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Human Factors Competence in Aircraft Maintenance

Paul Liston

Thesis submitted for the Degree of Doctor of Philosophy (Ph.D.), Department of Psychology, Trinity College, University of Dublin,

July 2005
DECLARATIONS

This thesis is submitted by the undersigned to Trinity College, University of Dublin, for examination for the degree of Ph.D.

I hereby declare that this thesis has not been submitted as an exercise for a degree at this or any other university. This thesis is entirely my own work and the work of others who were involved with the study is duly acknowledged within the text where appropriate.

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July 2005
for Pixie and John
ACKNOWLEDGEMENTS

My greatest debt, both intellectual and personal, is to Dr. Nick McDonald. I am very grateful to him for giving me the opportunity to work and study in the Aerospace Psychology Research Group in TCD. It has been a thoroughly rewarding experience to work as part of a dynamic and innovative research group. I am especially indebted to Nick for the advice and direction he so willingly provided throughout this Ph.D. Our many conversations and debates have played a large role in shaping this thesis.

The industrial partners in the AITRAM and ADAMS 2 projects facilitated this research by giving me access to their organisations. I am very grateful to them for being so willing to accommodate and support my research efforts, especially in light of the difficulties experienced by the aviation industry following the terrorist attacks of September 11th, 2001. A special word of thanks also goes to Sam Cromie for his role in helping to conduct the observations of maintenance tasks in Chapter 2.

My time working in Trinity College has shaped my personal life in many ways. I have met some wonderful people who have become close friends. My colleagues in the APRG have contributed greatly to my enjoyment of work over the past six years – thank you Emer, Marie, Siobhán, Rabea, Susan, Sam, Daniele, Jose and Derek. Your friendship played an important role in making this Ph.D. an enjoyable experience.

My parents, my sister Maria, and Michele have been steadfast in their resolve to support my efforts. It was very reassuring to know that there was always a comforting voice at the end of the phone. I found your belief in my ability to complete this Ph.D. to be instrumental in sustaining my spirit in times of weakness. Thanks also to my cousin Anne, and my great friends Aidan, Anna, Dónal, Jon, Liam, and Sorcha. I am very grateful to each of you for your support and willingness to distract me when I needed it.

Finally, the author graciously acknowledges the generosity of Trinity College Dublin in awarding a Post-Graduate Award for the first three years of this Ph.D.
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<td>Anaesthesia Crew Resource Management</td>
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<td>ADAMS 2</td>
<td>Human Centred Systems for Aircraft Dispatch and Maintenance Safety</td>
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<td>AITRAM</td>
<td>Advanced Integrated Training in Aeronautics Maintenance</td>
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<td>AMC</td>
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<td>Aircraft maintenance organisation(s)</td>
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<td>AMP</td>
<td>Aircraft Maintenance Programme</td>
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<td>Anaesthetists Non-Technical Skills Project</td>
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<td>ATC</td>
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<td>BITE</td>
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<td>Crew/Cockpit Resource Management</td>
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<td>EASA</td>
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<td>EU</td>
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<td>FAA</td>
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<td>HR</td>
<td>Human resources</td>
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<td>IPC</td>
<td>Illustrated Parts Catalogue</td>
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<td>IT</td>
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<td>JAR</td>
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<td>KSA</td>
<td>Knowledge, skills, abilities/attitudes</td>
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<td>LOSA</td>
<td>Line Operations Safety Audit</td>
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<td>NRC</td>
<td>Non-Routine Work Card</td>
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<td>NVQ</td>
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<td>OJT</td>
<td>On-the-Job-Training</td>
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<td>OPA</td>
<td>Operation Performance Audit</td>
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<td>PFR</td>
<td>Post flight report</td>
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<td>PMAT</td>
<td>Portable Maintenance Access Terminal</td>
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<td>SHEL</td>
<td>Software, Hardware, Environment, Liveware</td>
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<td>TEM</td>
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SUMMARY

The research summarised in this thesis sought to better understand the issue of human factors competence as it relates to the work performed by technicians in the aircraft maintenance industry.

An ethnographic study of normal maintenance operations was undertaken to explore maintenance activities in terms of human factors. The study outlined the characteristics of maintenance tasks and the findings highlighted some of the critical deficiencies of maintenance systems. Aircraft maintenance was found to be a highly unpredictable and variable activity, the performance of which is achieved through a complex, collaborative social process. Maintenance activities are not just about the actions of an individual; they are about the collaborative actions of individuals working together. As such, the performance outputs for individual and team maintenance tasks are collaborative and reflect the indirect input of those working in support functions (planning, parts supply, task design, etc.) as well as the direct input of the technical personnel.

A review of practical and human factors training practices (based on observations and interviews) gave prominence to some conceptual problems in relation to the notions of competence informing training courses in the maintenance industry. The focus on predefined categories of knowledge inherent in the regulator-specified curriculum for human factors training betrays a rationalistic and individually-oriented conception of competence. Prioritising a priori theoretical knowledge, this approach to competence emphasises ‘knowing about’ human factors in an abstracted way which has no grounding in the real world of maintenance operations. In locating competence somewhere within the individual this approach fails to reflect the social and collaborative nature of maintenance activities.

The thesis argues that individualistic, rationalist conceptions of competence are inappropriate for the aircraft maintenance domain so an alternative model of human factors competence was proposed. This model is based on the empirical understanding of
maintenance activities established in the ethnographic study and emphasises 'doing' human factors rather than 'knowing about' human factors. The model also accounts for the social and collective nature of maintenance activities.

Drawing on interpretative, and social constructivist approaches to competence this model of competence is grounded in the social reality of operations. Competence is conceptualised as the behaviour which is able to compromise between the various coalitions and interests in an organisation and competence relates to being able to cope as deemed appropriate by the opinion makers in the community of practice. At the same time competence, at a more mentalistic level, is related to workers' understandings of their work (as informed by their lived experience of it) and this understanding of work delimits certain knowledge, skills and abilities which are necessary to perform the work.

The final part of the thesis details an exploration of the utility of the competence model. The performance elements of the model were instantiated in a performance assessment tool which was pilot implemented. The data gathered by the tool, albeit limited, revealed that the performance oriented elements of the competence model (as instantiated in the performance assessment tool) were useful in explaining and understanding the performance of maintenance personnel. This success is largely derived from the way in which the model systematically links the behaviour of workers to the contextual situation thereby facilitating an examination of the role it plays in mediating the performance of maintenance tasks. This is taken as support for the contention that a human factors competence model can only explain the realities of maintenance operations (as reflected in the ethnographic study) by accounting for the neglected issues of practical competence and the profoundly social nature of maintenance tasks.

The thesis is organised around 6 chapters. Chapter 1 provides an overview of the background to the thesis and describes the aircraft maintenance system and the role of human factors in aviation. Chapter 2 presents an ethnographic analysis of normal maintenance operations; while Chapter 3 seeks to explore the training of maintenance technicians in order to understand the way in which training equips technicians to deal
with the operational realities of maintenance activities as highlighted in Chapter 2. Chapter 4 reviews dominant rationalistic approaches to competence, explores two alternative perspectives and proposes a new model of competence which is based on the findings of Chapters 2 and 3. Chapter 5 focuses on exploring the utility of this new model and Chapter 6 reviews the theoretical and practical implications of this research.
CHAPTER 1
INTRODUCTION AND BACKGROUND TO THE THESIS

Introduction

Competence has emerged as an important topic in increasingly volatile business markets where competition (from Asia in particular) serves to make market forces less and less predictable. For many theorists and commentators the key to survival lies in the ability to develop committed, flexible and effective workforces (Hamel & Prahalad, 1994; Prahalad, & Hamel, 1990). Workers who succeed are those who are knowledgeable, flexible and able to produce quality results (Meyer & Rowan, 1983; Keenoy & Anthony, 1992). Competence, in these terms, is seen as something which can allow workers to achieve positive outcomes in unsettled and ever-changing environments.

Since the terrorist attacks of September 11th 2001 the face of the aviation maintenance industry has changed irrevocably. The resultant downturn in the aviation sector has meant that many aircraft maintenance organisations have restructured and reorganised in order to survive in the new world order. In practice, this has meant that some maintenance organisations have been wound up, and many more have been downsized or taken over by large competitors. Aircraft maintenance organisations have had to change in unprecedented ways in order to remain viable in an industry that has been dealing with longstanding problems relating to shortages of qualified staff, a growth in contract labour, and issues to do with the introduction of new aircraft systems, diagnostic tools and information technologies.

The issue of human factors competence is critical to safety critical industries such as aviation maintenance. ICAO has proposed human factors as a technology which allows organisations to make their operation safer and more profitable (Maurino, 1995) and given the economic difficulties in which aircraft maintenance organisations find themselves it is unsurprising that many have begun to look to human factors to provide assistance in weathering the storm. The problem is that human factors is not an easy
technology to use. The issue of human factors competence is explored in this thesis because it seems that there are problems relating to the way in which the issue is commonly considered. ‘Doing’ human factors well can help ensure that standards of safety, reliability and productivity are maintained and enhanced but this is not easily achieved. There is much confusion about what constitutes competence and a review of the literature shows that there is currently a revolution of theoretical conceptions of competence. For the aircraft maintenance industry to adequately tackle the issue of competence there must be a good measure of agreement about what ‘human factors competence’ actually is and how it can be fostered and controlled.

**The Thesis**

This thesis is based on research conducted in two different EU-funded human factors research projects: AITRAM and ADAMS 2.

The focus of each of these research projects was not specifically related to issues of competence or performance but as the research progressed the issue of competence began to feature as a recurring theme. The AITRAM project (‘Advanced Integrated Training in Aeronautics Maintenance’) was funded by the European Commission under the Information Societies Technology (IST) program. The overall objective of this project was to improve aeronautics maintenance training by developing an advanced training system using VR simulation technologies to integrate human factors training and technical training in a single training tool. The first phase of the project involved capturing the end-user needs. To this end reviews of existing training were conducted and observations of maintenance tasks were performed to understand more about the human factors requirements of maintenance activities such that they could be represented in the VR technology. The ADAMS 2 project (‘Human Centred Systems for Aircraft Dispatch and Maintenance Safety’) was funded by the European Commission under the Fifth Framework. This project explored the role of the human in ensuring the reliability and effectiveness of the systems governing aircraft maintenance. The objective of the project
was to develop tools and methodologies aimed at improving practice in design, quality management, and organisational learning following incidents.

The structure of this thesis sets out the research studies in chronological order such that the trajectory of the argument can be understood in terms of the temporal emergence of the critical issues. The first study in the thesis was focused on coming to a better understanding of the human factors requirements of aircraft maintenance tasks. The second study had a slightly different focus – that of training. These two studies were conducted in the AITRAM project and implicated the issue of human factors competence in their analyses. This precipitated a detailed exploration of competence theories which appears in the middle of the thesis. Then, having focused on the issue of competence, the thesis follows a more directed line of inquiry resulting in the specification of a competence model, the utility of which is explored in a third study using a tool developed in the ADAMS 2 project.

**Background Issues**

Human factors competence has become an issue for aircraft maintenance of late. Two explanations can be offered for its emergence as an issue. The first one relates to the developing recognition that competence may facilitate the achievement of strategic business goals. Having exhausted all possibilities to gain competitive advantage through downsizing and restructuring, the only viable option for many organizations is seen as increasing the competence of the remaining workforce. The second reason relates to regulatory developments which seem to suggest that future requirements may seek to mandate competence assessment. Recently EASA (the European Aviation Safety Agency), with the publication of Part-145.A.30(e), has mooted the issue of human factors competence for the first time. One can only assume that this is the first in a succession of requirements which will successively regulate for the issue of competence.

It is a peculiar anomaly that the issue of competence should unite two groups with interests and responsibilities that otherwise contrast starkly: senior management and
regulators. The senior management in aircraft maintenance organisations are responsible for ensuring the viability of the business on behalf of the shareholders, while the regulator is responsible in a stricter sense for the safety of the system and the travelling public at large. It could well be claimed that the underlying tension of human factors is the unhappy marriage of its two goals: improving safety and efficiency. The ethnographic study presented later in the thesis presents a picture of two competing models of performing maintenance tasks; each irreconcilable with the other: (i) getting the job done quickly, and (ii) following the procedures. One model satisfies the interests of management more readily than the regulator, and vice versa. Efficiency and the concomitant monetary savings it seems are not reconcilable with following procedures and doing the job safely.

The aircraft maintenance industry is an ideal environment in which to explore the issue of human factors competence. Reason and Hobbs (2003) succinctly explain why in their comments about aircraft maintenance:

“If some evil genius were given the job of creating an activity guaranteed to produce an abundance of errors, he or she would probably come up with something that involved the frequent removal and replacement of large numbers of varied components, often carried out in cramped and poorly lit spaces with less-than-adequate tools, and usually under severe time pressure. There could also be some additional refinements. Thus, it could be arranged that the people who wrote the manuals and procedures rarely if ever carried out the activity under real-life conditions. It could also be decreed that those who started a job need not necessarily be the ones required to finish it. A further twist might be that a number of different groups work on the same item of equipment either simultaneously or sequentially, or both together” (p.1).
Little wonder, they argue that aircraft maintenance faces difficulties with human factors and performance issues. There is considerable evidence to support this claim. Research has shown that procedures are not always followed because there are often quicker and better ways of doing the task (McDonald, Cromie, Corrigan, Daly and Ward, 2000); and incident and accident data (see examples later in the chapter) inform of the pervasiveness of procedural violations and workarounds.

Human factors problems are not discrete issues which can be easily identified and readily solved. More often than not they are issues which are deeply entrenched in organisational systems. These systems, primarily designed to manage the technical functions of aircraft maintenance, are populated with technicians who maintain aircraft. The struggle to adapt organisational systems to address human issues is one with which technicians are very familiar. This thesis attempts to understand, in a practical sense, what it means to be human factors competent. It is all very well having abstract, theoretical notions of human factors but what does human factors mean in practice? What does it mean to act or behave in a way which is human factors competent?

This thesis attempts to answer these questions by understanding more about the work of maintaining aircraft and the training systems which develop competence. Eraut (1998) asserts that the term competence is increasingly being used for rhetorical effect and that the range of different meanings of the term leads to much confusion. For him the most valuable and meaningful discussions of competence are those which are explicit and clear about why the term competence is being used, the nature of the problem being addressed and the theoretical assumptions upon which the discussion is based. This thesis is about providing this information from Chapter 2 onwards.

The remainder of this chapter is given over to an overview of the aircraft maintenance system, an exploration of the role of human factors, and (below) a description of the companies involved in the research studies.
A total of five separate companies were involved in the various research studies upon which this thesis is based. Four maintenance organisations and one manufacturer collaborated on the research tasks detailed in Chapters 2, 3 and 5. In order to ensure confidentiality each of these organisations has been de-identified. The organisations (all based in the EU) are referred to as Company A, Company B, Company C, Company D and Company E. This terminology is consistent throughout the thesis. Company A is the maintenance division of a large national carrier and is involved in base and line maintenance of the parent airline’s fleet and third-party contract aircraft. Company B is a large third-party maintenance organisation involved in both base and line maintenance. Company C is the maintenance division of a medium sized low-cost carrier. It performs only line maintenance on the parent airline’s fleet – they contract another company for base maintenance. Company D is a large commercial aircraft manufacturing company. Company E is a small, but growing, maintenance operation which is part of a small airline. It is involved in both line and base maintenance and also performs some third-party maintenance.

**Aircraft Maintenance**

Recent advances in aircraft engineering and technology have contributed greatly to improvements in the safety of flying. This applies not just to flight operations – maintenance activities have also benefited from the latest innovations. New generation aircraft have sophisticated Built-In Test Equipment (BITE) which monitor and interrogate systems on-board the aircraft to establish the location and nature of any faults. This technology allows maintenance technicians to access this data from cockpit displays or using portable computer systems (Portable Maintenance Access Terminal, PMAT) which can be plugged into sites around the aircraft. The latest aircraft also have on-board systems which allow maintenance personnel to gain data from an aircraft in flight. Despite these advances (and the concomitant benefits) aircraft still require regular maintenance from human operators. The nature of this maintenance may be changing however: technological advances mean that maintenance is moving towards a model of
operations which is more focused on avionics and the use of computers than the ‘torque wrenches and elbow grease’ model of the past. Notwithstanding these changes the task of maintaining aircraft still plays an important role in guaranteeing the safety of the aviation industry.

Aircraft maintenance is carried out by aircraft maintenance organisations (sometimes termed AMOs). These companies, small and large, are licensed by national aviation regulatory bodies to carry out maintenance on aircraft. Some aircraft maintenance organisations exist as subsidiaries of an airline, while others are independent maintenance organisations which carry out maintenance on third-party aircraft (a third-party AMO). The aviation sector in general is characterised by a large amount of diversity in terms of the size and range of operations. In maintenance organisations this diversity ranges from maintenance organisations owned by large international carriers, repair and maintenance out-station facilities (overseas bases), through small regional and commuter airline-owned maintenance organisations, to the fixed-based third-party maintenance organisations who work on a contract basis (Drury, Prabhu, & Gramopadhye, 1990).

Aviation is a highly-regulated industry and in the European Union all member states are governed by a single aviation regulator – EASA. The European Aviation Safety Agency (EASA) is an agency of the European Union (EU) and is the regulatory body governing all aviation regulations; maintenance included. All maintenance organisations in Europe, thus, operate in the same regulatory context and as such they share similar operating conditions. Notwithstanding these similarities, aircraft maintenance organisations can differ greatly in terms of their organisation of maintenance tasks and the terminology they use for grades of personnel, maintenance tasks, etc.

Having briefly outlined the background issues of the maintenance industry it is now appropriate to explore, in more depth, the activities involved in maintaining aircraft. What follows is a simplified description of aircraft maintenance. It is intended as an overview of aircraft maintenance in a generic sense: it may not reflect the exact reality of
any one maintenance organisation. That said it does, as an overview, hold true for the industry when considered as a whole.

*Types of Aircraft Maintenance*

The following is based on a detailed description of aircraft maintenance provided by Corrigan (2002) and focuses primarily on the actual production activities that play a role in influencing how maintenance operations are planned, carried out and monitored.

Aircraft maintenance can be divided into three main types:

1. Ramp or Line maintenance
2. Minor or Light maintenance
3. Major or Heavy maintenance

**Ramp / Line Maintenance**

There are three main types of line (or ramp) maintenance: transit checks performed after each flight; daily checks performed every 24 hours; and a weekly check. These checks and repairs are typically carried out on the ‘line’ (on the airport apron) or at the terminal gate. Line maintenance is scheduled according to flying cycles (one check between each flight cycle), and calendar days and weeks. When an aircraft arrives at its destination and parks at its assigned gate there begins a process of maintenance which is concerned with correcting any problems reported by the flight-crew during the flight. This ‘transit’ check also involves thorough checks on the aircraft prior to the next flying cycle. As passengers disembark the aircraft and baggage is offloaded a ramp maintenance technician assigned to the task will board the aircraft, retrieve the technical log and investigate any problems which have arisen on the flight. The technical log details the physical state of the aircraft at that moment in time. Any unusual occurrences, readings or technical problems occurring during the flight are recorded by the captain in the technical log. The maintenance engineer will attempt to rectify all of these problems before the aircraft is
due to depart. If a minor problem (or snag) occurs which the technician cannot, for
whatever reason, fix immediately the Minimum Equipment List (MEL) is consulted to
determine if the aircraft can carry the defect until such a time as it can be rectified. If
this is allowable the defect will be deferred (for a length of time specified in the
maintenance manual), otherwise it must be rectified immediately (often incurring a delay)
or the aircraft will have to be withdrawn from service (necessitating the sourcing of an
alternative aircraft to perform the scheduled flight).

