business the design department sits in and the wider global economy are still important factors and indirectly impact on the individual designer's experiences, activities and beliefs. Future research is needed in these macro areas to better understand the affect they have on the performance and creativity of designers.

Figure 10.1b is another representation of the sources of conditions drawn from the data and placed against the main categories. This matrix also highlights how examples of perceived barriers to creativity interconnect across the categories under various sources of conditions. In this figure the cells of the matrix are populated with examples of the phenomena drawn from the data. There is inevitably a lot of duplication as perceived barriers to creativity rarely happen in isolation. They happen as a result of the complex interplay between other conditions and sources. It is the intention of this matrix to demonstrate this complicated picture. The grey shaded area was beyond the research focus and is therefore less populated, but interviews and observations identified a number of references to macro issues. The literature review produced supporting evidence to allow some speculation as to the importance of such factors in influencing an individual's perception of barriers to creativity.

The best way to demonstrate the complexity of the interconnectivity of conditions, sources and consequences where the phenomena occurred is by giving an example drawn from the matrix (see figures 10.1a & 10.1b). The words in *italics* represent the factors and examples (highlighted in colour in figure 10.1b) of the phenomena drawn from the data in relation to particular categories. The words in **bold** represent the source under which the perceived barrier was found and influenced by.

Rolls-Royce operates within a **global** aerospace industry where the market is volatile and highly competitive and there is a need to be flexible to cope with these influences. *International crises* and *economic* problems are unpredictable factors which can influence strategic decisions made by the company. For example, during the write-up of this thesis an international crisis, the destruction of the World Trade Centre, September 11th 2001, is likely to have dramatically changed the environment, fortunes and market conditions of aerospace industries.

CATEGORIES	MICRO CONDITIONS ◄						► MACRO CONDITIONS	
	Individual	**Project team**	**Customer**	**Department**	**Other departments**	**Company**	**Other companies**	**Global**
Organisational processes	SAP Resources Transactive memory Business case Project Derwent Demarcation Fragmentation Projectisation Exit Review Gates New initiatives out-sourcing Accounts led Isolation	SAP Resources Transactive memory Business case Project Derwent Demarcation Fragmentation Projectisation Exit Review Gates New initiatives out-sourcing Accounts led Isolation	SAP Resources	SAP Resources Transactive memory Business case Project Derwent Demarcation Fragmentation Projectisation Exit Review Gates New initiatives out-sourcing Accounts led Isolation	SAP Resources Transactive memory Business case	Demarcation Fragmentation Projectisation Resources SAP Exit Review Gates New initiatives out-sourcing Accounts led Project Derwent	Culture Politics Franchising	Globalisation Market-led forces Economics Politics International problems/crises Advancements in technology Regulatory standards
Weltanschauung	Site cultures Shared information "slaves to the system"	Site cultures Shared information "slaves to the system"	Site cultures	Shared information "slaves to the system"	Site cultures Shared information "slaves to the system"	Site cultures Shared information "slaves to the system"		
Timescales of project	'Rush' jobs "Thinning" down of studies Project Derwent Constraints Interruptions SAP	'Rush' jobs "Thinning" down of studies Project Derwent Constraints SAP	'Rush' jobs "Thinning" down of studies Constraints	Resources Project Derwent SAP		Project Derwent		
Integration with other companies	Data transfer Communication/ information flow Politics	Data transfer Communication/ information flow Politics	Data transfer Communication/ information flow Politics			Data transfer Communication/ information flow Politics	Data transfer Communication/ information flow Politics	

Figure 10.1b: A matrix indicating the interplay and interconnectivity between categories under micro and macro conditions in relation to perceived barriers to creativity.

CATEGORIES *(continued)*	MICRO CONDITIONS ◄ Individual	Project team	Customer	Department	Other departments	Company	Other companies	► MACRO CONDITIONS Global
Working practices	PowerPoint engineers Workarounds Administrative demands Less secretarial support Less opportunities for informal discussion & debate Data tracking Housekeeping SAP Interruptions Working environment Transactive memory Access to data Communication/ information flow Security	Workarounds Less opportunities for informal discussion & debate Data tracking Housekeeping SAP Interruptions Working environment Transactive memory Access to data Communication/ information flow Security	Workarounds Constraints Communication/ information flow Security	Less secretarial support Housekeeping Interruptions Working environment Transactive memory Access to data Communication/ information flow Security	SAP Transactive memory Access to data Communication/ information flow Security	SAP Working environment	Mis-match in practices attitudes	Globalisation Market-led forces Economics Politics International problems/crises Advancements in technology Regulatory standards
Project management	SAP Co-located projects & teams Transactive memory	SAP Co-located projects & teams Transactive memory		SAP Co-located projects & teams Transactive memory	SAP Co-located projects & teams Transactive memory	SAP Co-located projects & teams Transactive memory		
Management style	'Rush' jobs Interruptions	'Rush' jobs Interruptions	'Rush' jobs Interruptions		'Rush' jobs Interruptions			

Figure 10.1b: A matrix indicating the interplay and interconnectivity between categories under micro and macro conditions in relation to perceived barriers to creativity.

CATEGORIES *(continued)*	MICRO CONDITIONS ◄							► MACRO CONDITIONS
	Individual	**Project team**	**Customer**	**Department**	**Other departments**	**Company**	**Other companies**	**Global**
Experience of designers	Attributes Educational background Demographic time bomb Motivation Opportunities for learning & development Relationships Loss of specialist expertise Transactive memory Training	Attributes Educational background Demographic time bomb Motivation Opportunities for learning & development Relationships Loss of specialist expertise Transactive memory Training	Relationships	Demographic time bomb Motivation Opportunities for learning & development Relationships Loss of specialist expertise Transactive memory Training	Relationships Loss of specialist expertise Transactive memory	Demographic time bomb Loss of specialist expertise Transactive memory Training		
Design process	Less opportunistic meetings Limitations of technology Less opportunity for impromptu social interaction Co-located projects & teams Transactive memory Access to data Communication/ information flow Satisficing Access to specialist expertise Resources SAF Exit Review Gates New initiatives out-sourcing Administrative demands	Diversity of approaches Less opportunistic meetings Limitations of technology Less opportunity for impromptu social interaction Co-located projects & teams Transactive memory Access to data Communication/ information flow	Access to data Communication/information flow Satisficing	Less opportunity for impromptu social interaction Co-located projects & teams Transactive memory Access to data Communication/ information flow	Less opportunity for impromptu social interaction Co-located projects & teams Transactive memory Access to data Communication/ information flow	Demarcation Fragmentation Projectisation Resources SAP Exit Review Gates Accounts led Project Derwent		Globalisation Market-led forces Economics Politics International problems/crises Advancements in technology Regulatory standards

Figure 10.1b: A matrix indicating the interplay and interconnectivity between categories under micro and macro conditions in relation to perceived barriers to creativity.