The maintenance technician also performs a series of inspections of varying detail during
turnaround. These include pre-flight checks and departure checks. Here the engineer is
looking for signs of visible damage, leakage, blockage of air intakes, etc. De-icing
checks (if necessary) are also performed as clear-ice build up is particularly hazardous.
Refuelling (including a fuel quality check) is commonly the responsibility of the ramp
maintenance technician. The maintenance ends when the technician, in conjunction with
the captain of the departing flight, signs that the aircraft is ‘released for service’.

**Minor or Light Maintenance**

Light maintenance checks are scheduled according to both flight hours and calendar
months. Minor or light maintenance is prescribed by the aircraft manufacturer (in the
Approved Maintenance Schedule). The intervals vary according to the aircraft type but
are usually scheduled every 500 flight hours but this can rise to 5,000 flight hours.
Checks following a calendar month schedule are conducted usually every 18 months.
Maintenance of this type can last for anything from 10 to 24 hours; this includes the
maintenance service checks often referred to as ‘letter checks’ (A or B). Minor
maintenance would also include overnight hangar work which does not receive the same
level of advance planning. Tasks concern the whole of the aircraft and not specific
components as is the case with line maintenance. Examples include clearing of the
Technical Log, completion of Airworthiness Directives, Alerts, Service Bulletins or Free
Routine Tasks.
**Major or Heavy Maintenance**

Heavy maintenance refers to checks which are much more extensive than any of the other types of maintenance. Heavy maintenance covers airframe and other tasks and occurs less frequently and involves much more manpower to complete the work. This type of maintenance is scheduled every 5,000 - 20,000 flight hours and typically takes a minimum of 48 hours in the hangar to complete the work; checks C and D fall into this category. Like minor maintenance it consists of scheduled tasks from the Approved Maintenance Schedule – the plan of all maintenance tasks to be carried out over the lifespan of the aircraft. Heavy maintenance, as the name suggests, is a particularly thorough and arduous form of maintenance. In D checks for example, aircraft are stripped of their components and dismantled; this is very detailed maintenance work and takes place every six to ten years. Then the shell of the aircraft and its systems are thoroughly checked before the aircraft is fitted with new components, rewired and rebuilt.

**Aircraft Maintenance Activities**

Aircraft maintenance activities occur in a complex and highly involved socio-technical system. In tightly coupled systems such as this workers must display high levels of co-ordination, communication and co-operation in order to achieve a safe and efficient operation. The complexity of the aircraft maintenance system is compounded by the inter-disciplinary membership of the work teams which perform, and manage, the maintenance of aircraft. Technicians are at the ‘sharp end’: actually carrying out the maintenance tasks, but they work in a broader context in which they perform under the guidance of supervisors, inspectors and shift managers; where they interact with planning, stores, quality and engineering personnel; and where they are held to account by the regulator and the customer (McDonald, 2005; Drury, Prabhu, & Gramopadhye, 1990; Gramopadhye & Kelkar, 1999). Stated in these terms, the difficulty of the challenge of ensuring safe and efficient maintenance operations is easily understood.
Corrigan (2002) has distilled the key functions of the aircraft maintenance system into a simple illustration. Figure 1 (below) provides a diagrammatic representation of the important aspects of the maintenance system.

![Diagrammatic Representation of Aircraft Maintenance](image)

**Figure 1**: Diagrammatic Representation of Aircraft Maintenance (Corrigan, 2002, p.37)
The diagram depicts what Corrigan (2002) sees as four of the key aspects of the aircraft maintenance system:

1. Regulations
Regulatory bodies have a significant input into aircraft maintenance activities. Detailed and stringent regulations govern maintenance activities. Organisations must show compliance with quality and operational requirements in audits and approvals which are conducted by the regulator.

2. Other external bodies
Further influence comes in the forms of the manufacturer, the customer, the vendor and the airline. Individually, and collectively, each has an impact on maintenance operations. Task procedure documentation is provided for the maintenance organisation by the manufacturer and vendor; all tasks are legally required to be performed in accordance with these manuals. Customers can dictate operational aspects of the maintenance – things such as the scheduling of maintenance checks and the timeframe allowed for completion of these checks are decided by the customer.

3. Internal functions
Prior to the actual performance of maintenance activities a number of departments, internal to the maintenance organisation, have an input to the pre-check stage of the maintenance system. This primarily relates to the pack-to-plane (pre-planning stage) process and involves contract negotiation, personnel selection, personnel training, etc.

4. Maintenance production system
This function relates to the actual performance stage – where the work is actually carried out. The work can occur in the hangar (aircraft overhaul) or on the ramp (line maintenance) and each of these activities is supported by personnel in engineering, planning and quality departments.
**Organisation of the Maintenance Schedule**

The maintenance schedule is a crucial aspect of the maintenance system. All aircraft have an Aircraft Maintenance Programme (AMP), otherwise referred to as the Approved Maintenance Schedule (AMS). This document, approved by the national aviation authority, specifies the mandatory minimum maintenance program which an aircraft must follow during its life in service. It is drawn up by a Maintenance Review Board (MRB), comprising manufacturers, aviation authorities, airlines and maintenance organisations to ensure compliance with the maintenance needs of the aircraft. The maintenance program specified in the AMS must be followed, though it can be adapted (within specified limits) by individual maintenance organisations to better suit their needs (Corrigan, 2002).

**The check process**

The AMS decomposes the full range of maintenance activities into a number of checks which occur at various intervals. This amounts to a maintenance schedule for an aircraft and governs the rectification of known problems and the maintenance intervals for the replacement of items which can wear after a certain number of flying hours, flight cycles, or calendar time. A check can best be described as a set of maintenance tasks which are grouped together and which are all performed at the same time. There are three main types of checks: line checks (those conducted after each flight – also termed turnaround or transit checks), overnight checks (performed nightly on aircraft when not in-service), and A, B, C, D (the heaviest checks).

The first stage of a check occurs at the planning stage. Based on the information in the AMS, the planning department of the AMO can see which aircraft are due for maintenance. All documentation used in the check is produced and task cards for each individual task in the check are issued. Task cards play an important role in aircraft maintenance. They are the instructions which the technician follows when carrying out the tasks. Heavy checks, such as a C or D check may have as many as 5,000 – 10,000 task cards. Each card contains a description and detailed diagram of the task and will include references to more detailed procedures and information which are contained in
manuals such as the Aircraft Maintenance Manual (AMM), Illustrated Parts Catalogues or Wiring Diagrams Manual.

The AMM is an exhaustive instruction manual which contains the step-by-step guide to performing every maintenance task for that aircraft type. The AMM is produced by the aircraft manufacturer but a maintenance organisation's engineering department have some options to adapt the procedures contained in the document in order to better reflect the work practices of their particular organisations. Technicians use print-outs from the AMM to guide them through the task procedure. Technicians also obtain task information from other documents which are produced in order to support them in their job. These include: Illustrated Parts Catalogues (IPCs), Service Bulletins, and Trouble-shooting manuals.

**The Check Itself**

Hangar-based (A, B.C, & D Checks) maintenance activities are typically organised around shifts and accomplished through different teams dedicated to different zones on the aircraft. In line and ramp maintenance task resourcing and work allocation are different in that a co-ordinator assigns technicians to certain aircraft and there may be only one or two technicians working on an aircraft. During the entire maintenance process both hangar-based and line-based maintenance personnel work with their colleagues from the same shift and the next one as well as with personnel from engineering, quality, planning, and stores departments, to ensure task completion. The maintenance activities are also supported by technical training, human resources (HR), marketing, finance, purchasing departments etc. Operational maintenance also relies a great deal on the logistical support departments based around the hangar floor (e.g., stores, materials, component workshops etc).

Checks can involve both scheduled and unscheduled tasks. Some tasks are based on cycles of time and can be scheduled for a check *before* they become overdue – these are termed 'hard-time’ items. Scheduled tasks such as this might include replacement of parts
which have ended their performance life or many of the inspection and testing tasks. Checks can also include tasks deferred from previous maintenance or may involve unscheduled items such as repairs on defect components which were previously logged by flight crews.

Another source of unscheduled tasks is the inspection which occurs at the beginning of each check. A critical aspect of the workload on a check relates to recognising and identifying defects during the inspection and also during the maintenance itself. In particular there is pressure to identify critical defects that necessitate lengthy follow-up maintenance and additional logistical support early in the inspection process. Therefore there is usually a heavy inspection workload at the commencement of each check. Any defect items which are detected during the pre-check inspection generate Non-Routine Work Cards (NRCs) which are, essentially, task cards for unscheduled maintenance. These tasks are unplanned and cause many problems for the maintenance organisation; particularly in relation to the availability of parts and appropriately qualified personnel to carry out the maintenance. Only after the inspection activities and identification of defects can the planners and managers provide a more accurate estimate of the expected maintenance workload, order replacement parts, assess manpower levels, assess additional technical support, and re-schedule maintenance items. About 40% of the tasks conducted during a typical check are scheduled prior to the check but about 60% of the tasks completed are unscheduled defect items which have been raised as a result of the scheduled inspections which occur at the beginning of a check.

When each individual task is complete the technician 'signs off' the task card (depending on the types of tasks they are licensed to complete). Some safety-critical tasks require that a technician gets a colleague to inspect their work and supply a second signature for the job card. The job card is then returned to the aircraft's technical records. When all tasks in a check have been completed the check manager signs that all work has been completed correctly and that all the paperwork is in order. This means that the aircraft is released to service.
Accidents and Incidents: Insights into maintenance
human factors

McDonald (2005), in describing accident investigation, asserts that until recently accident investigations were deemed to have reached an adequate conclusion when (wherever appropriate) the human was found to be responsible for the accident or incident. Maurino, Reason, Johnston and Lee (1995) echo McDonald’s views. They acknowledge that the central preoccupation of aviation human factors is ‘human error’ and claim that traditional views of human error focus solely on the individual human operator. Maurino et al. are critical of traditional conceptions of error, however. They argue that in focusing on the mechanisms of individual human error there is an implicit judgement that it is individual pilots, controllers and mechanics who assume sole responsibility for the safety of aviation. Instead they argue for an organisationally-rooted, proactive style of managing human error and while they are not alone in criticising traditional approaches to human error (see Dekker, 2002; Reason, 1997) there are still those who believe that the presumption of ‘human error’ is a satisfactory outcome to an accident investigation.

The aviation industry is known for its impressive safety record but it has yet to achieve total safety (termed a ‘non-event’ by Weick (1991)). Aircraft accidents occasionally occur and when they do they tend to be highly publicised. Media scrutiny tends to be reactionary and predictable and coverage is quick to attribute blame to ‘human error’. Air accident investigations and the reports they produce are more measured and considered but often still come up with the same conclusion. It is clear from the Table 1, over, that maintenance related error has contributed to some of the most high profile aircraft incidents and accidents in recent years.
Table 1: Maintenance Related Incidents and Accidents

<table>
<thead>
<tr>
<th>Date</th>
<th>Reference</th>
<th>Aircraft type and Carrier</th>
<th>Event</th>
<th>Direct Maintenance Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>Chicago DC-10-10</td>
<td>McDonnell-Douglas DC-10-10</td>
<td>Left engine and leading edge of wing broke away from a/c at takeoff</td>
<td>Improper maintenance procedures ('workaround')</td>
</tr>
<tr>
<td>1983</td>
<td>Miami L-1011</td>
<td>Lockheed L-1011</td>
<td>In-flight loss of oil and engine failure</td>
<td>Failure to fit O-ring seals on master chip detector assemblies</td>
</tr>
<tr>
<td>1988</td>
<td>Aloha Airlines 737</td>
<td>Boeing 737-200, Aloha Airlines</td>
<td>In-flight structural rupture, upper fuselage detached during flight</td>
<td>Inspection failure - cracks in skin escaped detection</td>
</tr>
<tr>
<td>1989</td>
<td>Sioux City DC-10</td>
<td>McDonnell Douglas DC-10, United Airlines</td>
<td>Engine disk failure during cruise flight</td>
<td>Inspection failure – failure to detect fatigue crack</td>
</tr>
<tr>
<td>1990</td>
<td>BAC 1-11</td>
<td>BAC 1-11, British Airways</td>
<td>Cockpit windscreens blown out</td>
<td>Replacement windscreens refitted with the wrong size bolts</td>
</tr>
<tr>
<td>1991</td>
<td>Continental Express</td>
<td>Embraer 120, Continental Express</td>
<td>In flight structural break up</td>
<td>Screws attaching left leading edge of the horizontal stabiliser not re-installed after maintenance</td>
</tr>
<tr>
<td>1993</td>
<td>Excalibur A320</td>
<td>Excalibur A320</td>
<td>Pilot could not turn left</td>
<td>Wing spoilers left in the wrong position</td>
</tr>
<tr>
<td>1994</td>
<td>B747 New Tokyo</td>
<td>Boeing 747</td>
<td>Engine and pylon broke loose during landing</td>
<td>Fuse pin retainers were not re-installed after maintenance</td>
</tr>
<tr>
<td>1995</td>
<td>Daventry B737-400</td>
<td>Boeing 737-400, British Midland</td>
<td>Rapid loss of engine oil</td>
<td>Oil caps on both engine sumps not re-installed after maintenance</td>
</tr>
<tr>
<td>1995</td>
<td>Atlanta DC-9-32</td>
<td>Douglas CD-9-32</td>
<td>Engine fire at take-off</td>
<td>Failure to perform proper inspection of seventh stage compressor disk</td>
</tr>
<tr>
<td>1996</td>
<td>Gatwick B747</td>
<td>Boeing 747</td>
<td>Door handle moved to open on take-off</td>
<td>Failure to use jig to be used to drill new door torque tube</td>
</tr>
<tr>
<td>2000</td>
<td>Gatwick A320</td>
<td>Airbus A320</td>
<td>Fan cowl doors detached from No. 1 engine and struck fuselage</td>
<td>Doors were closed but not latched following maintenance</td>
</tr>
</tbody>
</table>

[Adapted from O’Connor, (1996); and ICAO Doc. 9824]

The table above highlights the fact that maintenance deficiencies are often contributory factors in accidents. Some of the statistics on this are quite alarming. Marx and Graeber (1994) assert that 12% of major aviation accidents can be attributed to maintenance and inspection deficiencies; King (1998) reports that the number of maintenance related accidents is on the increase, and maintains that over a 10 year period, whilst the number of flights had increased by 55%, the number of ‘maintenance concern’ accidents had increased by 100%; and Barton (1999) cites an aircraft manufacturer’s claims that up to
30% of engine in-flight shut downs and up to 50% of engine-related delays are caused by maintenance error.

These statistics show that things have changed since the early days of aviation, when technology was new and technical failures were common. Nowadays, as technology has become more reliable the focus has shifted to the human factor. It is clear that the human at the heart of the aviation system has been the most difficult component to control and manage. While major advances have been possible in the technical and engineering fields of aviation, successes in human factors have proven more difficult to achieve. The unveiling of new-generation aircraft such as the Airbus A380 is a powerful testament to the advances in aircraft and engine design. The industry’s success in controlling and managing the technology of flight only serves to underline the its failure to achieve similar success in controlling and managing the human component of the aviation system. The accident reports cited in Table 1 show that human error has been implicated in many high profile maintenance-related incidents and accidents and it is clear that the human factor has remained the most difficult aspect of the system to manage.

Why do accidents happen?

The statistics cited by Marx and Graeber (1994), King (1998), and Barton (1999) all demonstrate that aircraft maintenance plays a critical role in the overall system for ensuring safety in aviation. Aircraft maintenance is a highly dynamic and tightly regulated activity: one where systems are complex and interdependent, where procedures and documentation are detailed and legally binding, and where regulations play an important role in ensuring reliability, efficiency and safety.

So, why is it that maintenance error is implicated in many high profile accidents? Dekker (2002) writes about the human contribution to system failures and argues that there exist two views of human error. The first, termed the ‘old view of human error’, considers human error as the cause of the accident. The ‘new view of human error’ sees human error as a symptom of deeper trouble in the organisational system; the error is somehow
connected to the operational and organisational environment and it is here that the ‘cause’ of the accident lies.

‘Old views’ of human error have it that accidents just ‘happen’ – to err is human and humans are, after all, fallible. Dekker (2002) dismisses this approach to human error and accident causation. He argues that the old view of human error is too reliant on the use of psychological labels in descriptions of accidents and human error. These labels give an ‘illusion of explanation’. By this he means that the use of phrases such as ‘non-compliance with procedures’, ‘complacency’, and ‘loss of situation awareness’ to describe error give the illusion of explaining the phenomenon but they amount to little more than judgements. For Dekker the “interesting mental dynamics take place beneath the large psychological label” (p.43). Explanations of human error which rely solely on the mind are simplistic: the situation and context of the behaviour are important if we are to truly understand how accidents happen. Systematically looking at behaviour and connecting it to the circumstances in which the behaviour occurred gives a better indication of the sources of trouble.

It is in this way that Dekker introduces the dual notion of ‘blunt end’ and ‘sharp end’ workers. Accident investigations often implicate those workers who find themselves at the sharp end of the operation. They are the ones who were in direct contact with the safety-critical process. They were closest to the mishap and could have avoided the failure. Accident investigators who take the ‘old view of human error’ end their investigation at this point. Their verdict? ‘Human error’.

This view of human error is limited by its conception of operational systems. The approach does not account for an important aspect of an operation: the blunt end. This is the part of the organisation that supports and guides the activities that occur at the sharp end. In deemphasising the role of the organisation, and the broader context in which the behaviour took place, the focus of attention becomes ‘proximal’. Although Dekker argues that we can only understand failure when our focus is more distal rather than proximal, he does acknowledge the challenging and counterintuitive nature of approaches that seek
sources of failure away from the sharp end. Notwithstanding this he is adamant that accidents do not have a single root or primary cause: they result from combinations of different factors and we must do more than discover and label the error in order to make the system safe – to describe is not to understand.

**System safety**

Accidents are rarely just the consequence of a single isolated failure. This is especially true of large-scale, high-technology systems such as the aviation industry. Systems such as these involve much complex interaction between the human and technological components and have been termed socio-technical systems (Trist & Bamforth, 1951). In the aviation system the socio-technical components include the airlines, the manufacturers, air traffic control, maintenance organisations, civil aviation authorities, airports, and so on.

No single failure or error can, in these contexts, be responsible for an accident be it in either the human component of the system or the technical component. Accidents, it is widely accepted, do not just occur in isolation: they are usually the final stage in a chain of events that eventually result in damage to equipment or personal injury. While media reports focus on the injury rates and financial losses associated with accidents and incidents this is not of central interest to human factors experts. They are more concerned with *why* the accident happened (i.e. the sequence of events leading to the accident). The civil aviation industry has an enviable safety record, but, as stated earlier, accidents do occur. What interests the human factors expert is not just the accident itself but the underlying aspects of the system of aircraft operations which allow failures to result in accidents.

An accident is (usually) merely the conclusion of a long process of other, related events. System safety relates to the study of whole systems, for the specific purpose of reducing risk. The human component is merely one component of the system, (usually the most
troublesome) and to better understand the contribution of the human operator to the safety of a system it is necessary to understand the general principles of system safety.

Perrow (1984) suggest that a system can be plotted in two-dimensional space using two axes: linear versus complex systems and tight versus loose coupling. In this scheme aviation would find itself categorised as a complex, tightly-coupled system – one where people and technology are interdependent, where system interdependencies are complex and often underestimated and where the work activities are high-risk. Perrow’s conceptualisation of organisational systems relies on categorising organisations in terms of two dimensions (complexity and coupling). In doing this, Perrow succeeds in explaining how it is that complex systems (with many interacting processes) with tight coupling (where there are strong causal and temporal interrelationships between these processes) often allow isolated events to permeate the system leading to disasters with far-reaching consequences.

System safety mostly applies to complex, tightly coupled systems as these are the systems most at risk of having a ‘system’ accident (i.e. multiple, minor failures leading to a catastrophic event). The high level of complexity and interdependency in the aviation system invites failure into the system. The only way to improve safety in this context is to remove the earlier events or failures in the causal chain. Even by breaking just one of the links in this chain of events, which may not be in close proximity to the actual accident, accidents can be prevented (Reason, 1997). In complex systems such as aviation there exists an irony of systems safety, though. In an attempt to attenuate the risk of ‘system’ accidents many organisations insert barriers which are designed to prevent accidents. Unfortunately, the barriers often compound the problem by rendering the system even more complex and extending the inherent weaknesses of organisational systems to another level in the organisation. This is especially true of the aviation industry.
Systems Approaches to Accidents

As mentioned earlier, safety critical organisations are increasingly recognising the need to protect against possible failures by creating layers of defence. The rise in this can be attributed to the ubiquity of Reason’s (1990) model of accident causation. Reason’s theory of accident causation was instrumental in changing conceptions of accidents and human error. It can be considered one of the first systems-based approaches to accidents, the foundation of which is the belief that accidents result from collective mistakes and not individual errors (Reason, 1992).

Reason’s (1990) model of the accident causation process considers the whole production system and says all systems have five basic elements where problems can occur:

1. Fallible decisions
2. Line management deficiencies
3. Psychological precursors of unsafe acts
4. Unsafe acts
5. Inadequate defences

The model uses a ‘swiss cheese’ analogy to explain the trajectory of an accident and the way in which layers of defences can halt the progression of a failure and thus prevent an accident. Each layer of defence is depicted as a slice of ‘swiss cheese’: the defences are not solid and holes exist in each defence. As long as the holes in each layer do not line up, an accident will be prevented. See Figure 2 (over).
Fallible decisions

The model starts at a point (organisationally) remote from the actual accident. Reason argues that the seeds for most accidents are sown at the higher levels of the organisation. The model starts with fallible decisions at the highest level. He suggests that even with the best intention, higher levels of management will make mistakes in the priorities that they set which have a knock-on effect at the ‘sharp end’. It is argued that top management decisions are most likely to be motivated by rapid and tangible gains (e.g. cost savings, efficiency increases) whereas safety gains always cost money, are unpredictable (prone to random fluctuations) and are often invisible.

Line management deficiencies

Line managers are responsible for translating policy into practice. It is best to think of components at this level in terms of departments within the organisation. Any safety management deficiencies in these areas will have the effect of creating psychological pre-
cursors of an unsafe act but you will not be able to specify what effect they will have. Examples include inadequate procedures, poor scheduling, insufficient resources etc.

**Psychological precursors of unsafe acts**

This level interacts closely with the preceding one. This is where the line management deficiencies first present themselves to the worker. For example, a ‘can-do’ culture may increase time pressure on technicians, causing stress, low morale, violations etc., each of which increases the likelihood of an unsafe act (or error). Psychological precursors are, in essence, error enhancing conditions in the human operators. Examples include conflicting organisational goals (on-time service or safety) and poor supervision.

**Unsafe acts**

This relates to the productive activities in the system and it is at this stage that active failures begin to play their role in the trajectory of an accident. In terms of an accident trajectory the three previous stages feature only latent failures. Here, at a local level, an active error or violation is committed. This unsafe act has an immediate effect and may be the result of errors committed unintentionally in the normal course of the job or it may result from deliberate violations of procedures (‘workarounds’).

**Inadequate defences**

When unsafe acts are committed in an operational context which already has latent failures the error can promulgate through the system if the final defensive barriers are not in place. When the defences are breached an accident can result, although every error does not necessarily result in an accident. In a well defined system barriers will be in place to ‘trap’ errors before they spread through the system to result in an accident. Defences include actions such as double-inspections, signing off on tasks and visual inspections.

Reason’s model relies on the concepts of active and latent failures. Active failures are those which have an immediate and direct effect. Latent failures, however, may lie dormant for long periods before they combine with active failures and local triggering
events which breach the system’s defences (Maurino, Reason, Johnston & Lee, 1995). Front-line workers, operating at the ‘sharp end’, are usually responsible for active failures. Latent failures are usually the result of a decision made well before an accident and are thus far removed in time and space from the resulting accident. In this way, front-line operators inherit a system and all its defects. They are burdened with a flawed system, and they are the last line of defence in the trajectory of an accident. As humans, however, their performance is inherently variable, and they can only act as barriers to specific ‘knowable’ problems which the barriers have been designed to intercept. Almost every complex system has some latent defects (depicted in the Swiss cheese diagram as holes), and some of them are known by those with a working knowledge of the system. Other latent failures only become evident when an accident occurs. Management deficiencies can create the potential for many different types of unfortunate defects, but not all are ‘knowable’ in advance. On their own these defects will not result in an accident. The problem arises when the systems defences are rendered vulnerable by an active failure and a number of these latent defects line up at that particular point in time to create an accident. Perrow’s (1984) suggestion that the characteristics of tight system coupling (e.g. limited control options to deal with unexpected events) restrict a worker’s ability to respond to the unanticipated event means that in aviation the issue is further compounded.

Reason’s model is useful in that it takes a systems approach to error and accidents. In so doing it helps to explain distal contributors to the mishap and provides a useful method for communicating the complexity of failures and accidents and the effort necessary to keep systems safe. That said, in attempting to account for the interdependence and dynamism of organisational systems the model defines layers of defence which are are neither static, nor independent of each other. Rather there is a close relationship between each layer: they can support or erode each other. In this effort to accommodate the realities of organisational life it seems that the model invites criticism. Dekker (2002) is critical of the model in that it doesn’t offer an explanation of what constitutes a hole in the defences. Nor does it make an attempt to reveal why holes are present, and why they line up to produce accidents.
While Dekker’s criticisms are valid there is a sense in which Reason is expected, with this model, to answer the unanswerable. Some industry personnel criticise the model on the grounds that it does not assist them in deciding which barriers to put in place to defend their organisation. Reason’s model works as a description of the multi-facted nature of systemic accidents but it is not a panacea. One can only defend against ‘knowable’ accidents and incidents. It is impossible to defend against that of which one is unaware. In this sense, it is important that we learn from accidents and incidents. The human operator at the heart of a complex system is of prime interest nowadays and human error is now seen as the starting point for an accident investigation rather than it being the conclusion. Reason, along with other exponents of the ‘New view’ of human error, most notably McDonald, Weick, and Hollnagel, have all contributed greatly to our thinking about human factors in general.

Table 2: Maintenance Accidents Relating to Systemic Maintenance Errors

<table>
<thead>
<tr>
<th>Date</th>
<th>Reference</th>
<th>Aircraft type (and Carrier)</th>
<th>Event</th>
<th>Direct Maintenance Cause</th>
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<td>1979</td>
<td>Chicago DC-10-10</td>
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<td>Failure to fit O-ring seals on master chip detector assemblies</td>
</tr>
</tbody>
</table>

Table 2 (above) shows two of the previously mentioned accidents. These accidents, in particular, are related to systemic maintenance error. In the case of the Miami based L-1011 incident there is evidence that the failure to fit O-rings was a serial maintenance error. Over a 20 month period the airline had experienced 12 separate incidents relating to in-flight engine shutdowns. In all cases the aircraft had to make an unscheduled
landing as a result of problems with the O-ring seals and master chip installation problems. Interestingly the airline failed to notice the pattern and didn’t perceive these repeat incidents as signs of a systemic problem (NTSB, 1984).

The Chicago DC-10-10 accident (again in Table 2 (above)) is another example of incidents stemming from repetitive maintenance errors. The NTSB (1979) report details how a quicker and easier method of maintaining the engine and pylon was developed and used by two airlines. This new method saved 200 hours of labour when compared to the procedure as specified by the manufacturer. The airlines also considered the new method to be safer than the official procedure as fewer fuel lines, hydraulic lines and wiring needed to be disconnected. Before the Chicago accident another airline damaged the engine pylons while using the new method. The damage was attributed to “maintenance error”, no internal investigation was conducted and the damage was not reported to the FAA.

The errors cited in these examples are not without a genesis and they reflect the systems in which they work. Clearly there were important deficiencies in the maintenance systems which supported activities in each of these organisations. The human and the organisational factors are the critical issues in these accidents. In order to adequately understand the causes of the accident it is necessary to understand the role of the human and the broader organisational setting in which they work. Analyses of aircraft accidents and incidents show that accidents are not simply a consequence of direct technical failure or ‘human error’. The underlying causes are often deeply rooted in organisational and management factors.

Human factors: What is it?

It is well documented that human factors are important contributors to accidents and incidents (e.g. Hawkins, 1987). The accidents and incidents cited earlier in this chapter speak to the role of human factors in the aviation maintenance sector. But what do we mean by human factors? At an elementary level, human factors can be described as the
discipline which seeks to better understand the complex sets of interactions between people and the tools or methods which they use to perform their work and the organisational systems in which this work is performed. This is a rather ambiguous and non-committal definition but then human factors is an amorphous and nebulous thing. Its meaning differs according to its use and it is understood in different ways by different expert groups. For example, a sub-group of the JAA – the Maintenance Human Factors Working Group (MHFWG) – propose one such definition of human factors which is specific to aviation maintenance:

“...‘Human factors’ means principles which apply to aeronautical design, certification, training, operations and maintenance and which seek safe interface between the human and other system components by proper consideration of human performance...” EASA Part-145.A.30(e).

Human factors can be considered as an applied discipline located within the work psychology tradition. The school of psychology is a very fragmented discipline and proffers many competing models of ‘man’: cognitive and psychobiological approaches believe in a biological basis for behaviour, while social psychologists favour accounts which explain behaviour in terms of its social construction. In some ways human factors has inherited this lack of unity. The term human factors is an umbrella term: it encompasses cognitive science, ergonomics, systems approaches, and others. The exponents of each of these perspectives conceive of human factors in a way which reflects their theories and schools of thought but which does not necessarily complement the other approaches. It is in this way that human factors means different things to different people and any attempts to concretise what is meant by the term often serve to confuse, rather than elucidate, the issue. It is best, therefore, to offer a more inclusive and multi-disciplinary definition of human factors where it is viewed as a field of study which attempts to account for environmental, physical, cognitive and organisational factors and the role they play in creating and managing safe, efficient, and effective operational systems.
For a long time human factors and human error were synonymous with each other. While there is currently a movement away from conceptions of human error which hold it as the sole source of human factors knowledge (see Dekker, 2002, 2005; Maurino, et al., 1995) there remains some distance to be travelled before human factors can truly shake off its preoccupation with human error. Most of what we know about maintenance human factors is gleaned from post-hoc analyses of accidents and incidents. Indubitably incidents and accidents tell us important things about systems and their ability to withstand error. In this sense they are an important source of human factors knowledge, but they are not the only source of knowledge. All too often however, it is only in the aftermath of a major accident that organisational analyses are carried out. This retrospective approach has limitations in that it gives precedence to analyses of the non-normal (accidents are, after all, infrequent) rather than the normal. In attempting to prevent errors and future possible dysfunctions it is better to understand the mechanisms of the ‘normal’ functioning of the systems which support the operation. Having a full and clear picture of the ‘normal’ operation will give a better indication of the strengths and weaknesses of the organisation than will an analysis of a ‘non-normal’ accident.

The ultimate goal of human factors is to achieve safety and efficiency. ICAO views human factors as a technology which may be used to allow organisations to make profit and at the same time to make aviation safer (Maurino, 1995). Analyses of ‘normal’ and ‘non-normal’ operations seem to suggest that in the aircraft maintenance sector ‘safety’ and ‘efficiency’ are competing models of task performance. In performing maintenance on aircraft, technicians are trying to achieve two goals: safety and efficiency (or productivity). The technicians aspire to both goals equally but in their experience this is impossible because the two are in fact competing goals. We know that the aviation industry as a whole has a good safety record. Moreover, rates of maintenance primary cause accidents are low, especially when compared with flight-crew primary cause accidents (Boeing, 1996). This is a clear indication that technicians performing maintenance tasks are able to successfully manage the compromise between safety and efficiency. They are adept at balancing the opposing forces of safety and productivity; however there are occasions where the balancing act becomes too difficult and safety
breakdowns can occur. On the whole, however, successful compromises far outnumber failed ones. This poses an interesting question. If most maintenance tasks successfully manage the compromise between efficiency and productivity, why is it that our understanding of human factors in aviation maintenance is informed by research which takes safety failures as its point of departure?

A study by McDonald, Cromie, Corrigan, Daly and Ward (2000) highlights this point. In a survey of maintenance tasks they found that 34% of aircraft maintenance personnel reported not following the official procedure for the task because there was an easier (both better and quicker) way to do the task and that the maintenance manual procedure was too complicated. Accident and incident reports have repeatedly cited the failure to follow procedures as contributory factors in aircraft maintenance disasters (see Wooton, 1998; Kanki, Blankmann-Alexander, & Barth, 1998; Daly, Corrigan & McDonald, 1997) but few would have predicted that violations of procedures were as widespread as the McDonald et al. study suggests.

The issue of task procedures and violations raises some difficult questions for aircraft maintenance. Research by Corrigan (2002) suggests that the industry as a whole is not in agreement about the role of procedures. There exist two models of task performance: one where technicians are supposed to exercise expertise and judgement in the execution of their tasks, a second where technicians should do their work by following the procedures to the letter. The industry has been unable to adequately address this issue and as a result there exist two operating philosophies: one where technicians are viewed as problem-solvers who get the job done (even if this involves taking shortcuts and performing ‘workarounds’), and another where the technician’s role is to operationalise the procedures and always perform the task as specified in the manual.

These two philosophies reflect the unofficial and official industry stances on procedures. The official management stance in aircraft maintenance is that procedures must always be followed. But are technicians supposed to blindly follow procedures which they know to be inefficient, flawed, ambiguous, or incorrect? Unofficially there seems to be room for
discretion. In certain circumstances it is routinely acceptable to take short cuts and not follow the procedure to the letter. The existence of this “double standard” suggests a professional sub-culture which provides the flexibility to deal with situations which are not fully anticipated or planned, and to make the judgement to do what it takes to get the job done (Corrigan, 2002). Weick (1987) asserts that professional practices and aspects of human complexity such as those involved in the ‘double standard’ allow workers to compensate for the deficiencies in the overall system. Mearns, Flin, Fleming and Gordon (1997) are similarly upbeat. They suggest that subcultures facilitate new understandings of a situation which can provide learning and development opportunities. The important thing is that the divergences between the management system and the subculture are adequately explored and understood so that this operational knowledge can be captured. It is only by properly understanding the gap between work as it is prescribed and work as it is actually performed that we can successfully manage safety.

All this argues for an understanding of normal operations. The research suggests that in over a third of maintenance tasks the procedures are not followed (McDonald et al., 2000). Technicians have their reasons for disregarding the prescribed method of performing these tasks. Often times there are quicker and better ways of doing the job. Technicians, we know, work in operational settings where safety and efficiency are often opposing forces. For the most part they are able to successfully offset one with the other. Successful compromises far outnumber failed ones and as such represent the normal face of aircraft maintenance. By analysing accidents and incidents we learn little about normal maintenance operations. Given this, surely it would be more beneficial to understand the ways in which successful compromises occur? Is it not better to understand the ways in which successful compromises are mediated when the system is operating at its limits rather than to look at just accidents and incidents?
A working definition of human factors

It is clear that human factors is a fragmented discipline: this is reflected in its inability to come up with and agreed definition of human factors. The uncertainty about what it is that human factors actually does allows for multiple definitions of the discipline. Below, is outlined the definition of human factors which informs this thesis and the research contained herein. This definition is, in some ways, an attempt to reconcile the different factions in the discipline by being as inclusive as possible. It has similarities with many of the popular models of human factors, such as Edward's (1972) SHELL (Software, Hardware, Environment, Liveware) model (later updated by Hawkins, 1987) but is neither an attempt to supplement nor to supplant this model. Rather the definition proffered below simply attempts to simplify the issue by reducing the notion of human factors to three constituent elements:

- The Individual
- The Social
- The Workplace

In the context of aviation maintenance there are many factors which impact upon the performance of workers in the maintenance system. Some of these factors relate to the fundamental aspects of the human condition which impact upon all humans. These are factors related to the individual and include fatigue, motivation, stress, memory, detection, perception and habituation. Individual differences impact on every aspect of human life. All humans are different and under similar working conditions there will be considerable differences in individual performance. In addition to this there is an inherent variability in human performance such that the performance of any one individual is not constant over time. The factors relating to the individual demonstrate their impact on performance at different points in the maintenance system: e.g. work schedules and rosters, overtime, shift work, time pressure, monotonous tasks, inspection tasks.
A second set of factors relates to interpersonal factors. These concern the interface between different sets of people or individuals as they go about their work. The following factors have a significant impact upon the efficacy and efficiency of social interactions: communication, co-ordination, and leadership. The factors relating to social relations demonstrate their impact on performance at different points in the maintenance system: e.g. interactions between flight crew and maintenance personnel, use of body language, and shift hand-over (the hand-over of incomplete tasks from one shift to another).

A third set of factors concerns the workplace. This set of factors relates to the working conditions which are created by the environment and the employer. These factors are both physical and social and are, for the most part, beyond the control of the workers. They include: documentation, equipment, aircraft design, training, and location of work (hangar, ramp) etc. These factors demonstrate their impact on performance at different points in the maintenance system: e.g. following procedures, use of tools, routine violations.

The distinction between the sets of factors is, in some ways, an artificial one as it is virtually impossible in complex systems such as aircraft maintenance to disentangle intractable problems. For example the issue of routine violations (or 'workarounds'), dealt with earlier in the chapter, is impossible to explain without recourse to all three sets of factors listed above. To explain workarounds solely in terms of the workplace is rather facile. Similarly, explanations which rely on Occam's Razor give precedence to individual factors and ignore important social and interpersonal factors which are implicated (e.g. norms, professional sub-cultures). Nonetheless, this three-tiered conceptualisation of human factors is sufficiently all-encompassing to accommodate and account for the difficult issues being faced by the discipline; issues such as workarounds, and the role of management decisions in safety failures. The definition situates our understanding of the term 'human factors' and acts as a foundation upon which the arguments contained in this thesis can be presented in the following chapters.
Summary

Aircraft maintenance organisations are changing rapidly. More often that not, these changes are being driven by economics rather than safety or quality considerations. The post 9/11 slump in the aviation sector precipitated many difficulties for maintenance companies. Many airlines went out of business and maintenance facilities felt a trickle-down effect. The industry looks very different today when compared with its pre-September 2001 self. Many companies have reorganised. Many more have been downsized or taken over by large competitors. Aircraft maintenance activities are also being transformed through new aircraft systems, diagnostic tools and information technologies. Along with this there are changes in training pedagogies, changes in the apprenticeship system, shortages of key qualified staff, and a growth in contract labour.

The sum effect of these rapid changes has proven difficult to manage for maintenance companies. As each successive change makes its presence felt the industry has been feeling increasingly beleaguered. In an attempt to manage these changes they have turned to human factors. This is not an ill-informed move on their part. ICAO proposes human factors as a technology which allows organisations to make their operation safer and more profitable. But, as we have seen in this chapter, human factors, to borrow Maurino’s (1995) metaphor, is not an easy technology to use. ‘Doing’ human factors well can help ensure that standards of safety, reliability and productivity are maintained and enhanced but this in not easily achieved.