CATEGORIES *(continued)*	MICRO CONDITIONS ◄						► MACRO CONDITIONS	
	Individual	**Project team**	**Customer**	**Department**	**Other departments**	**Company**	**Other companies**	**Global**
Communication (social)	Social connectivity Resources Communication/ information flow Information/knowledge sharing Misconceptions Relationships Co-located projects & teams Transactive memory SAP	Social connectivity Resources Communication/ information flow Information/knowledge sharing Misconceptions Relationships Co-located projects & teams Transactive memory SAP	Communication/ information flow Misconceptions Relationships	Social connectivity Resources Communication/ information flow Info./knowledge sharing Misconceptions Relationships Co-located projects & teams Transactive memory SAP	Social connectivity Resources Communication/ information flow Info./knowledge sharing Misconceptions Relationships Co-located projects & teams Transactive memory SAP		Communication/ information flow Misconceptions Relationships	
Technology	CADs Limitations of software Access to information Reliability of the system Limitation of hardware Shared practices Information overload Data transfer problems Usability issues Loss of specialist expertise	CADs Limitations of software Access to information Reliability of the system Limitation of hardware Shared practices Information overload Data transfer problems Usability issues Loss of specialist expertise	Data transfer problems Security issues	CADs Limitations of software Access to information Reliability of the system Limitation of hardware Shared practices Information overload Data transfer problems Usability issues	Limitations of software Access to information Data transfer problems	Contracts with ITSS Security issues		Globalisation Market-led forces Economics Politics International problems/crises Advancements in technology Regulatory standards
Creativity	Qualities Attributes interruptions Limitations of technology Transactive memory	Qualities Attributes interruptions Limitations of technology Transactive memory		Qualities Attributes interruptions Limitations of technology Transactive memory		Qualities Attributes interruptions Limitations of technology Transactive memory		

Figure 10.1b: A matrix indicating the interplay and interconnectivity between categories under micro and macro conditions in relation to perceived barriers to creativity.

CATEGORIES *(continued)*	MICRO CONDITIONS ◄							► MACRO CONDITIONS
	Individual	**Project team**	**Customer**	**Department**	**Other departments**	**Company**	**Other companies**	**Global**
Workload & time pressure	'Rush' jobs Satisficing "Thinning" of projects SAP Juggling priorities Interruptions Access to data Administrative demands	'Rush' jobs Satisficing "Thinning" of projects SAP Juggling priorities Interruptions Access to data	SAP "Thinning" of projects	'Rush' jobs SAP Juggling priorities Interruptions				

Figure 10.1b: A matrix indicating the interplay and interconnectivity between categories under micro and macro conditions in relation to perceived barriers to creativity.

Inevitably *market forces* have affected the workforce of Rolls-Royce Aerospace. Over the last ten years the **company** has responded to *global factors*, such as increased international competition, by aiming to *reduce time-to-market* with regard to aero-engine development by the introduction of *Project Derwent* (see chapter 1, section 1.7.1). Focusing on one outcome of this approach, concurrent engineering and *projectisation* have led to the emergence of multidisciplinary **project teams**. As described in earlier chapters, **individuals** have felt the impact of this change in many different ways. One of the dangers of this approach is that the exchange of ideas and experience that sustain the *specialist expertise* built up over years is lost. It would seem that those interviewed felt this was happening. For example perceived obstacles to *information access* and *communication* arising from the *fragmentation and demarcation* of the company were seen to impede creativity. Social networks *(social connectivity)* and the *transactive memory system* so evident throughout the research and which had taken the experienced designers years to establish, were being undermined by the *disbanding of discipline* based groups, the introduction of new accounting systems (*the SAP system*) and reductions in manpower.

Thus changes in the way they (**teams and departments**) worked meant they had lost some of the social interactions *(relationships)* necessary to generate and nurture creative ideas while at the same time more *administrative demands* were being made. The potential *isolation* of the conceptual design engineers reduces the opportunities for cross-fertilisation of creative ideas and problem-solving activities with colleagues. *Resource issues* were another major impact on their creativity with *inappropriate or inadequate hardware and software* for some aspects of design.

This example based on the findings from the research illustrates that macro and micro conditions are heavily interdependent and interconnected, and thus it is difficult to distinguish their individual influence and what could be done to improve the situation in terms of the perceived barriers to creativity. However the deconstruction of the complex interrelationships has been helpful in understanding the individual elements of NPE (people, technology, resources etc.) and how they work together and within the wider environment. Some conclusions and suggestions are outlined in the following section.

10.3 Conclusions and recommendations for reducing the perceived barriers to creativity

The following suggestions are made simply as logical explanations of the findings of the research. It is very likely that Rolls-Royce management is already well aware of the situation and has investigated suitable remedies. No presumption is intended.

10.3.1 Design is a social skill

Throughout the research it has been evident that design does not take place in a vacuum, but that it is a social skill developed through experiential and situated learning. In chapter 3, section 3.2.2 various models of design were discussed. Although previously few authors recognised the importance of the social aspect of design, recent descriptions of design models have addressed this omission (e.g. Pugh, 1996; Cross & Cross, 1996).

Many social mechanisms were found to facilitate the design process such as "social permissions" and social connectivity (Baird et al, 2000). Evidence of a transactive memory system where "who you know" was just as important as "what you know" was referred to and observed many times throughout the research. As one experienced designer said, "Long term knowledge about design is passed on from person to person and feeds design thinking." This is a valuable and irreplaceable resource which needs to be cultivated, sustained and developed possibly by introducing a skills/expertise/experience register, personal development plans and exploration of informal and formal communication systems such as discussion groups and brainstorming workshops.

10.3.2 Communication channels

Communication flowed both laterally across departments and vertically through the hierarchy of the company. They were not thought to be as open and flexible as they should be. Demarcation, projectisation and the personal insecurities of individuals were some of the perceived reasons given by the interviewees. Majaro (1992) suggests that poor communication can inhibit the creativity of an organisation and suggests that audits should be carried out to see where communications are effective and ineffective. West (1997) suggests that communication can be enhanced by producing newsletters, team briefings and the use of integrated team meetings or cross team memberships and liaison personnel.

Such ideas can generate the sharing of information and encourage a mutual understanding of objectives, strategies and processes between groups and teams. This could reduce the feeling of isolation experienced by those interviewed in NPE arising from the separation of engineers into project teams and the department's security status.

10.3.3 Appropriate technology

Individual needs in terms of the technology, the benefits of physical modelling, opportunities for sketching and social interactivity are important aspects of conceptual design practice.

Appropriate investment in technology both in terms of hardware and software is needed to sustain and enhance the design engineers working environment as suggested by the engineers' comments in previous chapters. For example, CADs were found to be inappropriate for aspects of the conceptual design stage. New developments in technology are providing better scope to aid conceptual design and offer fully integrated packages. There is a need to find tools that integrate report writing and PowerPoint into design operating tools to enable these activities to be more seamless. Shneiderman (1999) proposes the "Genex framework" which comprises four phases of "collecting, relating (consulting), creating and donating (disseminating)" to offer integrated creative support in the future. A similar approach may be of value to the development of the technical environment in NPE.

The use of stereolithography as a tool for illumination rather than simply for support was important to the design engineers and could not be compensated by the current software technology in enabling a clearer understanding of the form and function of a component. As visualisation was so important it would be worthwhile to exploit graphic, aural, tactile and other forms of output to support this. Further investigations into Virtual Reality as this technology matures and the solid modelling process is something that could also be considered further.