In terms of the accidents featured in Tables 1 and 2 it is essential to understand the active error which led to the accident but it is equally critical (some would argue more so) to understand and address the organisational and management shortcomings which contributed to these errors. Without this acknowledgement of the systemic basis of errors it is impossible to improve flight safety, reduce the accident and incident rates, and enhance maintenance operations in a real and meaningful way. The investigations into the Chicago and Miami accidents discussed earlier in the chapter (and presented in Table 2) neatly demonstrate that errors made at the ‘blunt end’ of an organisation (in the form
of bad decisions, for example) can filter down through the system defences until they conspire with a latent failure to result in an accident. The Reason model (1990) represents a bold move forward in that it marks a departure from the ‘old view’ of human factors when the focus was on errors committed at the ‘sharp end’ of the operation. Much of the human factors research prior to the specification of the Reason model was purely focused on errors and the out-dated notions of human error bandied about at the time conceived of it as an inherent limitation of human performance: *to err is human*. This is not necessarily untrue: human performance certainly varies and is subject to important limitations and these limitations in human performance and capability can often result in safety breakdowns. Of this there is no doubt. But there is an argument which states that maintenance errors are mostly latent (laying dormant until triggered at a later stage) and reside in tasks and/or situations and only emerge as a consequence of an inability to achieve a compromise between safe and efficient task performance at the ‘sharp end’.

Working out how and why latent errors combine with active failures to result in an accident is one way of making systems safer. But by focusing exclusively on the non-normal situation (workarounds, errors, incidents) our understanding of what needs to be improved is solely informed by the ‘official view’ of what is appropriate, required and ‘should be done’. Another way of achieving the goals of human factors is to focus on the normal operational context of action. It is only by looking at the real situations in which maintenance is performed that we will be able to reveal the peculiarities of normal operations as experienced by technicians. In following this approach it is possible to truly do what human factors sets out to do: comprehend the interface between the worker and the equipment, the environment (both physical and social) and the procedures/systems which impact upon the workers performance of their job.

Chapter 2 details the first study of the thesis. Taking an ethnographic approach, the next chapter seeks to deepen our understanding of aircraft maintenance activities and human factors by observing the performance of maintenance tasks in normal operational circumstances.
CHAPTER 2

A 'THICK DESCRIPTION'¹ OF AIRCRAFT MAINTENANCE

Introduction

The study described in this chapter formed part of the first phase of the AITRAM project: capturing end-user needs. An ethnographic methodology was employed in this study. This consisted of a series of observational studies of normal aircraft maintenance operations which were conducted in two companies in order to explore the ways in which the human and organisational aspects of a maintenance task and situation can influence how tasks are performed. The overall objective of the study was to understand more about the human factors requirements placed on aircraft maintenance technicians in the performance of aircraft maintenance tasks in their normal everyday working environment. What is lacking in our understanding of the nature of maintenance tasks is an appreciation of how the work is actually done. Training manuals, job cards and procedures tell us much about how the task ‘should’ be done: what we do not adequately understand is how the task is ‘actually’ done.

Chapter 1 detailed the move away from ‘old views’ of human error and their focus on learning from accidents and incidents. While it is true that accident and incident data tell us important things about systems and their ability to withstand error, they are not the only source of knowledge. Retrospective approaches such as this are limited in their focus on the ‘non-normal’. Normal maintenance operations do not involve accidents and incidents: tasks are usually performed without failures. But there is undoubtedly a tension in the operational environment: between the opposing organisational goals of efficiency and safety. For the most part, this tension is successfully negotiated by operational personnel and a successful compromise is made between safety and efficiency. Using accident and incident data to learn about the human factors of aircraft maintenance does not allow us to understand the ways in which these successful compromises are achieved.

¹ A term coined by Gilbert Ryle (1971) and later borrowed by Clifford Geertz (1973) to define the essence of ethnography: a “thick description".
This study attempts to elucidate this issue by observing normal maintenance operations in context. In answering this question we are able to better understand the normal performance of maintenance tasks. By having a valid description of normal activity then we are better positioned to take the first steps towards constructing an understanding of the critical human factors issues which relate to maintenance activities.

**Research Design: Review and Rationale**

The observational research carried out in this study adopted an ethnographic approach from the qualitative research paradigm. Two maintenance companies collaborated in this study. For reasons of anonymity they have been de-identified. They are termed Company A and Company B. Company A is a large international maintenance organisation which is a subsidiary of an international airline. The maintenance organisation performs maintenance on the airline fleet and also provides maintenance for third parties. Company B is a third-party maintenance organisation. It is a medium-sized independent maintenance organisation which solely maintains third-party aircraft. Two human factors experts (with backgrounds in psychology) acted as observers in this study. The following section details some of the issues that were considered when deciding upon the appropriate research design for this study.

**Quantitative and Qualitative Research Models**

The content and format of a research question gives a good indication of the type of methodological approach that a research project should take. Ragin (1987) stated that quantitative researchers conduct research with a few variables and many cases, whereas qualitative researchers work with a few cases and many variables. This assertion attempts to show, in a simple way, the differences between qualitative and quantitative approaches to research. Many of the central themes regarding the relative merits and demerits of the two approaches can be traced back centuries, though the debate reached fever-pitch in the 1960's.
Henwood and Nicholson (1995) posit that academic psychology has attached considerable importance to implementing a model of research which tends to be known as the ‘scientific method’. The combination of a particular epistemological approach – (empiricism) with a tendency to privilege the collection and statistical analysis of numerical data, has led to the description of this model as the ‘quantitative paradigm’. A second paradigm involves a different epistemological position (constructivism), and this research emphasises a more context-sensitive method of data collection and analysis. This paradigm has a preference for grounding accounts of social reality in subjects’ perceptions of their environment and is described as the ‘qualitative paradigm’.

Bryman (1988) asserts that the tendency to view the two traditions as reflecting different epistemological positions, and hence divergent paradigms, as above, has led to an exaggeration of the differences between them. As a consequence of such thinking, he argues, quantitative and qualitative research approaches are frequently depicted as mutually exclusive models of the research process. Instead, he attempts to reconcile these competing models of research by suggesting that it may be advisable to take an alternative standpoint; one where quantitative and qualitative research are each appropriate to different kinds of research problems and where the research question or issue should determine which style of research is to be employed. Walker (1985) agrees and has proposed that “certain questions cannot be answered by quantitative methods, while others cannot be answered by qualitative ones” (p.61). This view implies that the decision over whether to use a quantitative over a qualitative approach should be based on ‘technical’ issues and, thus, moves the debate away from emotive philosophical discussions.

The debate regarding qualitative and quantitative methodologies is interesting but it is a controversy in which philosophical issues tend to be interwoven with discussions about the nature and capabilities of different methods of research. Walker’s comment reflects the voice of reason. Technical considerations were paramount in the choice of methods and approaches adopted in this study.
The Choice of Methodology

The aim of this study was to explore the factors which impact upon performance of aircraft maintenance tasks. What interested us was acquiring knowledge about the range of variables that can interact in the performance of maintenance tasks. Given that aircraft maintenance is a specialised and particular activity it is clear that the research was not dependent on gathering data on a great number of cases. Taking Ragin's (1989) view as a starting point it seemed that a qualitative methodology best suited the aims of the research. When one looks to Creswell (1998) it is immediately apparent why a qualitative methodology was chosen for this study. He listed a number of reasons for choosing a qualitative methodology, four of which are listed below:

1. The research question begins with 'how' or 'what' – research questions beginning with 'why' are best suited to quantitative methods.

The main question which this study is attempting to answer is: 'what normally happens in aircraft maintenance?' or 'how do things go when technicians are performing maintenance tasks?' It is clear, thus, that using quantitative methods would not aid in furthering knowledge.

2. The topic needs to be explored – the variables of interest are not known before the research is begun, there are no theories to explain the behaviour of the participants and this is what you want to develop.

The main reason for conducting this study was a belief that there was more to aircraft maintenance than following procedures. We know about how maintenance tasks are supposed to be performed (from documentation, etc.) but know little of how this is translated and interpreted in practice. Accident and incident reports indicate that procedures are often not followed but we don’t know why this happens in normal everyday operations which don’t result in incidents or accidents. No theories explain how it is that successful compromises are mediated when the system is operating at its limits and we need an understanding of the
ways in which maintenance is performed in everyday situations in order to answer this question.

3. **There is a need to have a detailed view of the topic.**

   This study attempts to understand all those factors which impact upon the performance of maintenance tasks. Maintenance is not performed by one technician working in isolation. The technician is part of a broader socio-technical system – this system places requirements on the technicians and the technicians have to provide inputs for the system. It is only by understanding the details of this socio-technical system as it manifests itself in normal everyday operations that we can construct an adequate conception of the task of maintaining aircraft.

4. **The participants need to be studied in their natural environment**

   This study is attempting to construct an understanding of maintenance operations which reflects the normal everyday work of maintaining aircraft as experienced by technicians. This can only be achieved by studying technicians in their natural environment (the hangar, or the line). Placing technicians in an artificial setting would alter the very dimensions that we were seeking to explore and would lead to contrived findings. From a practical perspective it would not have been possible for the maintenance companies participating in the research to release their personnel in order to facilitate an experiment.

   It is clear therefore, that the qualitative paradigm was appropriate to further our understanding of maintenance human factors. The next section affords attention to the particular choice of method and the technical considerations which informed the decision.

**Which Qualitative methodology?**

Writers such as Silverman, Wolcott, Bryman, Huberman and Miles have all written extensively about qualitative research and are well respected in their field. What unites them all is their commitment to the cause of qualitative research. A naïve observer might
claim that it is their abhorrence of quantitative research traditions and approaches that brings them together – they are all universally scathing of the “dire abstracted empiricism present in statistical studies” (Silverman, 2001, p.71) and firmly believe that “qualitative inquiry represents a legitimate mode of social and human science exploration without apology or comparisons to quantitative research” (Creswell 1998, p. 9). Kirk and Miller (1986) argue the case for qualitative research a little more strongly when they state that “qualitative research is an empirical, socially located phenomenon, defined by its own history, not simply a residual grab-bag comprising all things that are ‘not quantitative’” (p.10). Also there is consensus regarding the belief that qualitative research can collect data inaccessible to other methods; thereby facilitating research that opens up new worlds. What these authors fail to do however, is examine the relationship of research tradition and research design in such a way that comparisons can be made between different methods.

By examining five different approaches to qualitative research, Creswell (1998) succeeds where other writers fail: providing an up-to-date, working definition of different qualitative research methods and an effective way of choosing one method over another. He limits his discussion to five different traditions of qualitative inquiry – biography, phenomenology, grounded theory, ethnography and case studies – and examines the way in which they shape the design of a study. He defines ‘tradition of inquiry’ as the “approach to qualitative research that has a distinguished history in one of the disciplines and that has spawned books, journals, and distinct methodologies that characterize [sic] its approach” (p.2) and following Bogdan & Taylor (1975) he defines research design as “the entire process of research from conceptualizing [sic] a problem to writing the narrative; not simply the methods, such as data collection, analysis, and report writing” (p.2).

Creswell’s work is important because it tackles an issue that has dogged qualitative research for some time. Much criticism is levelled at the qualitative approach to research. Researchers, in particular, are criticised for not adequately understanding which tradition informs the method they are using. This is not all that surprising when one considers that
as recently as the mid-eighties some researchers termed all qualitative research 'ethnographic' (Goetz & LeCompte, 1984). It is generally agreed that researchers who are unaware of the principles that inform a method are limited in their ability to carry out rigorous and erudite research. Critics of qualitative methodologies often voice other concerns about the research. Unstructured data collection and the introduction of bias in the data analysis stage through the imposition of the researcher's agenda ('the facts should speak for themselves' is the belief of quantitative researchers) are often cited as problems with the qualitative approach. This is a frequent criticism and one which is quickly dismissed by the main protagonists of qualitative research methods. Silverman (2001), for instance, is keen to point out that qualitative methodologies are no more tolerant of sloppy and disorganised work than are quantitative methods of research.

What is fundamentally more damaging to the credibility of qualitative research is the fact that many researchers are unsure of which types of qualitative research design to use in which circumstances. Moreover, many researchers are ignorant of the history of the disciplines that inform the different methods. Ethnography, case study and grounded theory methods, all find their genesis in different academic disciplines and Creswell (1998) argues that in order to assess the appropriateness of one approach over the other we must first understand the principles of the tradition informing the method. From a preliminary review of the literature it was clear that an ethnographic approach could well answer all the questions which this study wishes to answer. Detailed below are the issues that were considered.

**Ethnography**

The origins of ethnography date back to methodological shifts in anthropological research where there developed a trend towards collecting data first-hand. Most writers agree that this occurred in the late 19th and early 20th centuries though some believe its true genesis to be in the 18th century or as early as the writings of Herodotus (Rowe, 1965; Wax, 1971; Hammersley, 1989). This is a moot point but what is clear is that most
everybody agrees that the 'style and substance' of ethnography are a 20th century phenomenon (Atkinson and Hammersley, 1994).

**Defining Ethnography**

Ethnographic inquiry has, as its strength, the ability to show how people respond to particular settings, and has been used as a methodology for social research by researchers in many different disciplines: from anthropology, to sociology, through to educational research. Interestingly, while ethnography is growing in popularity within the social sciences it has been subject to much scrutiny and debate. Across this range of disciplines engaging in social research there is no consensus on a single philosophical or theoretical orientation regarding the rationale for ethnography (Silverman, 2001).

Indeed, it is difficult to come up with an agreed definition of ethnography. Opinions about ethnography range from those which hold it to be a philosophical paradigm deserving of exclusive commitment, to those who believe it to be simply a method to be used where appropriate (Atkinson and Hammersley, 1994). These polarised stances on ethnography reflect the divisive nature of the debates on the issue and speak also to its rise in profile and popularity.

Silverman (2001) goes about defining ethnography by comparing and contrasting it with observation. He defines ethnography as "social scientific writing about particular people ('ethno' deriving from 'folk', 'graph' deriving from 'writing')" (p.45). Observation, he goes on to say, is a large part of our everyday life and many people make observations as part of their occupation (traffic police, social workers, etc.). In order to differentiate these everyday observations from those of social scientists we use the term 'ethnography'. Atkinson and Hammersley (1994) are more sweeping in their conceptualisation of ethnography when they define it as "the production of knowledge" (p.254) but they do provide more substance in their proposition of four common aspects of ethnographic research (over):
1. A strong emphasis on exploring the nature of particular social phenomena, rather than setting out to test hypotheses about them
2. A tendency to work primarily with "unstructured" data, that is, data that have not been coded at the point of data collection in terms of a closed set of analytic categories
3. Investigation of a small number of cases, perhaps just one case, in detail
4. Analysis of data that involves explicit interpretation of the meanings and functions of human actions, the product of which mainly takes the form of verbal descriptions and explanations, with quantification and statistical analysis playing a subordinate role at most

Atkinson and Hammersley (1994, p.248)

Agar (1980) expands the notion and views ethnography as both a process and an outcome of research. The literature on ethnography is quite extensive and represents many varied accounts of what ethnography actually is: a method for some researchers, and a paradigm for others. What is clear from the many definitions of ethnography proffered is that the focus is the observable and learned patterns of behaviour of a system or social group (Harris, 1986). Creswell (1998) argues that all researchers engaging in ethnographic research should be explicit about the school or approach to ethnography espoused and followed in their study. The study contained herein ascribes to the 'enlightenment model' where the knowledge produced by an ethnographic study is important in its own right as it contributes to disciplinary knowledge. In this context the value of the research is described in terms of its contribution to understanding.

**Ethnography and Aircraft Maintenance**

Table 3 (over) lists the data collection characteristics of ethnographic research and illustrates that the observations of aircraft maintenance detailed in this chapter includes each of these features.
Table 3: Ethnographic data collection techniques as they pertain to this study

<table>
<thead>
<tr>
<th>Data collection Activity</th>
<th>Ethnography</th>
<th>Condition Satisfied?</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is traditionally Studied? (site/individuals)</td>
<td>Members of a culture-sharing group or individuals representative of the group</td>
<td>✓</td>
</tr>
<tr>
<td>What are typical access and rapport issues?</td>
<td>Gaining access through gatekeeper, gaining confidence of informants</td>
<td>✓</td>
</tr>
<tr>
<td>How does one select site or individuals to study? Sampling strategy?</td>
<td>Finding a cultural group to which one is a ‘stranger’, a ‘representative’ sample</td>
<td>✓</td>
</tr>
<tr>
<td>What type of information is typically collected?</td>
<td>Participant observations, interviews, documents</td>
<td>✓</td>
</tr>
<tr>
<td>How is information recorded?</td>
<td>Field notes, interview and observational protocols</td>
<td>✓</td>
</tr>
<tr>
<td>What are common data collections issues?</td>
<td>Field issues (e.g. reflexivity, reactivity, reciprocity, ‘going native’, deception)</td>
<td>✓</td>
</tr>
<tr>
<td>How is information typically stored?</td>
<td>Field notes, transcriptions, computer files</td>
<td>✓</td>
</tr>
</tbody>
</table>

[Table adapted from Creswell (1998, pp.112-13)]

Ethnographic methods have, since their inception, relied on participant observation as the favoured data collection method. The study in this chapter is no different. The focus of the study is the work of aircraft maintenance technicians. Access to this specific cultural group was negotiated through a ‘gatekeeper’. Insofar as was possible a representative sample of maintenance tasks was chosen, and complete observation was employed as the data collection technique. Through the use of an observation protocol (the development of which is detailed later) the researchers were able to record information in the field. All workers who worked on tasks which were observed were briefed on the research and were assured anonymity.
Issues concerning participant observation

Ethnography's claim to facilitate a unique humanistic, interpretative approach to studying social life owes much to its reliance on participant observation methods. Immersing a researcher in the daily lives of the participants leads to a unique insight into the social processes involved in the reality being documented by the researcher. Atkinson and Hammersley (1994) write that a participant/non-participant distinction relates to the way in which observations are conducted. They go on to argue that this dichotomous description of participant and non-participant observation is not a useful one, as it implies that the non-participant observer plays no role in the research. A more useful expanded typology was proposed by Gold (1958) and Junker (1960): complete observer, observer as participant, participant as observer, and complete participant. Even this typology, Atkinson and Hammersley argue, tends to run together many dimensions of variation, such as the following:

- "Whether the researcher is known to be a researcher by all those being studied, or only by some, or by none
- How much, and what, is known about the research by whom
- What sorts of activities are and are not engaged in by the researcher in the field, and how this locates her or him in relation to the various conceptions of category and group membership used by participants
- What the orientation of the researcher is; how completely he or she consciously adopts the orientation of insider or outsider" (p. 249)

It has been argued that all social research is a form of participant observation because we are part of the world we are studying (Hammersley & Atkinson, 1994). In the study reported in this chapter, in so far as possible, the researchers assumed the role of complete observer. Regulatory considerations preclude unlicensed persons from working on aircraft maintenance so researchers could not be involved in task activities. Moreover, the researchers were attempting to further their limited knowledge of maintenance by observing the process – getting involved in the process would have confounded the
observations. While recognising the validity of Hammersley and Atkinson’s (1994) statement the researchers tried to occupy as little of the world being studied as was possible.

Procedure

Observational methods are ideal for contributing to knowledge about aircraft maintenance as they do not abstract people from their everyday contexts. The procedure employed in this study can be decomposed as follows (Figure 3 represents the procedure in diagrammatic form):

1. Protocol development  
2. Task selection  
3. Task observation  
4. Collation of observations  
5. Trainer and operational manager feedback  
6. Revision and consolidation

![Diagrammatic representation of the procedure of the ethnographic study](image)

**Figure 3:** Diagrammatic representation of the procedure of the ethnographic study
1. **Protocol development**

The first step of the research involved specifying a protocol which could be used to guide the observations of the tasks. The protocol consisted of a list of categories which were intended to guide the ethnography and to facilitate an efficient use of the restricted access that the researchers were given to the two maintenance organisations. Another reason for having a standardised instrument relates to the need to ensure consistency across the two observers who conducted this study.