The design engineers would welcome enhanced access to previous designs and their associated solutions. Therefore there is a need to capture solutions for future reference and communicate these across departments and sites. Engineering Knowledge Management

(EKM) using a Knowledge Representation Methodology (KRM) framework has been developed at Lancaster University Engineering Design Centre incorporating a search engine which responds to a Knowledge Base Vocabulary (KBV). This EKM software is named Schemebuilder© and has been designed "to assist the designer in the conceptual phase of complex mechatronic systems". It provides the capability for the searching of past solutions along with other many beneficial features such as expert advice and rapid prototyping. With such developments on the horizon, future software applications will serve to enhance the conceptual design engineer's design process (Porter et al, 1998).

Other software developments such as "Desperado" (Lambell, Ball & Ormerod, 2000) and JANUS (Fischer, 1993) are further examples which may facilitate thought processes and creativity throughout the whole design process. Desperado seeks to provide support in the reuse of designs and the encoding of current design work for future use and JANUS is a knowledge-based system for supporting design (see chapter 3, section 3.6.4).

In light of the findings from this research new IT technology should only be adopted after the evaluation of the user interface. The features of the software should support and enhance the creativity of the designers without excessive mental load. In other words the technology needs to be transparent and not get in the way of thought processes.

10.3.4 Accessing information

Security and IT systems were causing barriers to accessing information and interrupting thought processes, work flow and levels of engagement. The systems were counter-intuitive and trying to find the relevant information was not always easy. With the advances in bio-informatics it may be possible in the future to use alternative methods such as fingerprint, voice or retina recognition to speed access and security. Alternative forms of presenting electronic material could be considered using multimedia formats. Also different ways to search and view data could be considered. For example, the VIBE system discussed in chapter 6, section 6.4.1 is based on visualisation of a collection of related documents (Olsen et al, 1993).

Electronic bulletin boards could be used to present problems, disseminate and share important information, such as new developments, and used with intranet systems. These types of technology could support, enhance and develop the transactive memory system, which is already in place, especially for the new designers.

Finding the 'right' person through the electronic telephone directory proved to be difficult for those interviewed. An 'experts' database, accessible by subject keywords, might improve access to finding the skills and knowledge required.

10.3.5 Working collaboratively

There is a need to understand the socio-technical aspects of designers' work and to ensure that communication flows between departments and individuals are enhanced and supported. For example the available technologies focus on support for individuals' productivity and there needs to be a greater emphasis upon technologies that support collaborative work and enhance a shared understanding of situations.

Remedies could include the shared work environments and group communication support systems (GCSS) which are currently being developed. For example, "video walls" which provide a "common" area in different locations where individuals can enter and participate in 'automatic' synchronous video communication (McGrath & Hollingshead, 1994). The ClearBoard developed by Ishii and Kobayashi (1992) offers a real-time collaborative drawing space for remote users. Such technologies could partially compensate for the reduced opportunities for face-to-face communications in remote groups, but which are preferred by the designers, providing they take into account the important aspects of social interaction. These issues are highlighted in the literature (e.g. Tang & Leifer, 1988; Gribbons, 1991; Scrivener & Clark, 1994; Easterbrook, 1995; Fussell & Benimoff, 1995). Recent developments in technology means large interactive whiteboards could be used to aid discussion and interaction between groups which work collaboratively on projects but are located on different sites.

10.3.6 Working relationships and practices

Working relationships and practices between different individuals, sites and companies suggest a need for a better understanding of the cultural differences in terms of background, experience and work ethics. The shared work spaces mentioned in section 10.3.5 could enhance social interaction and provide an opportunity for a better understanding of different working practices and help in learning to accommodate these differences.

Individuals organised their computer files and drives in a haphazard way which caused problems when transferring information between groups. General housekeeping IT skills could be improved through developing a support infrastructure, training and adopting a departmental policy/protocol on topics such as archiving, curating, naming and general information management. Improved facilities regarding access to the internet and the development of intranets and computer-mediated-communication, email and other groupware could be considered. Better technical connectivity could improve social connectivity between individuals, sites and collaborators.

10.3.7 Human resources

There is a need to manage the demographic profile of NPE in terms of succession planning. For example the loss of expertise and knowledge and the impact that has on the social connectivity of the company and the transactive memory system.

The senior engineers whilst highly regarded for their knowledge and expertise, did not appear to be delivering all of the value of which they were capable. Those interviewed felt that the senior engineers' presence at the Exit Review Gates came too late. Earlier input and advice in a less formal manner would help to alleviate some of the pressure and angst felt at the review gates and could provide opportunities for nurturing the social connectivity and transactive memory system. Perhaps some low-key post-retirement consultation mechanism would help.

As already mentioned projectisation and demarcation have meant that individuals on project teams have lost a degree of contact with their discipline base. This suggests there could be a need for continuing professional development or discipline-based discussion groups which could enhance the individual, the project they are involved with and the intellectual capital of the company.

Rush jobs and the fluidity of human resources between projects created feelings of unsuitability and uncertainty. A way to help alleviate this situation may be to have a number of 'core' designers allocated to a 'roving' project team who could deal with the unplanned tasks that cropped up in NPE without putting other projects in jeopardy. This team would need to have a broad repertoire of skills and could support skill development by seconding designers for a period of time.

It seems likely that the market-led requirements in respect of engineering skills will be an important influence in the future. For example, will it be mainly design by analysis (using a rationalist approach) or design as synthesis (using a more constructivist approach) (Ramirez, 1995)? This would have an impact on the types of designers required in the future. One way to help make that decision could be to use Culverhouse's 4-path model of design (1993). This could establish the percentage of different types of design found in NPE and help identify the appropriate "types" of designer best suited to the different models of design. The designers involved in the research had referred to "innovative" and "technical" types of designers already found in the company. Research into these perceptions may be useful.

Psychometric testing using inventories such as the Kirton Adaption Innovation Inventory (KAI) (1987a; 1987b, as cited in Isaksen & Kaufmann, 1990) could help to identify the types of designers best placed to work on particular types of design. However there is a risk of 'pigeonholing' designers into permanent roles and this would need to be considered. Methods for measuring an individual's creativity attributes/levels could also be implemented (West, 1997). It may be that software could be tailored to offer different types of designers support whilst taking into account the different approaches used by novices and experts in the future (Perez et al, 1995).

10.3.8 Education and training needs

One of the benefits of the traditional engineering apprenticeship route was the vast knowledge base which was constructed through experiential learning. New engineers who were graduates appeared to lack this knowledge base. Lave and Wenger (1995) propose the concept of "legitimate peripheral participation" to characterise learning in a community of practice. They argue legitimacy and peripherality are what is required to make participation in a community of professional practitioners possible. Legitimacy relates to being accepted into the community as a "newcomer" (new designer) which enables learning to take place.

Peripherality relates to the opportunity for full participation within the community so an understanding of how that community operates is acquired (Wenger, 1998). To some extent this approach was being used with the new group of recent graduates which had been introduced to NPE during the second phase of the research. Creative design is inherently a learning process and whilst these trainees were involved in their own project they did have access to the tools and expertise in the NPE department.