A set of broad categories to guide the ethnography were specified prior to the observations. The choice of categories was largely driven by the standard definition or model of human factors which was described towards the end of Chapter 1. This model of human factors conceives of three constituent elements:

- The Individual
- The Social
- The Workplace

The premise of the model is that all maintenance human factors issues can be categorised according to these three elements. For example, fatigue, lack of motivation and feelings of stress are all human factors issues that affect the individual. Lack of supervision, poor communication and a lack of co-ordination are instances of human factors issues which relate to the social aspects of the work. While insufficient tools and poor manuals are examples of human factors problems which relate to the workplace (see Chapter 1, for more details).

This model of human factors is a variant on the SHEL model as advanced by Edwards (1972) and later updated by Hawkins (1975). The SHEL model is a simple framework which can be used to organise human factors issues. The title of the model is a useful mnemonic describing the constituent elements (over):
• Software (e.g. maintenance procedures & documentation),
• Hardware (e.g. design for maintenance),
• Environment (e.g. lighting)
• Liveware (i.e. the person or people at the heart of the operation)

This model places the human at the centre and emphasises the interface between the person and the four elements S, H, E, and L. The UK Health and Safety Executive (HSE, 1999) operate under another variant of the SHEL model. This model focuses on the interrelationships between:

• The job (e.g. task, workload, environment, displays and controls, procedures)
• The individual (e.g. skills, personality, attitudes, risk perception)
• The organisation (e.g. culture, leadership, resources, work patterns, etc.)

The model which informs the ethnographic study presented in this chapter is a pragmatic one. The SHEL model is generally accepted as the industry standard, as evidenced by ICAO’s use of it to describe human factors in its documents (e.g. ICAO, 1989), but the model presented here departs from it to a certain extent. The differences between the two models are noticeable but are not sufficiently substantial for the model presented here to be perceived as a challenge to the dominance of the SHEL model. That said, while it doesn’t attempt to supplant the SHEL model neither does it attempt to supplement it. Rather it was adopted as a simple, pragmatic method of assisting, in an applied (maintenance-specific) way, the observations of maintenance tasks by guiding the observers to some of the key human factors issues in aircraft maintenance. The choice of categories which are subsumed in each of the three elements of the model was driven by expert knowledge of maintenance related accidents and incidents, previous experience of human factors research projects and information gleaned from state of the art training programs (in particular STAMINA training, which was collaboratively developed by human factors experts and maintenance personnel in the STAMINA² project).

² The STAMINA (Safety Training for the Aircraft Maintenance Industry) project was funded under the EU Leonardo Da Vinci Programme
The three elements of this model of human factors (the individual; the social; and the workplace) were used to group together all the individual human factors issues which relate to aircraft maintenance. The three category titles (the individual; the social; and the workplace) were decomposed into seven sub-categories before all elements were listed. Each of the elements listed in Table 4 (below) was represented on the observation protocol form as an open-ended question (e.g. 'How do tools affect the task?'). Observers filled in their free-form comments in the spaces provided on the observation protocol. Appendix A contains the full observation protocol. Table 4 (below) illustrates the way in which the different elements of the observation protocol were organised according to the working model of human factors.

**Table 4:** The observational protocol framework which guided the task observations

<table>
<thead>
<tr>
<th>Category</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Individual –</td>
<td></td>
</tr>
<tr>
<td>• Individual Capabilities</td>
<td>Strength/agility, Physical effort, Skill, Understanding of the system, Knowledge, Experience, Motivation, Fatigue</td>
</tr>
<tr>
<td>• Task management</td>
<td></td>
</tr>
<tr>
<td>The Social –</td>
<td></td>
</tr>
<tr>
<td>• The Team</td>
<td>Multi-tasking, Organisation and planning, Distraction, Interruption, Situation awareness, Task focus</td>
</tr>
<tr>
<td>• Communication</td>
<td></td>
</tr>
<tr>
<td>The Workplace –</td>
<td></td>
</tr>
<tr>
<td>• Task Support</td>
<td>Access – physical/visual, Dexterity, Weather, Comfort, Safety/efficiency critical, Time pressure, Commercial pressure</td>
</tr>
<tr>
<td>• Performance Shaping Factors</td>
<td></td>
</tr>
<tr>
<td>• The Operation and Organisation</td>
<td></td>
</tr>
</tbody>
</table>
The initial protocol was pilot-tested on a number of occasions in order to refine it. Portions of maintenance tasks were observed using the protocol and improvements and modifications were made on an iterative basis. This process continued until such a time as the instrument was deemed fit for use.

2. Task selection

The overall objective of this research study was to understand more about the human factors of aircraft maintenance tasks as experienced by technicians. The focus was on aircraft maintenance tasks in a generic sense: not one particular task; nor one particular type of task; but on the whole range and breadth of tasks that are necessary to maintain aircraft.

Pragmatism dictated that it was not feasible to analyse all maintenance tasks (even for a single aircraft type): there are thousands upon thousands of discrete tasks that have to be performed at different intervals and frequencies in order to maintain an aircraft. Ideally it would have been advantageous to obtain a large sample of tasks which could be observed. This was not possible either: observations of tasks would consume too much of an already limited supply of end-user resources (time and effort). This meant that a sampling strategy was pursued to maximise the representativeness of the range of maintenance tasks in the observations conducted.

The two maintenance organisations involved in the research were very involved in the selection of these tasks. Both organisations maintained Airbus aircraft and it was decided to choose this fleet because it was common to each company. The Airbus Industrie categorisation of maintenance tasks (for OJT purposes) is as follows:

1. (FOT) Functional Operational Test
2. (LOC) Location identification of system Components
3. (MEL) Minimum Equipment List items requiring a maintenance procedure
4. (SGH) Servicing Ground Handling
5. (TVC) Thorough Visual Check
6. (RIA) Removal Installation Activation

This categorisation of maintenance tasks presented an authoritative and useful framework for differentiating maintenance tasks and was borrowed in this study to assist in selecting the tasks for observation. The project which funded the research had specific requirements (regarding the suitability of tasks for modelling in a VR environment) which also influenced the choices of tasks to be observed. This meant that the most appropriate categories for analysis were categories 1, 4 & 6. Tasks in categories 2, 3 & 5 are simple tasks like checking oil levels, locating panels etc., all of which are features of larger, more complicated, tasks.

Once these broad areas were decided upon, the selection process became more operational and opportunistic. The final choice of tasks related, for the most part, to the opportunity to observe tasks in the companies. That is to say, within each of the categories some tasks would be performed more frequently than others. As opposed to choosing a task up-front and waiting for it to present itself, it was decided to adopt an opportunistic sampling method. In this way as tasks presented themselves they were considered for suitability (i.e. in relation to the categorisation of the task according to the Airbus scheme) and if suitable the observations would be conducted straight away.

The tasks which finally passed through this selection process were as follows:

1. Front Wheel Strut Seal Replacement
2. Transit check
3. Wheel change
4. Operational Check of Cargo Door Snubber

The first three tasks were all group tasks; task 4 was an individual maintenance task.
3. Task observation

Tasks were observed in two maintenance organisations as follows:

Table 5: Breakdown of tasks and the company in which they were observed

<table>
<thead>
<tr>
<th>Task</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>1. Front wheel strut seal removal and replacement</td>
<td>✔</td>
</tr>
<tr>
<td>2. Transit check</td>
<td>✔</td>
</tr>
<tr>
<td>3. Wheel change</td>
<td>✔</td>
</tr>
<tr>
<td>4. Operational Check of FWD Cargo Door Snubber</td>
<td></td>
</tr>
</tbody>
</table>

Two human factors researchers (each with experience in human factors research and training) conducted the task observations³. The observations consisted of sustained engagement with the technician(s) as the task was being completed. Technicians were informed of the purpose of the research beforehand and every effort was made to conduct the observations in as unobtrusive a fashion as possible. The two researchers were introduced as human factors researchers from Trinity College Dublin to all personnel present at the beginning of the observations. This was done by the 'gatekeeper' (the contact person through which all arrangements for observations were made) in the organisations: usually a well-known and well-respected member of staff from the in-house training department. Technicians who joined the task mid-way through would not have been officially informed as to the identity of the observers but one assumes their colleagues would enlighten them. Some of the personnel in the company may have had interactions with the researchers before – as part of other research projects. Each of the two companies involved in the research project had dissemination policies regarding the

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³ Task 4 (Operational Check of Cargo Door Snubber) was observed by only one human factors expert.
research collaborations being pursued. It is not possible to ascertain the exact extent of knowledge about the research.

The protocol was used to note all relevant aspects of the task in the appropriate category. Attempts were made to get rich descriptions of the task, with all behaviour noted down in a semi-structured format. The researchers were engaged in observing all aspects of maintenance tasks and accompanied technicians on trips to stores, management offices and so on, as long as this was related to the task being observed.

Clarification was sought, when required, from shift leaders or trainers who were always at hand to explain unfamiliar aspects of maintenance and the procedures that proved unclear to the observers. This was an important aspect of the observation as it meant that ambiguities could be cleared up immediately and that misinterpretations were not made due to a lack of technical knowledge on the part of researchers. In some cases the comments of these secondary sources (and occasional, unsolicited comments of the technicians being observed) are presented in the task descriptions presented in the results section of the chapter.

4. **Collation of observations**

Each task was observed by two researchers who produced two completed observation forms (apart from the task ‘Operational Check of Cargo Door Snubber’). The outputs of each researcher’s observations were then collated and summaries of each task were developed on the basis of the broad categories outlined earlier. These collated analyses (once approved by trainers and operational managers (see below)) provided the task descriptions which appear in the Results section later in the chapter.

5. **Trainers and operational manager feedback**

This step in the procedure functioned as a formal quality-control check. The task descriptions generated from the observation forms were completed by the researchers
who are not technical experts. In order to avoid any misinterpretations the completed task descriptions were presented to trainers and operational managers who were present at the time of the observation to ensure that all statements were factual and correct.

6. Revision and consolidation

This is the final stage of the procedure. The main tasks here were to incorporate any feedback received from the trainers and managers into the summaries and adjust the narratives to reflect their comments.

Results

Task Descriptions

Task 1: Front Wheel Strut Seal Replacement A330-200

Task Orientation

This task involves replacing a rubber o-ring seal which is part of the front wheel strut on an aircraft. A strut is a reinforced shock absorber which holds the wheel assembly to the aircraft but stops it from making contact with the fuselage when the aircraft lands.

Individual Capabilities

The removal and installation of a front wheel strut seal is a task that is not frequently performed – the opportunity to gain experience of the task is limited. The landing gear is quite a complex system, requiring a good understanding of its workings to be able to carry out the removal and installation. In the task observed, an informed understanding of the front wheel system was necessary in order to diagnose the exact nature of the problem with the faulty strut. Neither the shift leader nor his team had completed this task before and as such this lack of operational experience forced reliance on generic knowledge of schematic comprehension and knowledge of hydraulics, as well as other principles. Some experience would have been an advantage, as would task-specific procedural knowledge.
Abilities to comprehend schematics are of pivotal importance as there is constant reference to maintenance manuals in which schematic diagrams feature heavily. In addition to this, basic technical skills would be required.

The task required some considerable strength and agility in order to lift the wheel and access some recesses in the fuselage. The physical effort required at some times was considerable, especially in removing some larger components. It is conceivable that some aspects of the task would be impossible to perform by someone of less than average stature.

Fatigue, difficult visual and physical access and uncomfortable working conditions all featured in this task. While the main motivation was to do a thorough job with continuous checks and constant supervision by the shift leader, evidence of fatigue was present after 7hrs 45mins. Prior to this, technicians showed no signs of tiredness. After this time however, levels of interest seemed to wane as technicians became fatigued. The level of verbal communication dropped, and technicians not directly involved in an action tended to stare into space rather than observe. There was a certain amount of stress due to the problem-solving difficulties encountered in the task. The arousal level of the technicians started off low as they were doing the preparatory work, increased as they got down to the actual removal of the strut, peaked during the problems with the final disassembly, and lowered during the installation. Performance is probably most vulnerable during the peak of arousal or at the lowest point at the end of the shift (lapses in concentration).

Task Management

In this instance the task of replacing a strut seal was non-routine, and unscheduled. It has to be replaced approximately every two years so there is some element of predictability with regard to scheduling. The task is not intrinsically subject to interruption or distraction, although multi-tasking is common for some of the team members.

The task itself is very complex. This complexity derives from the fact that the system itself is intricate and the seal is deeply imbedded in large components. No single technician completed the whole task, as it took longer than one shift to complete. The
team (the composition of which changed regularly) saw the task to completion though. Owing to this, situation awareness could be quite a factor. Good levels of communication are required to ensure that it does not have adverse effects on the task performance. The good level of communication in evidence at the start was difficult to maintain at the end due to fatigue.

Good organisation and planning of the task were required at certain points. Much of the task was linear – subtasks that needed to be performed one after the other. But there were occasions where efficiency could be gained by doing some tasks in parallel. The challenge for the leader was to recognise these occasions, and manage them without losing situation awareness.

**The Team and Communication**

Overall, approximately 8 technicians of various grades were involved in this task. Two shifts worked on the task, with an overlap period of three hours during which both shifts worked on the task. Given the large numbers of personnel working on the task at any one time, some prior experience of working in a team would be necessary.

There was a shift leader, but his exercise of leadership was not obvious. There was an informal allocation of roles, which seemed to be dictated by experience and knowledge. Informal task leadership changed frequently with apparently no verbal indication of the change – a different technician would take the initiative while the others supported him with tools. This was particularly the case when the team encountered a difficulty and several team members took a turn at solving it. The only sign of tension in the group was at one point when an older technician with little experience of this task had to yield task leadership to a younger technician from another team who had been “borrowed” because of his relevant expertise. But this tension was only non-verbally expressed and momentary; with the older technician quickly adopting an assisting role. The team members worked quite closely, as their actions were quite interdependent. The team itself changed during the course of the task. Initially only two or three were working on the task, one of whom was also assisting with a different task on the same aircraft; others
joined as the task demands became higher, and ultimately, when the group were having difficulty, two more experienced technicians were borrowed from another aircraft.

Communication levels were quite high – primarily during the diagnosis stage, although lots of verbal interaction took place throughout the task. This is unsurprising given the lack of experience of most of the team. The team worked on the same localised part of the aircraft, although some team members were at other locations on the same aircraft for some periods of time. The team was very cohesive and all members seemed to be working towards a common goal. This team worked well together to carry out the task and solve the problems that occurred. However, it is easy to imagine difficulties arising if the leader was being overly autocratic, or if team members were disagreeing about how to carry out the task, particularly given their lack of experience. The task was quite stressful for the team when they could not work out how to perform a particular sub-task and had to call in “experts”. Being observed by the researchers probably added to their stress, but also may have reduced the overt friction in the team.

**Task Support**

Parts and tools were vital in helping to support the efficient execution of the task. The lack of suitable tools meant a delay of approximately 15 minutes on one occasion. There was difficulty getting the correct platform at one point. This platform was needed to gain access to the landing gear which was about 2 meters off the ground (the aircraft was raised on jacks). Instead of waiting for the correct platform to be located the technicians reached the landing gear by actually standing on the wheel of the aircraft and climbing up to where they needed to work. This is not official procedure, though it is tolerated by managers and trainers – they say that it does not damage the aircraft.

Much effort went into organising the parts which were carefully catalogued and arranged prior to the task beginning. When the task was in the installation phase, there were a number of different sets of O-rings set out in labelled packages on a table. At one point several of these were opened and removed from the packaging which detailed the specification of the O-rings. Confusion arose about which O-rings came from which package. Solving this required a careful examination of the packages. There is very clear
scope here for getting parts mixed up. This difficulty could be addressed by designing more clearly distinguishable parts, but a local solution would be to only open one packet at a time. Organisation and management of parts is related to ‘good professional housekeeping practice’. One technician confided that modern apprenticeships do not emphasise this in the training any more.

Three maintenance manuals were consulted regularly. Some technicians reported that the manuals were not clear or accurate. One ambiguity in the manual led to delays, as there was considerable confusion and discussion.

**Performance Shaping Factors**

This task was performed in a busy hangar. Noise was a factor but not a major issue. The hangar environment is, by its very nature, a noisy workplace. There was a great need for manual dexterity, with numerous intricate tasks requiring the ability to manipulate small components. There was also the issue of visual and physical access. It took a considerable length of time to locate and gain access to certain seals. Similarly, with disassembling and reassembling the strut there were problems gaining access as some of the components are deeply imbedded in large components. This meant that the task is quite uncomfortable for the technician – very difficult and challenging tasks to be completed in cramped, badly-illuminated working conditions.

**The Operation and Organisation**

There was no evidence that the technicians were under any kind of time pressure. It was the evening shift and the aircraft was not due in service until the next day. Sufficient time was allocated to complete the task and it was scheduled early in the evening. The task was clearly safety critical and managers emphasised getting the job done correctly. If there was more of a time constraint it is conceivable that greater pressure would have been brought to bear on the work team. As it was there was little time pressure but the lack of trained and experienced personnel presented its own difficulties.
Task 2: Transit Check A330/321

Note:
The following description of a typical transit check is based on observations made of real transit checks observed in two maintenance organisations. Owing to availability and fleet issues, observations were made of an A330 in Company A and an A321 transit check in Company B. Typically a single technician will perform a transit check on the A320 fleet and the A330. However, on some occasions where staffing levels allow it is possible that more than one technician will perform a transit check on an A330. Two technicians performed the A330 transit check that was observed in this study. Unless otherwise stated the comments included here refer to a transit check in its generic sense (i.e. irrespective of aircraft type). Any issues particular to one aircraft type and not the other will be made specific in the text.

Task Orientation
A transit check is a particular type of inspection task which is performed after each flight sector. Transit checks are performed on the line or at the terminal gate. They involve visual inspections as well as some flight-deck based systems checks.

Individual Capabilities
The average transit check demands little in the way of specific technical skills although irregular occurrences may demand specialised skills on the part of the technician (such as repairing a faulty refrigerator, as occurred on one transit check observed). There is also occasional need for trouble-shooting and problem solving skills. For transit checks the technician needs basic on-the-job experience, a good level of overall working knowledge of the aircraft, and basic technical skills. He/she also needs good overall knowledge of the procedure to be followed when conducting the walk-around, and the items to check in the cockpit.

The task itself consists mainly of visual and sometimes tactile checks (with some monitoring of levels and gauges). Minimal physical effort is required. Experience could increase efficiency in carrying out the task, and, in particular, trouble-shooting when it is needed. The transit check is a very responsible role which can place a lot of demands on
the technician’s human factors skills – time and task management and decision making in particular. The transit check can be a very stressful task – it is often performed under time pressure. In these instances technicians have to make decisions and liaise with a wide range of personnel (flight crew, refuelling, dispatch, baggage handlers) each of whom have a different agenda. At the same time, all this work is conducted in a noisy environment, oftentimes with adverse weather conditions. The main motivation which the technicians displayed suggested that they wished to complete the task as quickly as possible. One technician also added that his main motivation was to rid the task of monotony.

Task Management

The transit check is a routine, scheduled task which is subject to both distraction and interruption by flight crew and refuelling personnel. The task itself dictates the organisation and planning of the activities – a number of the tasks have to be done in a predetermined sequence. The transit check is carried out after each flight and may include some unscheduled repairs or replacements to systems or components which were found to be faulty in the previous flight. The technician sees the whole task to completion (and in cases where there are more than one technician, each team-member will complete his part of the task).

This task puts high demands on the technician’s task management skills. It often involves multi-tasking, with the risk of interruption and distraction. Efficient performance requires good task organisation and time management. The transit check can become an over-learned task and thus there are concomitant risks of complacency, and perception biases.