The concept of metacognitive knowledge, that is knowing what you know and when and where to use it learnt from experience, is a characteristic of apprenticeship rather than formal attention to this aspect of knowledge (Collins et al, 1989).

Practice sessions, guidance tutorials and the opportunity to participate under some guidance could enhance the repertoire of the trainees as well as more informal involvement in the community of engineers at Rolls-Royce and NPE. Skills packages and focal points of contact (experts) was an initiative in Rolls-Royce which had yet to materialise at the time of this research. It would be worthwhile to explore ways to facilitate the experiential learning and professional development of the new designers and trainees across the company.

Hsi and Agogino (1993) have developed computer-based case studies for teaching engineering design. Based on Kolb's (1984) experiential cycle it provides opportunities for active experimentation and reflective observation using a range of multimedia inputs designed to accommodate different learning styles. Such software could be used with new trainees to provide further support in their development.

The Designer's Terms of Reference manual (see chapter 8, section 8.3.2.2) could be made more accessible by integrating it within a learning framework and publishing it using accessible technology. For example an electronic intranet version could be made available.

10.3.9 Support systems

Support and administrative systems could be considered integrally with the conceptual design process. For example it was evident throughout the research that design engineers were involved in increasing levels of administration in recent years which took time and energy to deal with. It may be possible to use this time more creatively. Further research could explore this.

Majaro (1992) suggests "lack of slack" can be a barrier to creativity, but argues that extra pockets of time can be found. He suggests encouraging personnel to keep log diaries of the sorts of things they do day-in and day-out. This identifies what types of activities could be undertaken by other personnel freeing up time for thinking and those activities which require more specialist skills.

A quiet area could be designated to provide an environment which fosters informal discussions and the opportunity to resolve problems, find solutions and for creative ideas to emerge. Collaborative technologies could be installed to support discussions. West (1997) suggests a number of strategies such as physical relaxation away from the stress of work to help people develop their creative potential.

The sorting of information electronically and the fielding of phone calls also caused problems and unwanted distractions. Email filters could help control the circulation and prioritise the influx of emails and the use of a voice mail system could alleviate the need to answer and respond to other people's calls.

10.3.10 Business demands verses professional demands

Business needs would seem to be at odds with what designers think they should be doing as a professional group of design engineers. Business Process Re-engineering (BPR) changes the emphasis in conceptual design from functional specialism to product development focus. It was suggested that there are tensions between short term profitability and creativity. Long term intellectual capital growth is a related issue. The designers felt that the need for a creative environment was poorly understood with a focus on work becoming more procedural and mechanistic, for example with the development of key systems and the SAP system, rather than being flexible and responsive. Shortened timescales meant projects were not as complete and thorough as designers would have liked them to be. Many of those interviewed felt accountants were in charge of company decisions and that they had little appreciation of the impact of this 'accounts led' approach on designers, their resources and environment. There appears to be a constant balancing act between resource management and creativity and innovation and project completion (process view) verses creative practice which could not be resolved by IT alone.

Realistically Rolls-Royce Aerospace (Bristol) is subject to its business environment and cannot change easily because of the nature of its business, its long established infrastructure and the competitive global market within which it operates. The response from Rolls-Royce Aerospace was developments such as Project Derwent that was implemented to address the need for reduced time-to-market. Some perceived barriers to creativity were a consequence of these changing pressures, but other phenomena may be unintended and detrimental to Rolls-Royce's apparent inferred goals. For example, concern regarding the possible redundancies had been suggested as the cause of a reluctance, or even blocking, in data being shared and in departments having conflicting agendas.

10.3.11 Making NPE more creative

Whilst the pressures of market competition may mean that design evolution is incremental, small projects or training/development programmes could enable more adventurous creative leaps to be made. Creativity cannot be separated from social relationships, culture and business need. It might help to identify a new skill set to enable creative activities and to deal with the barriers by adapting to new business, social and cultural conditions.

There are various measures and inventories which seek to measure a companies creative climate (e.g. Ekvall et al, 1983, as cited in Isaksen & Kaufmann, 1990; Koester & Burnside, 1992; Majaro, 1992; West, 1997). Ekvall (1999) (see chapter 3, section 3.6.5) suggests there are a number of determinants and conditions which are necessary to support a creative climate in an organisation.

West (1997) suggests that providing rewards, seeking out of best practice amongst other companies, inputting of resources, encouraging a "learning" organisation, providing opportunities for creative thinking, and "idea champions" (similar to the "roving" teams mentioned in section 10.3.7) are all ways creativity can be supported. Majaro (1992) states that there are three major characteristics for creative organisations. They are, "the climate for creative thinking must be right, an effective system of communicating ideas must exist at all levels and procedures for managing innovation must be in place" (p.24). He suggests using the McKinsey 7-S Framework for enhancing the creativity and innovation in companies. By employing this framework it explicitly makes a company consider the hardware (strategy and structure) and the software (style, systems, staff, skills, and shared values) within the organisation (Peters & Waterman, 1982). Other strategies Majaro (1992) recommends as techniques to help solve problems are the "Why? Why?", "How? How?" and "Fishbone Diagram" methods.

10.4 Creativity as a multidimensional activity

Creativity is not a wholly rational process. It is multidimensional, it often happens subconsciously and does not fit into overly structured organisational systems easily.

The essence of the present work has been to identify ways of improving multiple facets of creativity (engineering designer's creative activities) within a multi-layered context (micro and macro conditions).

In chapter 1, section 1.3.1 three aspects of creativity were discussed in terms of an individual's creative attributes, the creative process they engage in and the end product. The design engineers are working in a multiple constrained design space. They may be involved in generating performance figures or designing components, but ultimately the utility of the engine will be judged in terms of the engine's airworthiness, certification and performance. In some aspects at least, the pressures of the competitive market place and the pressures on designers for greater productivity constrain the freedom to achieve ultimate performance and creativity. There needs to be a trade off between design creativity and business imperative. However, it must be remembered that simple cause and effect cannot explain the complexity of the situation, a number of interactions between macro and micro conditions make up the contextual situation in which the phenomena occur (see figures 10.1a & 10.1b).

Figure 10.2 illustrates an interpretation of the relationship between creativity and perceived barriers to creativity. The grid is populated with some examples illustrating aspects of the observed situations and comments from the design engineers.

HIGH CREATIVITY	Sketching Consulting the right expert	Operating CADs Finding information
LOW CREATIVITY	Routine design	Fielding phone calls Navigating CADs and database systems Using the SAP system
	LOW BARRIERS	HIGH BARRIERS

Figure 10.2: Representation of perceived barriers and their relationship to high and low creativity issues/activities.

By resolving/reducing some of the issues and barriers, the relative proportions of the cells might shift closer to those shown in figure 10.3. It has been the intention of the research to shed light on that transformation.

HIGH CREATIVITY	More user friendly technology Increasing access to information Keyword access to experts Wider social networks	*Reliability and security issues*
LOW CREATIVITY	Voice messaging Alternative forms for logging into systems Greater flexibility in using the SAP system	*Reliability and security issues*
	LOW BARRIERS	HIGH BARRIERS

Figure 10.3: Representation of perceived barriers and their relationship to high and low creativity issues/activities after issues and barriers have been reduced.

The general challenge facing NPE and individual designers is to reduce the barriers to creativity, in effect squeezing the right hand area of the grid. Secondly, to maximise the high creativity area of the grid to enable the increased productivity of the NPE project teams for new ideas. This would be in close association with the professional development and need for creative satisfaction of designers. Of course such ideals are bound up with complex interrelationships exhibited in figure 10.1b and would need further research into the relationship between the viewpoint of the design engineers and the wider needs of the organisation in the global market place.

10.5 Future research

The focus of the present research was on the perceptions of design engineers of barriers to their creativity. It would be interesting to elicit the reaction of the company, perhaps at a higher strategic level, to the findings to understand their perspective on creativity as a competitive asset to the business and how it is managed within the organisation.

This implies a need to investigate the culture of the organisation and how it makes transitions to new demands and how the creative activities then change in response to the new circumstances. That might entail an action research or ethnographic study over a prolonged period

This research was undertaken in one department focusing mainly on the micro conditions of where barriers to creativity occurred from the engineering designer's perspective. It would be useful to take a closer and more detailed look at where the phenomenon occurred under macro conditions and from a number of specialist perspectives. This could involve interviewing strategic management, sales and marketing, accounts, production personnel at senior or all levels within the company to understand how innovation and creativity contribute to the company's performance.

It is recognised that there is a lack of the organisational and managerial perspective in this research and future work could address that issue. In particular the research has focused on the human needs of creativity in NPE without fully understanding the economic and business imperatives of keeping the company solvent and understanding the short and long term vision for creative design at the various levels in the company. The interplay between aspirations and motivations of engineering design professionals and business professionals and how they learn to accommodate each others' viewpoints could also be addressed in future research.

10.6 Methodology

10.6.1 Validation

In chapter 2, section 2.5 issues relating to validity and reliability were discussed. The issue of validity is often questioned, when using qualitative methods in research, suggesting they are prone to subjective interpretation by the researcher. However Hammersley (1992) suggests that there are two basic criteria on which research findings should be judged. That is truth (validity) and relevance. Accounts are deemed to be valid if they are true and represent the features of the phenomenon under investigation accurately. Appropriate audiences judge the relevance of the accounts which should make a contribution to knowledge. The process of triangulation can also demonstrate the validity of the research. This research is measured against Patton's (1990) four types of triangulation as follows:

1. *Methods triangulation*: As reported in chapters 4, 5, 7 and 8 a variety of different methods have been employed namely interviews, direct observations, Interrelationship Digraph, interview diaries and shadowing.
2. *Triangulation of sources*: Data were collected from different participants with different roles in NPE using the same methods at different points in the research. Confirmation of the findings in the Scoping Study was validated by the data collected in the Design Group Interviews Study. Data collected in the Tracking Study were confirmed by the observations in the Shadowing Study.
3. *Analyst triangulation*: The findings from Phase 1 of the research were confirmed in three presentations to different groups, on different sites. A workshop with employees from Rolls-Royce further confirmed the categories which had been drawn from the data at the end of Phase 1.
4. *Theory/perspective triangulation*: Multiple perspectives on the data were collected from project managers and team leaders, experienced designers, new designers and trainees.

As a further confirmation, many of the findings were found to be supported by the literature (see chapters 6 & 9).

10.6.2 Generalisations

Many of the perceived barriers to creativity which include communication flows and channels, resource issues, technology, culture and changes in working practices are highly likely to be found in organisations which undertake conceptual design production with a similar set of issues. For example, organisations with a structured hierarchy find that decisions about changes in working environments and resources are usually made at the higher levels with little apparent thought for those who function in them. As organisations get bigger so the ability for open and free communication channels becomes more difficult.

Some general aspects of the findings of the research were found to be generalisable with respect to the other Rolls-Royce site in Derby (see chapter 5, section 5.4.4). Some of the broad issues may be extrapolated to other large hierarchical institutions where changes in working practices and technology are likely.

10.7 Reflection on the research process

In chapter 2, section 2.4 the argument for employing an ethnographic approach to the research was articulated. The time frame over which this research was undertaken was relatively short which meant that "pure" ethnography, as described by Ball and Ormerod (2000), could not be employed. Instead a "quick and dirty" approach (Hughes et al, 1994) was used which provided a broad, but naturalistic understanding of the phenomenon under investigation in the NPE environment. This derivative of "pure" ethnography is referred to as "applied" ethnography by Ball and Ormerod (2000) and is fundamentally different due to the length of time of the study and its "purposiveness".

Although the research was conducted in the "spirit of ethnography" (Lloyd, 2000) without any preconceived idea of what was to be found in the research, a grounded theory approach was used to complement the ethnographic line of enquiry to collate and analyse the data.

The techniques used to collect the data (see chapter 2, section 2.4.4) were naturalistic and enabled a systematic, logical and integrated account of the phenomena under investigation from the designers' perspectives to be described, explored and articulated. This would not be achieved if an experimental, positivist approach had been taken as the findings would have been narrower, predetermined by some a priori framework and possibly not a true representation of the issues which are 'real' for the designers.

10.7.1 Grounded theory versus ethnography: advantages and disadvantages

The Scoping Study provided a considerable amount of anecdotal evidence which was important and interesting. The Design Group Interviews Study, Tracking and Shadowing Studies produced a wide range of problems and areas for discussion and were analysed by grounded theory. The use of grounded theory allowed for a data reduction exercise to take place. This permitted the categories relating to issues of importance, as perceived by the design engineers in respect of barriers to creativity, to be drawn from the data rather than predetermining them at the outset. However, in doing this, a trade off between the richness and manageability of the resulting data is unavoidably made. There is inevitably some loss of detail and insights of the research which true ethnography would preserve. This can be frustrating for the researcher as they are not able to follow these up in a way which ethnography would allow. Such findings must remain in the source data but are available for future research.

However, the use of grounded theory has allowed some quantifiable measure of the data to assess the weight given to the different issues by different groups of people. For example, looking at what the different groups who had been interviewed had said in relation to the categories by charting a frequency plot (see chapter 5, figure 5.1) enabled some sense of relative priorities of issues for different categories of design engineers. Thus it allowed for some assessment of the areas which were most important and interesting for future research at a more detailed level. This would not necessarily have been drawn out if "pure" ethnography had been conducted.

The use of a range of techniques, that is semi-structured interviews, interview diaries, direct observation and the Interrelationship Digraph, also provided opportunities for the data to be triangulated, validated and some tentative generalisations to be made.

The time spent in the company with regard to this research was limited for a number of practical reasons. Whilst the research generated a lot of data, the majority of it was based on retrospective accounts from those interviewed. The exception was the Shadowing Study which collected data in real time. This technique helped to validate the findings of the previous studies (see section 10.6.1). However, the data represented a snapshot in time and therefore any generalisations made need to be treated with caution. A longitudinal/ethnographic study would have enabled the long life-cycles of projects to be tracked thus providing more detailed accounts of barriers to creativity as perceived and experienced by design engineers in NPE, Rolls-Royce across time.