The Team and Communication

A321:

On the A321 transit check there are no internal team dimensions to the task as the technician worked alone. However, the task entailed communication and co-ordination with flight crew, refuelling personnel and ground handling staff.
Two technicians were involved in the task: one technician based on the fuselage of the aircraft ('exterior technician') and one based in the cockpit ('interior technician'). Each of the technicians had clearly defined tasks to perform. For the most part these tasks were independent of each other. Each individual technician was thus free to organise his own work. Communication between the two technicians was conducted via walkie-talkie and face-to-face interactions. They also had to communicate with the flight crew, cabin crew, refuelling, ground handling and the parts store.

The technician plays a leadership role in the transit check – with authority to instruct refuelling, ground-handling, cabin crew and flight crew. This leadership role often is not very obvious, but on occasion requires firm decisions and instructions.

Task Support

In one of the maintenance organisations an official checklist is issued to technicians performing transit checks. The checklist contains the step-by-step procedures for the walk-around portion of the transit check. Apart from this, manuals are not generally consulted, unless the technician is unfamiliar with an unscheduled repair task. Generally the manuals are kept in the line maintenance office which is often some distance away, discouraging technicians from accessing the manual. Most of the tasks carried out by the technician are minor tasks and are quite routine. Major tasks would entail calling in extra personnel, who may bring the manual with them from the line maintenance office.

Technicians also need to interface with the on-board information technology (IT) systems. In both observations the cockpit-based elements of the check involved some interaction with the on-board flight system computers, and one check was completed using an electronic flight log. This involvement consisted mostly of monitoring levels and gauges.

A major factor influencing the transit check can be the availability of parts, especially if there is an unscheduled repair task and a new part needs to be fitted, as occurred on the A330 check. The role of the parts store is critical – they must have the correct part in
stock and be able to deliver it quickly. Good communication with the parts store is important to ensure the part is correct, that it is delivered to the correct aircraft, and that the technician is aware of its delivery. Similar issues relate to the availability of equipment.

**Performance Shaping Factors**

The main factors which affect the performance of a transit check are concerned with the environment in which the task is performed: outside, in a noisy and sometimes stressful environment. The engine noise can make communication difficult between technicians and other personnel. The weather affects the task, with adverse conditions greatly influencing worker comfort and fatigue levels. The weather also can have a negative impact on manual dexterity. While transit checks are often performed in stressful situations the task can also be quite monotonous. The high frequency with which the task is performed can make technicians bored and complacent.

**The Operation and Organisation**

Transit checks are highly sensitive tasks from a commercial point of view. Timely, efficient and reliable checks reduce the costs of delays (and the loss of goodwill), while at the same time preventing any in-flight incidents. The checks are almost always carried out within a narrow time frame. If the aircraft arrives in on time, and there are no major problems on the log, the task can be relaxed, routine and monotonous. However, a late arrival coupled with unscheduled problems can increase the task demands considerably while reducing the time available to carry them out. In these cases considerable pressure is brought to bear on the technician’s skills – in terms of decision-making, problem solving, trouble shooting, and leadership.

In neither case that we observed was there tangible evidence of any unreasonable level of time pressure. The tasks that needed attention were relatively simple e.g. a faulty printer which needed replacing on the A330. When a repair is required its impact on the safe operation is evaluated while deciding upon a course of action. A refrigerator reported as faulty by cabin crew was also investigated, but no real action was taken and it was suggested that most likely the cabin crew had not switched it on. As such, when a fault
does not jeopardise the airworthiness of the aircraft, the technician decides to prioritise the timely departure of the aircraft – minor faults like this can be repaired later. Technicians are not given any training in handling the demands of the task. In the modern climate there is rarely any tension between flight crew and maintenance personnel regarding the airworthiness of an aircraft. Good relations now characterise the relationship between the two. Flight crew have confidence in the maintenance crew and their work. There are clear specifications of the roles and responsibilities that help the technician in situations where tension arises. In addition technicians are trained in how to deal with tension.

**Task 3: Wheel Change A319**

**Task orientation**

A wheel change is a light maintenance task. Wheels are typically replaced in two instances: when a tyre is punctured or blows out, and when inspections during the transit check show that the tyre tread depth has fallen below the minimum requirements. In both these cases the wheel must be replaced with a new one.

**Individual Capabilities**

The task does not require technicians to have much understanding or knowledge of aircraft systems. The wheel does not interface with many complex systems (other than the brakes) and as such precludes the need for detailed knowledge. That said, task-specific procedural knowledge is required, as well as an understanding of the wheel components. Technicians need only a Level 2 qualification to do this task (Chapter 3 explains more about qualification levels). General technical experience does not appear to be important, but experience in doing this particular task is critical. The observed technicians performed the task very quickly and efficiently, but they were very experienced, and it is likely that technicians doing the task for the first few times would be much slower. General technical skills such as loosening bolts, and using wrenches are required in order to remove and replace the wheel. Over and above these no specialised skills are required to complete the task.
Strength and physical effort are not required for this task. The requirement for these abilities is limited to removing tight-fitting bolts. Stress from time pressure, possibly compounded by pressure from flight crew or others, unavailable parts or equipment, and environmental conditions, has the potential to degrade performance. Another potential problem is carrying out the task at the same time as other personnel are interacting with the aircraft – such as in refuelling and catering. This could add to the stress of the task, as well as the personal safety of the technicians.

Task Management

The task of changing a wheel is a routine one and is carried out quite frequently (according to minimum tread depth requirements). The task is sometimes scheduled a day or two in advance but often is not scheduled. The task observed was not prone to distraction or interruption – both technicians were working solely on the wheel change task and there were no other personnel carrying out activities that could interfere with the work. The task focus is typically on the whole task with the technician seeing the task right through to completion. As such, situation awareness does not have a large role to play. It is not a very complex task and does not usually have to be completed at the same time as something else.

In removing the wheel, there are a number of steps, with a variety of different parts to be removed. The technician has to organise these parts as they are removed so that they are not lost and are in the right order to be replaced. The task is carried out frequently – technicians working on the line can readily get experience of doing the task. The technician observed was so used to doing the task he was able to continue with it while talking to the other technician; at one stage he was not even looking at the task. This over-learning of the task invites the risk of lapses in concentration and missing an important step. Contrary to our findings, it was suggested that the transit check might be subject to multi-tasking on occasion. Sometimes the technician may have to refuel the aircraft as well as perform his/her main duties.
The Team and Communication

Ordinarily team issues would not apply to a wheel change, as one technician working alone would usually perform the task. By its nature the task is not dependant upon team co-ordination, but can be completed in a more timely fashion when performed by more than one technician. When staffing levels permit, it sometimes occurs that two technicians would perform a wheel change. This is the case in the wheel change observed for this study.

Team member functions were allocated at the beginning of the task. The role allocations were such that one technician performed the task while the other anticipated the tools required for the task and performed a support role. The ‘lead technician’ made all the decisions and there was an element of interdependence in terms of the lead technician’s reliance upon the ‘support technician’ for parts and tools.

Verbal communication did not play a large role in the task, as the technicians were able to anticipate the other’s actions and requirements thereby precluding the need for verbal requests. Task division also limited the need for verbal communication – the lead technician did all the manual tasks – organising and retrieving the parts that he took off and put back on the wheel. There was reliance upon gestures and other non-verbal communication. The team dynamics were very strong; the technicians were cohesive and completed the task very efficiently. Also, the fact that all the parts and tools were available to hand limited the need for communication. Communication with the flight deck was required to carry out the brake test.

Task Support

More often than not a wheel change is performed on the line and as such it is imperative that all the appropriate parts and tools are available at the aircraft. The lack of the correct tools and parts makes the task impossible to perform, and delays are certain. Because of this the organisation always has a special cart with all the appropriate tools for wheel changes located on the line. The task does not involve any interaction with IT systems.
Performance Shaping Factors

The main performance shaping factors which affect wheel changes are related to the physical environment: the weather, and the conditions on the line (especially as related to the ground surface). Adverse climatic conditions (such as wind and frost) can impair a technician’s ability to change a wheel, affecting manual dexterity, visibility and comfort levels. The effect of weather is lessened by the location of the task, under the wing. Similarly, the line area can be noisy; the ground surfaces can be oily and slippery; and there can be a lot of engine fumes. Where possible the aircraft is moved inside in order to prevent any adverse impact on performance when the environmental conditions are unfavourable.

The Operation and Organisation

Time and commercial pressure are typical of wheel changes. The task would generally be carried out on the line within a short-time frame before the aircraft is due for departure. In the case we observed, the passengers were already on board. There was no evidence of the time-pressure putting the technicians under stress; however it is easy to imagine the stress increasing if the technicians are inexperienced in the task, are multi-tasking, and if the task support is inadequate (tools, parts, manuals) or if environmental conditions are unfavourable. Many wheel changes, however, are planned and are not as problematic as wheel changes which are called for following a transit check.

Task 4: Operational Check of FWD (Forward) Cargo Door Snubber

Note: This task was observed by only one researcher. The opportunity to observe this task arose when only one of the two researchers was on site and it was not possible to observe the task from beginning to end as the technician had to go on a mandatory break midway through and then was called on to assist on another task. Attempts to conduct a follow-up interview with the technician in order to document the outcome of the task were unfruitful. The technician (a contract worker) was released from duty the day after the
observation due to overstaffing in the quiet summer period. Given this, there is less content for this observation than for the preceding three.

Task orientation

This task involves disassembly of the forward cargo door on an aircraft to access the snubber spring. The internal mechanism of the snubber is inspected to ensure that it works effectively. A snubber is a spring-like device which pulls a door shut. It is fastened between the top of a door and the door jamb. Slamming doors can cause strain on door hinges and the snubber spring controls the closing of a door as it passes the midpoint of the door swing. The snubber spring absorbs the door momentum thereby preventing strain on hinges.

Individual Capabilities

This task is a routine, scheduled task – it is called up automatically on the maintenance schedule after a certain number of flying hours. The task is not very complicated and is an individual task - all that is required of the technician is a good working knowledge of the mechanics of the cargo door's operation. As the observation progressed it was clear that the technician needed considerable experience and in-depth knowledge of this task in order to successfully complete it (see ‘Task Support’ section below). In addition it was clear that there was a requirement for considerable upper body strength in this task – the technician had to support the weight of the door at some stages during the task due to a lack of special equipment. At one point the weight was too much to bear for the technician alone and the researcher had to assist in holding the door.

Task Management

The procurement of specialised equipment would seem to present the most difficult challenge for task management. (The observation of this aspect of performance was especially limited by the premature departure of the technician).

The Team and Communication

This task was performed by an individual technician operating alone, as is usually the case. He did not have any interactions with other technicians but this may not reflect the
usual circumstances in which the task is performed. There may, for example, be some interactions with the avionic technicians who control the power on the aircraft. When the observation was taking place the avionics had gone home and there was no electrical power on the aircraft – and therefore no lighting in the cargo hold.

Task Support

There were many problems with task support. Fortunately the technician was very experienced at performing this task and found ways of overcoming the problems.

Problems with the manuals and documentation were identified early on. The maintenance manual calls for the use of a lump of wood (painted red) to be used to support the weight of the door when the spring mechanism is disengaged. This is not an official part or tool – it is something that the maintenance organisation itself is supposed to make and paint.

The technician knows from experience that this lump of wood is not available in the organisation – it does not exist in the company and nobody uses it. The task is simply not conducted that way in the company.

The maintenance manual says nothing about needing a cable clamp but from experience the technician knows that you need it to disconnect the cable, otherwise the springs supporting the door will retract to such an extent that it is very difficult to put them back in place afterward – some springs are very stiff and extremely difficult to uncoil. The cable clamp is a home-made tool and is not held in tool stores. It consists of two long flat pieces of wood with a bolt threaded through the two ends such that they can be tightened to clamp a cable held between the pieces of wood. The technician didn’t have one himself so he finds one on an over-wing exit hatch which has been removed from another aircraft. He ‘robs’ the cable clamp from this hatch but fashions a replacement from a drill bit and fits this to the hatch before using the cable clamp on the cargo door he is working on. The procurement of the cable clamp resulted in a delay of about 15 minutes but the technician felt that it was worth the effort: releasing the cables without a cable clamp means that the tension of the cable would cause it to recoil at great speed into the internal workings of the door and would be difficult to retrieve (the door may have to be disassembled). Also if the procedure were to be followed the use of the red lump of wood to hold the door
would limit the actual access to the door making the task itself virtually impossible to perform, especially without a cable clamp.

There was an additional problem with availability of special equipment. A support brace which is used to support the weight of the door during the performance of that task was not available but the technician carried on regardless and used his own strength (supplemented, at one point, by that of the researcher).

Performance Shaping Factors
The lack of aircraft power meant that the cargo hold was in darkness but this was easily rectified by use of the technician’s torch from his personal toolbox. The weight of the door caused some difficulty for the technician and his performance was affected as it was so heavy. The cramped conditions in the cargo hold coupled with the diminished lighting were not conducive to lifting a heavy load.

The Operation and Organisation
This is a routine, scheduled task and it is not normally associated with any time pressure. There was no time pressure evident in the task observed by the researcher. It was not a critical task but one which is built into the maintenance schedule.

Note:
The technician used the cable clamp in order to ensure that the springs controlling the motion of the cargo door would not retract too much once the cables are disconnected. In the task observed here the cable clamp proved ineffective in securely holding the cable in place once its connections to the fuselage were loosened. The cable clamp was not strong enough to hold the cable: the cable slid through the clamp and the cargo door slammed shut. This led to some wearing of the metal cable and there are some concerns that this could have weakened the cable. Unfortunately the observation had to finish before it was possible to ascertain the outcome of the task.
Discussion

In general terms the results of this study provide a rich description of the range of human factors issues associated with the performance of maintenance tasks in a normal operational context. Each task highlighted human factors issues which impacted upon the performance of the technicians. These observations of maintenance tasks tell us important things about aircraft maintenance activities in general terms but more crucially they give us an important insight into some pertinent issues relating to competence. This section of the chapter will begin by reviewing the results in general before examining the implications of these results for the issue of competence.

The results provide for a ‘thick description’ or aircraft maintenance and gave prominence to a number of key characteristics of maintenance tasks which set them apart from any other type of technical activity, aviation related or otherwise. They are, in summary, the following:

- Many maintenance tasks are performed by technicians quite frequently: a technician may find himself doing the same task day after day. This level of familiarity with the nature of a task creates a situation where technicians often work on ‘auto-pilot’ and are not fully conscious of task execution.
- Many of the tasks can be quite lengthy, with different technicians working of certain aspects of the same system. Thus, long and complex tasks require awareness, not just of the immediate situation, but also of an extended sequence of activity involving various people and occupational groups. This means that communication issues are central to the smooth running of the system.
- There is a reliance on large amounts of documentation supplied by outside organisations (the manufacturer), which is a key characteristic of the aircraft maintenance industry. The manufacturers, who are remote from the actual maintenance environment, write procedures for guiding the maintenance of an aircraft. Regulations require that these procedures be used to guide task performance.
• Availability of appropriate tools and equipment may affect the way work is done. Issues such as noise and brightness factor in here also. Most maintenance work is done in a busy, noisy environment, be it in the hangar or on the line, and this can affect task performance.

• Certain maintenance tasks may involve limited physical and visual access. In these instances the discomfort experienced by the technician can influence his attention to detail.

• The technician’s understanding of the complete workings of the aircraft and the way in which their task fits into the whole system is critical to safe and efficient performance. Insufficient knowledge of the whole system will result in a low level of awareness of the consequences of one’s actions such that the technician will not be fully aware of the way in which their job affects the job of the next technician.

• Time pressure and pressure to keep to deadlines are characteristics of aircraft maintenance, in particular line maintenance. Quality of workmanship may be emphasised at an organisational level, while individual managers emphasise productivity. The inability to reconcile these opposing stances may prove troublesome for the technician and may impact negatively on their work.

• Work can involve planned and unplanned tasks.

• Maintenance tasks are such that it is possible to complete the task perfectly well without following exact procedures. Sometimes, the task may be completed in less time. As such the task is conducive to an element of autonomy on the part of the technician but the regulations do not permit this.

The results of the study go some way to inform on the unpredictability and variability of aircraft maintenance. It is clear from the observations that maintenance tasks vary quite widely in the requirements they place on those undertaking them. Some, like the transit check, demand a relatively non-specialist overview of the aircraft systems, while others, such as the strut seal task, require a detailed knowledge and understanding in order to be able to diagnose problems or reassemble complex structures. Many tasks require considerable co-ordination and teamwork amongst work teams whose composition, in
terms of experience and skill, may fluctuate according to the stage of the task. Some tasks can be carried out by a technician working on his or her own. Others (like the transit check) require co-ordination with other professionals like flight crew and refuelling agents. At different times tasks require physical strength, sufficient agility to work in awkward and inaccessible spaces and good manual dexterity. The execution of such work must be precise and accurate. They require the ability to understand the schematics of technical documentation and the functioning of on-board computer systems and built-in test equipment. Long and complex tasks require awareness, not just of the immediate situation, but of an extended sequence of activity involving a number of people. In some instances the safety criticality of the task is the overwhelming consideration, on others time is the critical factor and decisions need to be made as to what can be done within a limited time slot and what can be deferred within the limitations of the MEL.

Some of the demands and requirements of maintenance activities are task specific, such as the need for physical strength or dependence on task support in terms of equipment and parts. However, many of the factors which can influence the performance of maintenance tasks are not specific to the task itself, but are more enduring features of the 'socio-technical system' - the ways in which technicians are organised, the tools and technology with which they work, the environment in which they work, and the documentation and information systems which support their work. The environment in which work is done can be uncomfortable (extremes of temperature, weather or noise), may interfere with the task (poor illumination, accessibility or distraction) or may be dangerous (fumes, dust, chemicals, working at height, or poor surface conditions). Similarly, issues relating to inadequate procedures and ambiguous maintenance manual procedures are perennial problems encountered by maintenance technicians.

The study highlights problems of frequently performed tasks and equally those performed infrequently. Frequently performed tasks are prone to over-learning and technicians quickly become bored and complacent when working on these tasks. Conversely, infrequently performed tasks can be stressful for technicians when a lack of operational experience necessitates total reliance on procedures and maintenance manuals which are
often found to be inadequate, ambiguous or misleading. These human factors issues are related to the planning of maintenance tasks and as such are a feature of the maintenance system as a whole. What this study highlights in a stark way is the way in which these upstream functions have an impact upon the downstream operations which take place on the hangar floor. The planning departments clearly lack the flexibility to resolve the variable pressures of production which technicians experience. This is compounded by a wide range of human factors problems relating to teamwork and co-ordination, parts and equipment supply, inadequate documentation, and poor training.

The snubber task starkly highlights many of the human factors problems which seem to be a common feature of aircraft maintenance tasks. The maintenance manual proved to be woefully inadequate. In many respects it failed to provide a description of how the task is performed in that particular maintenance organisation. It calls for the use of specialised equipment which the organisation doesn’t have, and the procedures make no mention of using another tool which will prevent some common problems with the task. Clearly the cable clamp proved ineffective on this occasion but if it worked fine would it be acceptable to violate the procedures in this way? The task was not conducted under time pressure but the technician still engaged in unofficial action. He argued that, in his experience, it is impossible to perform the task according to the procedures specified in the maintenance manual.