Reflexivity is an important part of conducting qualitative research where the researcher personally reflects on the way they have engaged with the research methods and processes.

I think one of the strengths of the thesis is the comprehensive review of a number of literatures pertinent to the research question. A bottom-up approach was taken and the relevance of the different literatures emerged slowly and incrementally as the project progressed. As a non-engineer (my background is in psychology), it was challenging getting to grips with some of the different disciplines and multiple literatures which I had not encountered before. However, reviewing multiple literatures made me more open minded and responsive to numerous alternative mindsets which was vital for this research if I was to present a true and unbiased representation of the perceived barriers to creativity as experienced by the design engineers at Rolls-Royce Aerospace(Bristol). Had I had an engineering background, I could have had preconceived ideas about the issues and this would have influenced the approach and the findings.

The research methods and techniques employed were in many ways challenging for me. For example conducting 'active' interviews meant that in one respect they had to be open to allow new thoughts and ideas to come to the fore whilst, on the other hand, I had to ensure the interviewee did not lead the conversation too far away from the original focus. Ensuring that accurate accounts of the interviews were kept was also difficult, as I was not permitted to use a tape recorder in the later studies.

Working through the various stages of the data analysis was often complex. The large amounts of data made it an onerous task in assigning meaningful concept labels to the data. As the amount of data grew so higher order categories had to be developed. Categories had to be clearly defined to try to ensure there were no ambiguities. Therefore they had to be meaningful with well-defined parameters, properties and dimensions. The next difficulty was then in assigning the concept labels into the relevant categories which meant there was a need to keep checking, comparing and contrasting data with data to ensure reliability and consistency in this process. I had to return to the category definitions to check that the correct examples of data were placed under them. During this process there was a need to develop sub-categories, merge categories with other categories and produce new ones to accommodate new findings in the data. Memo writing helped to record the developments and clarified my thinking with these situations, as did discussions with colleagues to ensure that I was keeping on track and that I was answering my research question. With grounded theory, data analysis was taking place at the same time as new data were being collected to add further complexity to the analysis. Therefore constant cross-checking was needed to ensure I did not deviate from my category definitions.

I then had to devise ways to help me understand the what, why and how the categories were overlapping in terms of structure and process hence the 'paradigm'/models were developed (see chapter 5, section 5.4.2.3). Whilst these models helped to some extent, they could not represent the complexity of the situations highlighted in the data and the interplay and overlaps of the different categories. It was thought the generation of an Interrelationship Digraph (see chapter 5, section 5.4.2.2) would allow for the 'root causes' to the perceived barriers to creativity to be recorded by the participants who were chosen to be involved with this activity. However I found this was not a particularly useful tool to use to identify the problems encountered by Rolls-Royce. The tool could not deal with the complexity of the situation used in its current form. It was useful inasmuch as a shared understanding of the perceived issues and barriers to creativity reached a consensus within the group thus supporting the ontological perspective this research undertook. However, the tool could not cope with the highly complex situation the research was addressing and therefore had added little value to gaining an understanding of what was going on.

One of the main issues for undertaking qualitative research is the reliability issue and I had to make sure that I had addressed this issue throughout. There were times when I doubted my ability and had to reassure myself that I was carrying out the methodology in the appropriate manner. For example I found the concept of negative case analysis difficult to deal with. However I converted this into a practical fieldwork process by using the data from the Shadowing Study and comparing it to the data from the Tracking Study asking the question, "Was the evidence (observation) there to support what the design engineers had stated in their interview diaries?" If it was not then it provided examples of where, when or how the phenomena was not present under certain conditions.

The final drawing it all together and trying to make sense of it was very hard including decisions on how it should be presented in the thesis. Chapters 4, 5, 7 and 8 described and presented the analyses and the findings of the studies undertaken in Phases 1 and 2 of the research. A decision was taken not to interpret the findings in those chapters, but to do this in chapters 6 and 9 to enable the findings to collectively be reviewed and confirmed in terms of the data and the literature.

The outcomes of the research have been hard to represent in the form of a diagrammatic model due to complexity of the findings. Adapted from Strauss and Corbin's conditional/consequential matrix, figure 10.1a has been used to give the reader a conceptual guide to the phenomenon under investigation. The development of the other matrix (figure 10.1b) has provided another perspective on how to represent the interplay between the categories and sources of perceived barriers to creativity.

If I was to undertake similar research again I would try to establish an agreed schedule with the company involved in the research, and try to negotiate the use video and audio tapes whenever possible to ease data collection. I would also consider the possibility of using a software package such as Nudist to help with the categorising and integrating of the data.

Undertaking this thesis was a painful process at times, but ultimately a very developmental and enlightening one. I now have a detailed knowledge of how to employ the different research strategies and techniques and my reflections on the process will be useful to draw upon in the future should I choose to use these methods again.

10.7.2 Reflection on the paradigm chosen for the research

The choice of paradigm for the research was constructivist (see chapter 2, section 2.3). assuming a relativist ontology, a subjective epistemology and employing a naturalistic methodology. Having taken this stance, the findings mirror the realities of the mental constructions which were found to be socially and experientially based either on an individual level or shared collectively across individuals and cultures. Unlike a positivist epistemology, the researcher and subject are "interactively linked so that the findings are created as the investigation proceeds" (Guba & Lincoln, 1998). Thus there is an ongoing refinement and development of the findings as the research continues. This is reflected in the thesis, for example where the findings from the Scoping Study provided a framework and platform for the following DGI Study (see chapter 2, figures 2.2 & 2.5). The development of the Interrelationship Digraph, although limited in its value (see previous section), it did allow for further interpretations and reconstruction to take place. The drawing out of the categories continued through the studies in the second phase of the research with each stage informing the next until ultimately conclusions could be drawn in the final phase of the research.

The significance of this research is that it has involved looking at the real world of design in an environment of complex multidisciplinary teams working under commercial and political pressures. It is an interdisciplinary piece of work which has sought to clarify aspects of design which fall between other disciplines and to work on these to the benefit of engineering design. However by taking this particular stance the caveat is that inevitably there is a lack of great depth in knowledge in any single discipline considered, that is of engineering design, cognitive and social psychology, sociology and organisational literatures. If the research had taken a positivist approach the outcomes in contrast are likely to have been more deeply analytical, but much narrower and less holistic. The danger in taking a single disciplinary stance is that there is an underlying assumption that it is possible to include all issues from a single viewpoint or within a single conceptual framework.

The socio-technical systems approach has clearly illustrated the social dimensions of design as well as the technical. This has been demonstrated with projectisation where there was a conflict between the viewpoints of the designers, for example the importance of social networks for creativity, in contrast to the expectations of the company, for example the need to 'charge' other teams for time spent talking to them. A positivist stance would not have predicted this outcome nor revealed it due to the different methods of enquiry that would be used and the type of data collected.

In conclusion, a holistic, interdisciplinary research approach has found to be more likely than a single discipline, positivist approach, to be capable of producing findings which can address the overall goals of the system being studied and provide a better understanding of the various elements, influences and phenomena that operate with in it.