While the list of characteristics above does not constitute a comprehensive analysis of the factors affecting performance in maintenance it does go some way to contributing to an understanding of aircraft maintenance which acknowledges the range and extent of the human factors mediating performance in a maintenance setting. The study highlights some of the critical deficiencies of maintenance systems and the ways in which these problems manifest themselves in the operational setting. It is clear that procedural violations occur regularly, that procedures are often ambiguous and sometimes incorrect, and that maintenance systems often fail to provide adequate tools, and parts. This all seems to suggest a system which is malfunctioning. But the study does highlight some of the ways in which the system still manages to overcome these deficiencies. The tasks
observed featured many human factors problems but what stands out is the adaptive nature of technicians. In difficult situations it was the actions of the technician which ensured that the problems and difficulties were overcome. The technicians were working at the sharp end of the operation and continually found themselves facing problems which originate at the blunt end of the operation. Were it not for technicians' willingness to be flexible and accommodating it is conceivable that the job would get done on time and safely. Adaptive and committed workers are critical; it seems; to a successful maintenance operation.

Oftentimes a flexible and committed workforce is not sufficient to protect an operation from an incident or accident. Incident and accident reports such as those of the explosion of the Space Shuttle Challenger, the explosion at Chernobyl, King's Cross Underground Station fire, the sinking of the Herald of Free Enterprise, and the British Midland Boeing 737-400 accident (often referred to as the 'Daventry' incident) are united in citing as contributory factors the following issues: system failures, organisational failures, management failures, communication, design and maintenance failures and lack of an effective safety culture. The BAC 1-11 incident (AAIB, 1992), the Daventry accident (AAIB, 1996), and the Gottorora accident (SHK, 1993) in particular have highlighted some of the problems in planning and organising the human aspects of aircraft maintenance (particularly in relation to managing manpower and workload and co-ordination between different working groups).

It is interesting to note that the human factors problems which were cited as contributory factors in these aircraft accident reports also feature in the accounts of normal maintenance tasks which were produced as a result of the ethnographic study reported in this chapter. The four tasks observed in the study contained evidence of workarounds, the use of unsuitable equipment, the existence of common sets of inadequate work standards (in relation to general housekeeping, for example), a lack of procedural compliance, and reports of inadequate procedures and equipment. When we compare this description of normal everyday maintenance activities to the accounts of the maintenance activities which resulted in accidents and incidents there are some striking similarities.
The BAC 1-11 Aircraft Accident Report (AAIB, 1992) cites the following causal factors:

- A safety critical task, not identified, as a ‘vital point’ was undertaken by one individual who also carried total responsibility for the quality achieved and the installation was not tested until the aircraft was airborne on a passenger-carrying flight.
- The shift maintenance manager’s potential to achieve quality in the windscreen fitting process was eroded by his inadequate care, poor trade practices, failure to adhere to company standards and use of unsuitable equipment, which were judged symptomatic of a longer term failure by him to observe the promulgated procedures.
- The British Airways local management, product samples and quality audits had not detected the existence of inadequate standards employed by the shift maintenance manager because they did not monitor directly the working practices of shift maintenance managers.

The B737-400 Daventry Aircraft Accident Report (AAIB, 1996) identified similar causal factors:

- The aircraft was presented for service following borescope inspections of both engines which had been signed off as complete in the aircraft technical log although the HP rotor drive covers had not been refitted.
- During the borescope inspections, compliance with the requirements of the aircraft maintenance manual was not achieved in a number of areas, most importantly the HP rotor drive covers were not refitted and ground idle engine runs were not conducted after the inspections.
- The operator’s quality assurance department had not identified the non-procedural conduct of borescope inspections prevalent amongst company engineers over a significant time period.
- The civil aviation authority, during their reviews of the company procedures for JAR-145 approval, had detected limitations in some aspects of the operator’s quality assurance system, including procedural monitoring, but had not withheld that approval, being satisfied that those limitations were being addressed.
The Gottrora accident report (SHK, 1993) identified the following from their analysis:

- Insufficient company instructions and procedures for dealing with the clear-ice problem
- Inadequate equipment
- Insufficient reporting mechanisms.

There is, undoubtedly, some similarity between certain features of the organisational systems which have been shown, through the occurrence of incidents and accidents, to be deficient and dysfunctional and those organisations which are considered ‘safe’. The accident and incident reports point to serious problems in managing and organising the human aspects of aircraft maintenance at an organisational level. The observations of tasks conducted in this chapter show that normal everyday operations can often share similar underlying problems with safety events.

But, how is it that normal maintenance organisations share similar shortcomings to those which experience serious safety failures such as accidents and incidents? It emerges from this analysis of maintenance operations that one of the most noticeable features of the maintenance system is that organisations are often unable to fully support maintenance activities. The system can fail to routinely provide the basic requirements for task performance but at the same time requires the work to be done safely and in a timely manner. In situations such as these, where there are contradictory pressures and potential conflicts (e.g. safety vs efficiency) technicians must have an awareness of the task and the situation surrounding that task in order to successfully manage the compromise.

There is a requirement on technicians to understand their personal limits and the limits of the socio-technical system in which they find themselves. In this study there were occasions when the technician chose efficiency over safety; most notably in the Snubber task. In committing procedural violations, in using unofficial tools, and in ‘robbing’ equipment, this technician was exposing the task to the risk of a safety failure. But was the technician at fault for doing so? Or was he doing his best to manage the compromise, all the time remaining aware of his limits, and the limits of the system?
There is no easy answer to this question but it is clear that for some organisations the implicit trade-off between time (efficiency) and safety appears to be one of unresolved conflict and underlying tension. This study illustrates that maintenance organisations can sometimes fail to deliver the basic elements of production in a satisfactory manner. In order to maintain aircraft there is a need for personnel, tools, technology, parts, information, time and a work environment, all of which are adequate in quantity and quality to support the effective and safe performance of the tasks which make up that maintenance process. This study reported tasks where there was a lack of specialised equipment, poor manuals, a lack of personnel and inadequate training, but the tasks were still completed – on time and safely.

McDonald, Corrigan and Ward (2002) offer one explanation for situations such as these. They argue that there exists in the maintenance industry a dominant pattern of well-intentioned people in dysfunctional systems. The central premise of this theory is that the technician at the sharp end of the operation often compensates for the deficiencies in the organisational system in an attempt to do the job well and safely. Those who are best able to manage this compromise between safety and efficiency are amongst the most highly valued workers in the company. This theory explains how it is that on the one hand a system can malfunction in crucial ways but can still result in safe and efficient operations. The workers who compensate for the inadequacies of the system on a regular and routine basis are responsible for keeping the operation afloat. Without them safety would be compromised and the business would fail. It is this ability of workers at the ‘sharp end’ of the operation to successfully manage the contradictory pressures and conflicts that preserves the safety of the system, while at the same time hiding the vulnerabilities of the system.

In successfully managing the compromise between safety and efficient the technician is reconciling the technical requirements of the task (getting the job done) with the non-technical demands of the task (getting the job done safely and on time). This ability to satisfy the technical and non-technical requirements of a task is thus crucial to the functioning of maintenance systems and is a key aspect of human factors practice. The
study presented in this chapter affirms McDonald et al.'s (2002) concept of well-intentioned workers using their skills and abilities to counteract and compensate for the deficiencies of the organisational system. Competent workers are those who are effectively able to provide for the missing aspects of the system.

The results of this study give us a penetrating insight into the true nature of maintenance activities but the research did not produce a comprehensive analysis of the factors affecting performance in maintenance. The research does go some way, however, to contributing to an understanding of aircraft maintenance which not only acknowledges the range and extent of the factors mediating performance in a maintenance setting but which provides the basis for appropriately conceptualising the issues associated with competence and human factors.

The observations of tasks have shed light upon many critical aspects of aircraft maintenance. They have shown it to be an activity characterised by unpredictability and variance, one with a high degree of interdependency on organisational systems and other occupational groups. Moreover the observations have demonstrated the extent to which safety issues are a feature of normal operations, and the ways in which human and technical factors are inextricably linked. All these things are illuminating but in terms of coming to a considered understanding of competence our knowledge is not advanced by these findings in any real or meaningful way. There is, however, one aspect of the results which is extremely relevant in this regard. It is as follows.

What is abundantly clear from the four tasks observed is that there is a distinct social aspect to maintenance work. Many aircraft maintenance tasks are group/team tasks requiring technicians to work together to achieve task completion. But from this study we can see that each and every maintenance task, those completed by teams and those completed by individuals working alone, has a social element which remains constant. The social element of task performance in group tasks is easily understood: the task can only be undertaken through direct interaction between technicians working together. In individual tasks (i.e. tasks where a technician works alone) there is also a social element
to task performance, but in these instances it is indirect. Take the example of Task 4: Operational Check Cargo Door Snubber. This is an individual task, intended to be performed by a sole technician. While the technician does not work directly with any work colleagues there is still a social element to the task performance. This social interaction takes an indirect form and is mediated by documentation, parts and tools supply, organisational processes, etc. Through the use of the maintenance manual and the job card the technician is interacting with personnel in the manufacturer organisation, and also with personnel in the planning and engineering departments of his own maintenance organisation. There may be no immediacy inherent in the nature of the social interaction and it may not be actively perceived by the technician him/herself but there is a sense in which the performance of individual maintenance tasks is reliant on the actions of a collective. There is no way that the technician working on the snubber task would have been able to complete the task without documentation, without parts, without the organisational systems which scheduled the task, provided the training, and managed the check. All of these things represent the actions of other people in the system. No maintenance task, then, is performed in isolation or alone. All maintenance activities have a social element which facilitates the performance of team and individual tasks.

The observations of maintenance tasks also pointed to the existence of complicated interdependencies in the systems governing maintenance tasks. These interdependencies are an important manifestation of the social aspects of performing maintenance tasks discussed above. Technicians often have to take account of other maintenance work and the performance of other technicians. An individual maintenance task is performed in the context of a check: a broad collection of tasks performed together. In a transit check task, for example, the technician works around baggage handlers, the flight crew and re-fuelers and the nature of the task of ‘turning around’ the aircraft is dependent on many factors beyond the control of a technician: e.g. the MEL and operational issues. Interdependencies such as these are common in aircraft maintenance tasks and serve to further complicate the task of maintaining aircraft. The outputs of any maintenance task, it seems, are achieved through a complex social process. It is inaccurate to conceptualise
the performance of maintenance in any way which fails to account for the role of ‘the social’ in mediating a successful outcome to individual and group tasks.

This chapter has served to provide a ‘thick description’ of aircraft maintenance. The observations of maintenance tasks have illustrated the interdependent, unpredictable and varied nature of aircraft maintenance. Moreover we have seen how it is that human and technical issues are inextricably linked: there is an inherent interrelatedness of human and technical problems in aircraft maintenance. Human factors are embedded in maintenance tasks and are often implicated in difficulties in managing maintenance operations.

Aircraft maintenance is afflicted by many intractable human factors problems (procedural violations, poor planning, poor communication) and the systems supporting maintenance operations are often deficient. Notwithstanding this, the performance of maintenance tasks ensures that aircraft are maintained in a safe and efficient manner.

Along with obtaining a ‘thick description’ of aircraft maintenance this chapter sought to explore the issue of competence in aircraft maintenance. The competence of technicians is often invoked as an explanation for the ability of dysfunctional maintenance organisations to produce safe and efficient results. This chapter has highlighted an important social aspect of the performance of maintenance tasks. All maintenance tasks take place in a social space and the actions of the members of that social space have a direct, or indirect, impact upon the performance of any given task. This finding, in particular, has some important and far-reaching implications for the development and specification of any model of competence which attempts to describe maintenance operations. The next chapter, Chapter 3, picks up this thread and attempts to unravel some of the important questions relating to human factors competence from a training perspective. Chapters 4 and 5 will explore specific issues relating to the development of a competence model.
**Strengths and weakness of the study**

The main strengths of this study relate to the methodology and the data. The ethnographic approach facilitated an analysis of maintenance operations which has never hitherto been attempted. The observations of tasks performed in normal operational contexts have informed a new understanding of the mechanisms of organisational systems and the ways in which their activities impact upon maintenance tasks. It was only by engaging with the technicians and observing their performance in a normal, everyday context that we were able to explore what it actually means to maintain aircraft. The ethnographic methodology allowed us to explore the wider context in which maintenance is performed and the ways in which technicians respond to the contexts and situations in which they find themselves. Without focusing on the technicians' lived experience of maintenance this would not have been possible. So in this sense, the ethnographic approach allowed an appreciation of the context of maintenance activities and through its focus on gathering detailed descriptions of the tasks it also facilitated an appreciation of the roles of other agents in that context.

The act of looking at maintenance tasks in this 'new' way led to 'new' data: data which explains the technician's reality of maintaining aircraft. That said, this 'new' data doesn't necessarily tell us anything new. Survey data from a study conducted by McDonald et al. (2000) has already pointed to the pervasiveness of procedural violations and explains the reasons why technicians often disregard maintenance manual instructions. This illustrates that procedural violations are a part of normal operations, while accident and incident data speak to the presence of these activities in 'non-normal' situations. The data do, however, give us some insight into the ways in which technicians have to juggle their opposing commitments to safety and efficiency and show us how successful compromises are achieved on an everyday basis. This sits well with one of the main goals of ethnographic research. The ethnographic approach, as a methodology, focuses on the pursuit of what people actually do rather than what they say they do. Clearly this study has achieved this goal and reconciled the reports of what people say they do (e.g. McDonald et al., 2000) and what people actually do.
The study is limited by the amount of time the researchers were able to spend observing tasks. The maintenance organisations collaborating on this research had restricted resources and were unable to release unlimited personnel to organise the observations and provide feedback. Methodological purists would argue that to be a ‘true’ ethnography the observations need to continue for many months. This was not possible in this study and though the results are interesting the data are limited and relate to only a handful of tasks.

The observations of maintenance tasks which were conducted in this study adopted an ethnographic approach but the data collection was guided by a protocol which featured *a priori* categories. In doing so the research introduced an element of methodological and epistemological tension. This observational study of aircraft maintenance had a number of important considerations that informed the decision to use a structured protocol, and recourse was made to Miles and Huberman (1984) who argue that trade-offs have to be made and should be evaluated on a case-by-case basis. Firstly, there was the practical issue of access. Many maintenance organisations already operate with sub-optimal staffing levels and releasing contact personnel (or ‘gatekeepers’) for a long period of time was not possible: thus the research had to be focused. Observations were also disruptive to the maintenance work itself in that researchers had to be introduced, and consent given before the observations proper could begin. Secondly, the maintenance environment was one which was very familiar to the researchers. One researcher had worked for 7 years in human factors research and training in aircraft maintenance, the other researcher for 4 years. The maintenance environment and the culture of the maintenance technician were familiar to the researchers. It was the reality of the performance of the maintenance task that was interesting. Thirdly, from a methodological standpoint there was the issue that two researchers were to perform the observations. Miles and Huberman assert that an inductive approach to fieldwork where different fieldworkers gather data on multiple cases can end up providing data overload and a lack of comparability across cases. In this case there is a need to impose some structure on the data collection phase.

It is clear that there is a fine line to be negotiated in relation to this issue. Silverman (2001) writes that when researchers use field notes the analysis phase of research has
already begun prematurely. More than just recording data, the categories used are "theoretically saturated" (p.65) and will inform the data we record. In general terms this view is nothing revolutionary. In 1946 the German sociologist, Max Weber argued that it was impossible for a researcher to avoid contaminating his/her research with their own personal values. At each stage of the research process, he believed, there existed an opportunity for the researcher’s own beliefs and ideals to influence their work. He argues that personal and cultural values inform the choice of topic to be researched, the method employed and the conclusions drawn.

Notwithstanding Weber’s beliefs; Silverman (2001) does acknowledge that, in the initial stages, it may be useful to use broad descriptive categories. Indeed, structured data collection methods and data analyses methods are common in ethnographic research nowadays. To do so is no longer seen to champion positivism but to recognise the utility of different approaches for different research questions or problems.

Chapter 6 takes up these issues in detail and in a broader context relating to the thesis as a whole.
CHAPTER 3
TRAINING IN AIRCRAFT MAINTENANCE
‘Proving competence to yourself’

Introduction

This chapter seeks to explore aircraft maintenance training in a meaningful way. Two aspects of training are important: the way in which training equips technicians to deal with the operational realities of maintenance activities as highlighted in Chapter 2 and the conceptual model of human factors competence which underpins the training. The ethnography presented in the previous chapter gives prominence to fact that unofficial action, inadequate manuals and documentation, etc. are all part of daily working life for aircraft maintenance technicians. Moreover the observations pointed out the fundamentally social nature of aircraft maintenance tasks performed both by individual technicians and groups or teams of technicians.

We know little of how maintenance training actually prepares technicians to operate in this world: what does training say about the ways in which human factors are to be managed while performing maintenance on aircraft? How are technicians trained to balance the opposing forces of safety and efficiency? And, most crucially, how does training deal with the social aspects of performing maintenance tasks? This chapter contains a comprehensive review of training in aircraft maintenance in order to answer these questions. In attempting to answer these questions the analysis is driving the competence issue down to another level. Training is often considered one of the most effective methods of developing competence. In exploring maintenance training in a comprehensive manner we can ascertain the degree to which training reflects the characteristics of maintenance tasks as discovered in the previous chapter. This is an indirect way of elucidating the models of human factors competence which inform the training. Every training course is informed by a model of competence; be it explicit or implicit. This is closely related to the aims and goals of the training and quite often trainers and trainees alike are unaware of the model of competence which influences the
training. To this end, the review of training reported in this chapter attempted to unearth and make explicit what real life maintenance training courses say about competence.

The chapter reviews all critical aspects of maintenance training, and taken as a whole, was designed to be comprehensive and to reflect a real training chronology. The chapter begins with a brief consideration of the research approach which was adopted in the study. This is followed by a review of the history of maintenance human factors regulation — serving to situate the review of training in a broader context. The analysis then moves on to initial training: an appraisal of three maintenance organisations and the ways in which the technicians in these organisations receive initial basic training. Next the nature of human factors training is discussed and state-of-the-art human factors training is explored. This facilitates a refocus back to active research; this time tackling type training. Observations of practical training at a manufacturer and at a maintenance organisation were conducted (interviews with both trainers and trainees provide added perspective). All together, this review serves to explore many aspects of a training system for aircraft maintenance technicians in order to answer two fundamental questions: how well do human factors and practical training equip technicians to deal with the operational realities of maintaining aircraft, and what does training tell us about the nature of human factors competence?

**Research Approach**

In order to understand the true nature of aircraft maintenance training this research utilised a single, multi-sited, instrumental case study approach. The study focused on training in multiple locations to explore an important issue. Specifically, the focus is on the training provided for aircraft maintenance trainees in four training organisations. In focusing on these organisations it is possible to appreciate how training contributes to the human factors competence of an aircraft maintenance technician. Creswell (1998) defines a case study as “…an exploration of a “bounded system” or a case over time through detailed, in-depth data collection involving multiple sources of information rich in context” (p.61). Each individual study presented in this chapter, when considered
together with the others, comprise a case study. A number of things characterise this research as a case study:

- **There is a clearly identified case**
  The focus of this case study relates to training received by aircraft maintenance technicians

- **This case is a 'bounded system'**
  The focus of the research was a single issue bounded in time (3 month data collection period), and place (four specific organisations were studied)

- **Use of multiple sources of information**
  Observations, interviews and document reviews were conducted to provide an in-depth review of the issue

- **Consideration of context**
  Important contextual information (e.g. regulatory requirements for training, the organisational context, etc.) are discussed to situate the case

(from Creswell, 1998).