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Appendix A: Example of the memos written

Example of the memos written

24/11/98

Begin to categorise the notes, but already finding problems. Some categories overlap quite a bit. E.g.

Milestones and deliverables have been coded as a separate category, but the way they will present those deliverables will be in the form of a CD, therefore this also has links with communication category.

Design Process and technology are closely linked. So have decided to 'double' code in some instances. Also have decided to have a positive and negative technology category.

Changes in working practices and design process

Settings/context and organisational processes. 'Double' code again so that can identify where the setting/context interplays with the organisational process e.g. Security issue.

Indicated with some of the categories where they are positive comments on the technology

2/12/98

Unfortunately I haven't been able to return to this before now so I am hoping that I will be able to remember the categories OK. Concept labels and definitions and seem to be fine.

Links between project management and timescales of different projects. Linked with working practices as well re ECOM SHEETS

Links between project management and the organisational ways of doing things

20/1/99

Back to coding after having defined my categories and included some examples. However I have found going back to it that I need to include a new category regarding workload and time pressure.

As I carry out the coding, I can see more and more overlaps with the different categories. I will try to make sure these are all recorded appropriately in my analysis.

Need to define the category of wp and dp a bit more I think. It is difficult to differentiate between the two sometimes. For example how far does wp go in covering what some is doing. They have to implement certain practices to be able to get their job completed. But part of this will be the design process they are going through as well. Although not all designers are necessarily designing—some are running figures through engine cycles for instance—is this design *per se*?

21/1/99

I found it difficult to categorise this meeting as I was not interacting with the members, but observing what was going on between the two companies and their engineers in attendance. There was a lot of interaction between the two as they tried to reach a consensus on what was being discussed in relation to the points on the agenda. This activity is necessary because of the FOAS project that both companies are involved in. Artefacts such as drawings (in various formats) were used to highlight/represent different issues being discussed. Specialists from other areas and the designers working on relevant bits of the engine were called in as and when needed to clarify any issues to be resolved. Questions were bounced back and forth and problems articulated and thought through sometimes by thinking about previous scenarios where things have or have not worked before. Summaries and roundups were done to ensure all who were present knew what they had to do and by when.

Appendix B: Coding system to identify participants in each study of the research

Coding system to identify participants at each study of the research

To retain confidentiality and protect their anonymity all participants interviews and observations were coded.

A letter of the alphabet was assigned to each participant. As three groups were involved in the interviews a group number was also assigned (see below for definition of the groups). Finally an * represented their interview number. Therefore where excerpts from the fieldnotes were inserted in the text, it can be traced back to the person who said it, what group they were from, which interview it was, which book the field notes were recorded in (or tape if relevant), which page and which lines. For example:

C(1)3/tape3/counter581 (Scoping Study)

Q(1)26/bk1/pg144/ln51-54 (Design Group Interviews Study)

In the case of the Tracking Study the week was also included, for example:

N(2)23/wk4/bk2/pg11/ln72-74

Finally in the case of the Shadowing Study the day the observation took place was noted, for example:

X(2)day4/bk3/pg51/ln247-274

Definition of the groups

Group 1: Project managers and team leaders

These people had more involvement with the operational running of the department. Their primary goals within the department were the management of projects, resourcing and fostering a creative working environment.

Group 2: Experienced designers

These people undertook primary creative activities. This research focused on the design process, specifically where designers were having their thought/design processes interrupted and inhibited due to perceived barriers such as organisational constraints, technology, communication and co-operative activities with other designers. Interviews were undertaken to establish what were the perceived barriers and how or if they overcame them.

Group 3: New designers and trainees

These people were still at the stage where they were building upon their experiences and developing the necessary skills to enhance their problem-solving allowing them to develop more sophisticated solutions to creative design.

Appendix C: Semi-structured interview schedule for the Scoping Study

Semi-structured interview schedule for Scoping Study

The questions covered 5 main topic areas as follows:-

1. Biographical history of the individual

   e.g. training

   job in Rolls-Royce

   leading designs of engines known to them, eg the Tay

   other exceptional designs from history that may have some influence

2. Where they are 'coming from' in relation to the educational and vocational experiences and environments that have fostered their current way of thinking

   e.g. did they use meccano sets as a child

   hobbies or interests

   people they were brought up with

   members of their family with perhaps particular interests

3. Specific instances of creativity

   e.g. at what point did it happen

   what supported it

   where did it come from

   what led up to that point

   where/what did it lead to

   what tools, archives, procedures do they utilise in their design work

4. Constraints imposed on their creativeness

   e.g. systems they work with

   what could it do better

   what could enhance the whole creative process

   use imagination and get them to describe the tools they would like to have at their disposal

5. Other perspectives

   e.g. what makes their approach different to other cultures' approaches to the process

   what is it that makes them (the individual) different from others

   what particular qualities do they bring to the team

   do different people bring specifically different qualities as well

Appendix D: Semi-structured interview schedule for the DGI (Design Group Interviews) Study

Semi-structured interview schedule for the DGI Study

The questions covered the following areas:-

1. Biographical history of the individual

e.g. training
job in Rolls-Royce
leading designs of engines known to them, eg the Tay
other exceptional designs from history that may have some influence

2. Where they are 'coming from' in relation to their educational and vocational experiences and environments that have fostered their current way of thinking

e.g. did they use meccano sets as a child
personal hobbies or interests
people they were brought up with
members of their family with perhaps particular interests
professional support, relationships and mentors
their professional interests and expertise

3. Specific instances of creativity

e.g. at what point did it happen
what supported it
where did it come from
what led up to that point
where/what did it lead to
what tools, archives, procedures do they utilise in their design work

4. Current areas of work/activity in Rolls-Royce

   what current projects are they working on

   what activities do they do in the course of their work (not job specs!)

   e.g. aministration

   technical

   creative

   interpersonal

   management/supervision

   others?

5. Constraints imposed on their creativeness

   e.g. systems they work with

   what could it do better

   what could enhance the whole creative process

   use imagination and get them to describe the tools they would like to have at their disposal

6. Other perspectives

   e.g. what makes their approach different to other cultures' approaches to the process

   what is it that makes them (the individual) different from others

   what particular qualities do they bring to the team

   do different people bring specifically different qualities as well

7. Knowledge (theme 1 from Scoping Study … but not referred to as such)

   e.g. who do they go to for design advice and what kind of advice

   when do they discuss designs with colleagues

   what kinds of things do they talk about

   how are their ideas improved and approved by others

8. Social mechanisms (theme 2)

e.g. friendships in NPE, Rolls-Royce(Bristol) and beyond
mentors
formal meetings
informal conversations

9. Management and organisational structures (theme 3)

e.g. budgets and accounts
hierarchies and reporting lines
training and development/human resources
reporting structures and dissemination of work progress

10. Individual/personal capabilities and design processes (theme 4)

e.g. what do the designers mean by 'creativity'
how do they develop their knowledge/expertise/talents
how do they solve design problems and what frustrates them
what makes a good conceptual designer

11. Technical issues (theme 5)

e.g. describe the design process
do they have set roles in this process (if so what) or wide flexibility
design tools and support systems
compute technology and software

12. Unfulfilled support needs (theme 6)

e.g. what is lacking/causing problems
what would they like to see introduced to help their work
what would make them 'more creative'

Appendix E: Brainstorming exercise from the workshop

EXERCISE 1: brainstorming

Timing: 2.00-2.30 maximum.

* Rationale

Looking from them to confirm, elaborate and contradict (remind them not to be afraid to challenge anything I say or have said).

* Write my categories onto post-its and put them under the three groups on the flip-chart.

* Ask them to brainstorm in a group on Post-its any additional categories they think I have missed-try to keep them to short descriptive items of 2-3 three words. Remind them they will need to be able to define them.

* Remind them that the definitions for my categories are on pages 9-12 of the report when trying to establish whether their category matches it or not.

* TIME FOR THIS IS 30 mins.

* Stick these onto the flip-chart and go through them 1-by-1 by a process of discussion regarding the definitions and asking them whether that particular category has already been included, whether it is relevant, whether is needs to be added. Get them to expand where necessary.

* Come to some consensus re categories (theirs-if any and mine) and agree the groupings

* On the basis of this outcome move onto next exercise with my categories and any others I have had to include of theirs.

Appendix F: Interrelationship Digraph exercise

EXERCISE 2: The Development of the Interrelationship Digraph

Timing: 2.30-3.15 maximum.

* Rationale

This exercise is a modified version of Brassard's (1989) Interrelationship Digraph tool which seeks to graphically map out links among items generated in an attempt to identify 'root causes'.

* Put three sheets from the flip-chart onto desk and place and prepare Post-its in the groups on the sheets

* Provide them with coloured pens and Post-its

* Write on white board "Barriers to creativity"

* With the agreed categories in the groups I have identified, get Rolls-Royce to start to relate the categories in each group to each other by drawing one-way arrows between the Post-its That is, for example, which are the most weighty barriers in each of the issues. Or from another perspective, take one of the issues and ask them to identify which barriers they hit hardest.

* Arrows apart from being single headed if at all possible, where one arrow crosses another, build a bridge using a curved arrow.

* Ask them to draw out which environmental influences affect each of the barriers and issues.

* (Page 62 & 63) Look at where most of arrows are emanating from. Outgoing arrows indicates a basic 'cause'. Incoming arrows may represent a secondary issue or bottleneck. Look at relationships in turn or relative importance and ask;-

-How are these interrelated?

-Where are the common occurrences?

-Where are the patterns?

-Why are they linked?

-What are the relationships between the categories?

-Are there any sequences to any of the events?

-Can you give me examples?

-Can you formulate these links into some kind of model?

* Once gone through this exercise, ask:-

-Are these sorts of things commonly articulated and linked up to give a holistic picture?

-Does this match with individual's perspectives?

-Does it provide an unexpected picture?

* Hopefully the end result will be number of 'paradigms' and models where barriers, issues & activities and environmental categories are related.

Appendix G: Interview diary schedule for the Tracking Study

Interview diary schedule for the Tracking Study

DATE:

TIME:

NAME:

ROLE:

Say a bit about myself, give objectives of this study and set in the context of the first study

Background (1st interview)

1. Could you give me a brief job description?
2. How long have you been an engineer/doing this job?
3. What project are you involved with at the moment?
4. Who are you working with?
5. Who do you communicate with?
6. What stage of the project are you in at the moment? (Derwent etc.)
7. How do you think you are being creative?
8. What insights have you experienced in this project?
9. What difficulties are you experiencing in terms of your design process?
10. What makes doing your job difficult?
11. What impedes your progress

Diary interview schedule

Start with

On a weekly basis I will talk through what they have done and use the following categories and questions to prompt and help to focus my interview.

Need to think about the models I developed in my last study so begin by asking them:

1. What have you been involved with over the last week? (ISSUE)
2. What have been the most significant problems you have encountered? (BARRIERS)
3. Have you been stuck and/or stopped by something external to you? (BARRIERS)
4. How have you acted to overcome this problem? (ACTION/INTERACTION)
5. What was the outcome of this exercise? (OUTCOME)
6. In what context did this happen? (CONTEXT)

Prompts and cues:

Design process

1. What are the key stages you go through in the design process?
2. What skills are most important in your current piece of work?
3. What knowledge is most important in your current piece of work?
4. Do you feel you are being creative?
5. Do you have to think laterally across different disciplines?
6. Do you have to think logically and take a more pragmatic view?

Timescales

1. Are you having difficulty in working to the timescales of the project?
2. Why?
3. What is causing the delay?
4. Can you give me some examples?
5. What are the implications of these pressures?
6. How frequent does this happen?
7. How could you alleviate this problem?

Milestones and deliverables

1. How are these monitored?
2. What happens if new conditions are imposed?
3. What kind of conditions would that be?
4. What happens if you cannot meet the milestones?
5. How does this effect your design process or creative output?
6. Is there any way you can deliver milestones before they happen?
7. How?

Workload and time pressures

1. Apart from the current project you are involved in, do you have any other commitments to meet?
2. How does this affect your quality of work and level of output?

Technology

1. What sort of technological problems are you encountering at the moment?
2. Can you give me some examples?
3. How are you getting around these problems?
4. What sort of strategies are you using?
5. Do they work?
6. How often does this happen?

Communication

1. What types of communication problems are you encountering?
2. Can you give me some examples?
3. Are there any alternatives you could use?
4. What do you do to overcome them?
5. How often does this happen?
6. Are you waiting for information from any one? Who?
7. Are you supplying information to anyone? Who?
8. Where are they in the project?

Working practices

1. Are there any current working practices which are inhibiting your creativity at the moment?
2. Can you give me some examples?
3. How do you get around them?
4. How could things be done better?
5. Are you aware of any strategies in place to help you?

Project management

1. Does this impinge on your creativity?
2. How?
3. Can you give some examples?
4. Are there any strategies in place to help people get around problems?

Having to satisfice

1. Have you had to compromise your design activities on this project?
2. Can you give me some examples?
3. Why?
4. How do you feel about that?
5. Does this happen often?

Experience

1. Are there times when your lack of experience inhibits your creativity?
2. Can you give me some examples?
3. How do you cope with that?
4. Do you talk to anyone? Who?
5. How easy is that?

Integrating with other companies

1. How easy is this?
2. What are the problems you encounter?
3. Can you give me some examples?
4. How do you get around these problems?

Appendix H: Glossary

Glossary

AMBs	Active Magnetic Bearings
CA	Cognitive artefact
CADs	Computer-Aided-Design system
DGI	Design Group Interviews
ER	External representation
FOAS	Full Offensive Air Systems
GA	General Arrangement
GSL	Government Secure LAN
GSS	Group Support Systems
HP	High Pressure
ID	Interrelationship Digraph
ITSS	Information Technology Service Supplier
LP	Low Pressure
NPE	New Projects Engineering
OBU	Operating Business Unit
SAP	System Application Product
UAV	Unmanned Air Vehicle
WSCE	Weapons System Concept Engineering