In this research a multi-site case study was adopted: observations were conducted at four training organisations (three maintenance organisations and one manufacturer organisation). This multi-site approach facilitated a broader understanding of training in aircraft maintenance. The four training organisations differ greatly in terms of size, access to training resources, and other characteristics. Conducting observations in a range of diverse settings such as these permitted a more global and representative analysis of training in aircraft maintenance. Stake (1995) has differentiated between two different types of case study research on the basis of their focus. Intrinsic case studies are conducted on cases that are considered noteworthy due to the inherent uniqueness of the case. Instrumental case studies, on the other hand, are those where the case is used instrumentally to illustrate an issue. According to this distinction the case study presented in this chapter is an instrumental case study: an analysis of training in aircraft maintenance is used to make an important point about the human factors competence of aircraft maintenance technicians.
As stated above, a multi-faceted approach was taken to review training in the aircraft maintenance industry. Observations of on-the-job-training were carried out (supplemented by interviews with trainers and trainees); an analysis of manufacturer-provided training was performed; and an analysis of the training profile of three maintenance companies was conducted. Alongside these three active research tasks a supplementary desktop exercise was carried out: a review of the state-of-the-art in human factors training. Table 6 (below) sets out the research tasks and the methods used to gather data:

Table 6: Case Study Research Tasks and Data Collection Methods

<table>
<thead>
<tr>
<th>Research Tasks</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Factors Training</td>
<td>Document analysis</td>
</tr>
<tr>
<td>Analysis of on-the-job-training (OJT) in a maintenance organisation</td>
<td>Observations</td>
</tr>
<tr>
<td>Analysis of manufacturer-provided maintenance training</td>
<td>Interviews</td>
</tr>
</tbody>
</table>

Three aircraft maintenance companies and one aircraft manufacturing company were involved in the active research activities. Company A; the maintenance division of a large national carrier; is involved in base and line maintenance of the parent airline’s fleet and third-party contract aircraft. Company B is a large third-party maintenance organisation involved in both base and line maintenance. Company C is the maintenance division of a medium sized low-cost carrier. It is involved only in line maintenance on the parent
airline’s fleet – they contract another company for base maintenance. Company D is a large commercial aircraft manufacturing company. A sample of convenience was used to select the training sessions to be observed, and the interviews to be conducted. The research presented here was primarily undertaken as part of a broader EU funded research project (AITRAM) and the industrial members of the consortium allowed access for research. There were important differences between the four organisations (such as in size and access to resources) but the organisations and the training sessions observed were typical and ordinary (as determined by the trainers).

The analysis and interpretation phases of the case study were guided by Lincoln and Guba’s (1985) work on case study structure. They believe in the merits of studying the case in terms of: the problem, the context, the issues and the lessons learned. This chapter, in reporting the findings of the case study research, follows this structure in an indirect and implicit way.

**Training and Regulation**

Cromie (1999) has written that aviation is a training-oriented industry. The validity of this statement is without question. The career of a maintenance technician embraces training wholeheartedly: it begins with basic or initial training which develops general skills and abilities in maintenance, this is followed by type training which facilitates the development of specific skills associated with certain aircraft types, and continuation training which ensures the currency of these skills continues until the technician’s career ends.

Aviation is also a highly-regulated industry. The philosophy of regulation permeates all aspects of the industry; training included. In Europe there have been many changes in the regulatory framework in recent years. In September 2002, Regulation (EC) 1592/2002 was jointly adopted by the European Parliament and the European Council and heralded the establishment of The European Aviation Safety Agency. EASA is an agency of the European Union (EU) and plays an integral role in achieving the EU’s objective of
harmonising civil aviation safety in Europe and has been given specific regulatory and executive power in aviation safety. In essence, EASA is the regulatory body governing all aviation regulations in Europe; maintenance included.

Modelling itself on the US Federal Aviation Association (FAA), EASA sets itself the tasks of drafting common standards to ensure the highest level of safety; overseeing their uniform application across Europe; and also, promoting them at an international level. In practical terms this translates into many administrative and executive tasks: namely certifying aeronautical products and the organisations involved in their design, production and maintenance. These certification activities help to ensure compliance with airworthiness and environmental protection standards. Currently, there is a short co-existence of both EASA and the JAA (Joint Aviation Authority). This will cease when the JAA is disbanded and EASA takes overall responsibility for aviation in the EU member states.

**Maintenance Human Factors Training Regulation: Origins and History**

Before detailing the research of this chapter it is important to understand something of the regulatory background to training in aircraft maintenance. There are 4 primary EASA codes which concern aircraft maintenance: EASA Part-21: Certification Procedures for Aircraft and related products; EASA Part-66: Certifying Maintenance Staff; EASA Part-145: Approved Maintenance Organisations; and EASA Part-147: Approved Training Organisations.

Part-147 specifies the requirements for the issue of approval to training organisations to deliver approved maintenance training. Colleges of education or aircraft maintenance organisations must comply with these requirements for approval of the maintenance training they deliver. The regulations govern aspects of training such as the number of hours studied and the curriculum. The basic principle informing the Part 147 requirement relates to providing a basis for approving maintenance training organisations to support
Part 66. More critical are Parts 66 and 145, in that they deal with the content and format of training.

JAR (Joint Aviation Requirement) 66, when it came into effect in mid-1998, contained the first attempt by regulators to tackle the issue of maintenance human factors. The knowledge requirements for issuing an aircraft maintenance licence were expanded to include human factors elements. Module 9 of the JAR66 curriculum specified that all applicants for each of the four types of aircraft maintenance licence (A, B1, B2, or C) must satisfactorily pass a knowledge examination on human factors in a training organisation approved under JAR147 (now termed EASA Part-147). There was no requirement for human factors training, per se. Applicants for the maintenance licence merely had to demonstrate knowledge to an appropriate standard. Training was one way of acquiring this knowledge, but there were other options such as self-study (indeed CAP 715, a guidance document published by the UK CAA, contains guidance and study material for those sitting JAR66 examinations and who are not in receipt of human factors training). For whatever reason, the regulators chose not to directly mandate training. Instead they mandated a knowledge assessment in human factors, thereby indirectly suggesting that human factors training may well be required. This requirement, in general terms, served to implicate, for the first time, human factors knowledge in initial training for a maintenance licence.

A later amendment to JAR145 served to broaden the requirement for knowledge of human factors by including a reference to a requirement for continuation training to deal with human factors. It appeared thus:

“The organisation shall ensure that all certifying staff and category B1 and B2 support staff receive sufficient continuation training in each two-year period to ensure that such staff have up-to-date knowledge of relevant technology, operation procedures and human factor issues” JAR145.A.35(d) [italics not in original].
This statement was the first time that human factors training had been mentioned in the regulations. Continuation training is conducted every two years and is a means of ensuring the currency of the technicians’ skills and knowledge. The inclusion of human factors issues in continuation training was seen by the regulator as a means to build upon the developments of JAR66 and its requirement for examination of human factors knowledge in initial training for ab-initio maintenance technicians. Moreover, it was the first time that human factors training was mandated for maintenance personnel in Europe. The regulators were making slow, but purposeful, steps towards including human factors training as part of an integrated safety management system. With this new requirement in JAR145, the human factors message would be strengthened: organisations could embrace continuation training as an opportunity to concretise an abstract topic by including in the training real-life human factors issues from within their organisation.

While this was definitely a step in the right direction it was not without its limitations: chief amongst them the fact that the regulation focused on certifying maintenance staff only. The discrete approach to human factors inherent in JAR66 was being echoed in JAR145.A.35(d): in both instances only certifying staff were targeted for human factors knowledge assessment and training. There was no requirement for holders of category A licences (non-certifying staff) to be knowledgeable in human factors. The requirement for human factors knowledge lay with specific categories of hands-on technical staff (categories B and C) while the rest of the organisation remained unaffected by the regulations.

Move towards integrated Human Factors

The JAA Maintenance Human Factors Working Group (MHFWG) was set up to assist in drafting regulations in maintenance human factors and had a critical role to play in shaping contemporary maintenance regulation. The working group believed that training was the best way for an organisation to address human factors and therefore embarked on a review of human factors research in an effort to embed best-practice human factors principles in revisions to the original JAR145 requirements. It wasn’t until the
publication of amendment 5 to JAR145 that the human factors training requirement was expanded to include all staff (not just certifying) and to include both initial and continuation training. On the 1st of January 2003, amendment 5 (previously Notice of Proposed Amendment (NPA) 12) to JAR145 came into effect and on the 28th of November in the same year it became part of the EASA Implementing Rule (Part-145.A.30(e)). This amendment came about as a direct result of the work of the training sub-group JAA MHFWG. In relation to human factors it stated:

“The organisation shall establish and control the competence of personnel involved in any maintenance, management and/or quality audits in accordance with a procedure and to a standard agreed by the competent authority. In addition to the necessary expertise related to the job function, competence must include an understanding of the application of human factors and human performance issues appropriate to that person’s function in the organisation. ‘Human factors’ means principles which apply to aeronautical design, certification, training, operations and maintenance and which seek safe interface between the human and other system components by proper consideration of human performance. ‘Human performance’ means human capabilities and limitations which have an impact on the safety and efficiency of aeronautical operations” Part-145.A.30(e).

According to AMC-145.A.30(e) – a guidance and interpretation document for the regulations – human factors training is an acceptable means of compliance (AMC) with the Part-145.A.30(e) requirement. The requirement is comprehensive in that it mandates human factors training for all those personnel whose error or poor decisions could affect the airworthiness of the aircraft. AMC-145.A.30(e)6 listed the categories of personnel who are affected by this requirement: “This should include, as a minimum:

- Post-holders, managers, supervisors
- Certifying staff, technicians, and mechanics
• Planners, engineers
• Quality control staff
• Specialised services staff
• Human factors staff/trainers
• Store department staff, purchasing department staff
• Ground equipment engineers
• Contract staff in the above categories"

With the broad scope of the requirement it was clear that EASA had mandated human factors training to be included in the broader initial and continuation programmes for practically all staff in the maintenance organisation. In this way, human factors was to be integrated into the organisational practices rather than being sidelined and marginalised as a costly add-on.

There was much support for the move from national regulatory authorities, as evinced by the publication of manuscripts which clearly endorse an integrated approach to human factors and safety. CAP 716 is one such document. It is a UK CAA publication aimed at providing guidance on meeting Part-145 requirements. The document supports the seamless integration of human factors and existing company practices such as training and quality management. Part-145, as a whole, targets human factors training from an organisational perspective and has, through the inclusion of planners, managers and/or supervisors and quality personnel in the requirement, extended the scope of human factors to include initiatives such as occurrence management, quality systems and continuous improvement.

That said, the UK CAA made efforts to emphasise the centrality of human factors training to a broader total system (including error reporting and investigation, improved procedure design etc.) which manages human error and discourages procedural violation. It is argued that without adequately targeting the human engaged in “hands-on” maintenance (CAP 716, Chapter 11, p.1) through human factors training it will not be possible for organisational safety management initiatives to be effective.
Aircraft Maintenance Training

Aircraft Maintenance Licences

The aircraft maintenance licence underpins the whole of aircraft maintenance training. Without the appropriate maintenance licence a technician cannot legally carry out work on an aircraft. EASA sets out regulations governing the issuing of licences. These regulations make specific requirements in relation to the technicians' experience of active maintenance but they also specify the knowledge requirements (and curricula for training) for the various types of licence.

EASA Part-66 (previously JAR 66) is the set of regulations governing the issuing of aircraft maintenance licences for certifying staff. There are four categories of aircraft maintenance licence and each one has associated privileges:

1. A category A aircraft maintenance licence permits the holder to issue certificates of release to service following minor scheduled line maintenance and simple defect rectification within the limits of tasks specifically endorsed on the authorisation. The certification privileges shall be restricted to work that the licence holder has personally performed in a Part-145 organisation.

2. A category B1 aircraft maintenance licence shall permit the holder to issue certificates of release to service following maintenance, including aircraft structure, power-plant and mechanical and electrical systems. Replacement of avionic replaceable units, requiring simple tests to prove their serviceability, shall also be included in the privileges. Category B1 shall automatically include the appropriate A subcategory.

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4 The holder of a category A aircraft maintenance license may only exercise certification privileges on a specific aircraft type following the satisfactory completion of the relevant category A aircraft task training carried out by an appropriately approved Part-145 or Part-147 organisation. (Part-66.A.45.(a))
3. A category B2 aircraft maintenance licence shall permit the holder to issue certificates of release to service following maintenance on avionic and electrical systems.

4. A category C aircraft maintenance licence shall permit the holder to issue certificates of release to service following base maintenance on aircraft. The privileges apply to the aircraft in its entirety in a Part-145 organisation.

EASA Part-66 (66.A.20(a))

Experience and Knowledge Requirements

There are two ways in which an individual can obtain an aircraft maintenance licence. The first way is through practical experience (e.g. an apprenticeship scheme); here the applicant is required to pass written and oral exams. Each of the four licences has different experience requirements:

**Category A** – Requires a minimum of 800 hours of instruction; the technician can perform scheduled line maintenance and simple defect rectification.

**Category B1** (Mechanical rating) – Requires a minimum of 2,400 hours instruction; the technician can perform maintenance on aircraft structure, power-plant and mechanical and electrical systems, as well as change out line-replaceable avionics units.

**Category B2** (Avionics rating) – Requires a minimum of 2,400 hours instruction; the technician can perform maintenance on avionics and electrical systems.

**Category C** (combines B1 and B2) – Requires a minimum of 3,000 hours of instruction; the technician can perform maintenance on all aircraft systems.
The second way is by completing an approved training programme in a Part-147 approved training organisation, together with at least one-year's practical experience.

As stated above, all applicants must pass certain knowledge examinations in addition to having experience before they receive their licence. The examinations are structured in modules. Some modules are general and are required by all licence categories; others are more specific and relate only to certain licences. The modules can be taken in any order but must be completed within the five-year period prior to obtaining the licence. Listed below are all the modules which must be successfully completed for an aircraft maintenance licence to be issued in accordance with EASA Part-66 guidelines:

**EASA Part-66 Modules**

1. Mathematics
2. Physics
3. Electrical Fundamentals
4. Electronic Fundamentals
5. Digital Techniques/Electronic Instrument Systems
6. Materials and Hardware
7. Maintenance Practices
8. Basic Aerodynamics
9. **Human Factors**
10. Aviation Legislation
11. Airplane Aerodynamics, Structure and Systems (Mechanical)
12. Helicopter Aerodynamics, Structure and Systems (Mechanical)
13. Aircraft Aerodynamics, Structure and Systems (for Avionics licence)
14. Propulsion (for Avionics licence)
15. Gas Turbine Engine
16. Piston Engine
17. Propeller
EASA Part-66 has further specified the ‘levels of knowledge’ expected of holders of the different types of aircraft maintenance licence. These are indicated by allocating a knowledge level indicator (1, 2 or 3) to each topic or subject in a module (each of the modules listed above contains a number of different topics). These ‘knowledge level indicators’ are defined as follows (EASA Part-66):

Level 1
A familiarisation with the principal elements of the subject

Objectives:
The applicant should be familiar with the basic elements of the subject
- The applicant should be able to give a simple description of the whole subject, using common words and examples
- The applicant should be able to use typical terms

Level 2
A general knowledge of the theoretical and practical aspects of the subject
An ability to apply that knowledge [italics in original]

Objectives:
The applicant should be able to understand the theoretical fundamentals of the subject
- The applicant should be able to give a general description of the subject using, as appropriate, typical examples
- The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject
- The applicant should be able to read and understand sketches, drawings and schematics describing the subject
- The applicant should be able to apply his knowledge in a practical manner using detailed procedures

Level 3
A detailed knowledge of the theoretical and practical aspects of the subject
A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner [italics in original]

Objectives:
The applicant should know the theory of the subject and interrelationships with other subjects
- The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples
• The applicant should understand and be able to use mathematical formulae related to the subject.
• The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
• The applicant should be able to apply his knowledge in a practical manner using manufacturer’s instructions.
• The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

Level 1 is a rudimentary knowledge level. This level requires that trainees are familiar with the topic and can explain and describe, in non-technical language, the content of the subject and the way in which these topics can present themselves in everyday practice. Level 1 amounts to a descriptive kind of knowledge: one where the trainee knows a little about the topic and can describe it to others using examples.

Level 2 requires knowledge of the theories, concepts and general principles underlying the topic. At this level the trainee should have a deeper understanding of the specifics of a particular topic. Level 2 emphasises knowledge of the theoretical underpinnings of a particular topic and requires that trainees are able to transfer their knowledge into practice by following detailed procedures.

Level 3 is the highest level. Here trainees are expected to understand the theoretical aspects of the topic, together with the practical points. Here the focus is on the use of theoretical knowledge situated and understood in terms of a broader system to aid in solving practical problems. Level 3 emphasises the ability to judge ambiguous situations and decide upon an appropriate course of action.

It is clear from reviewing the different knowledge level indicators that there is an obvious progression of knowledge inherent in the framework. Level 1 being the most basic, provides the foundation upon which more sophisticated understandings can be based. Level 2 builds upon this foundation and adds more weight to the understanding of the topic. The general descriptions and explanations of Level 1 make way for the consumption of more abstract notions in Level 2. But it is only at Level 3 that a positive
synergy can be achieved: the rudimentary knowledge from Level 1 combined with the broad theoretical understanding of the core issues gleaned from Level 2 can now be harnessed and used to practical gain. Level 3 speaks to a more superior type of knowledge and for the first time speaks of using knowledge to solve practical problems.

As stated earlier human factors is one of the modules contained in Part-66. Module 9 contains nine different human factors topics which must be examined, and passed, before the trainee is issued with any of the four aircraft maintenance licences. The Part-66 regulations also set out the knowledge levels to be demonstrated by applicants for each of the four licences. Table 7 (below) shows the levels required by each licence.

**Table 7:** Human factors 'knowledge level indicators' required for each type of aircraft maintenance licence

<table>
<thead>
<tr>
<th>Module 9 Human Factors</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>9.1 General</td>
<td>1</td>
</tr>
<tr>
<td>9.2 Human Performance and Limitations</td>
<td>1</td>
</tr>
<tr>
<td>9.3 Social Psychology</td>
<td>1</td>
</tr>
<tr>
<td>9.4 Factors Affecting Performance</td>
<td>2</td>
</tr>
<tr>
<td>9.5 Physical Environment</td>
<td>1</td>
</tr>
<tr>
<td>9.6 Tasks</td>
<td>1</td>
</tr>
<tr>
<td>9.7 Communications</td>
<td>2</td>
</tr>
<tr>
<td>9.8 Human Error</td>
<td>1</td>
</tr>
<tr>
<td>9.9 Hazards in the Workplace</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: Category C applicants must meet either the category B1 or B2 basic knowledge levels.
Table 7 (above) shows that the highest knowledge indicator level required for any of the topics in Module 9 (Human Factors) is Level 2. Level A certifying staff must demonstrate knowledge of human factors to a Level 1 standard in all but two subjects; ‘Factors affecting performance’ and ‘Communications’ require a Level 2 standard. This means that Level 1 certifying staff have basic human factors knowledge: they can describe what it is and can use examples to explain the subject. For the ‘Communications’ (9.7) and Performance shaping factors (9.4) modules content the trainees must display Level 2 knowledge. Level 2 emphasises knowledge of the theoretical underpinnings of a particular topic and requires that trainees are able to transfer their knowledge into practice by following detailed procedures. For B1, B2 and C certifying staff one third of the Human Factors subjects have a Level 1 knowledge indicator. The remaining six subjects are at Level 2 and demand that the trainee should have a deeper understanding of the specifics of the subject. For these six subjects the technician should be able to “apply his knowledge in a practical manner using detailed procedures” (EASA Part-66).

Thus, for all grades of certifying staff the highest level of human factors knowledge required is Level 2. The superior knowledge levels emphasised in Level 3 are not deemed, by the regulator, to be necessary. Level 3 is the step which focuses upon translating theoretical knowledge into practice in the absence of any guidelines: emphasising the ability to judge ambiguous situations and decide upon an appropriate course of action without recourse to guidelines of procedures.

From the ethnography of aircraft maintenance and task performance in Chapter 2 it is clear that maintenance is an activity that is difficult to predict. Things change at a rapid pace and the good technician is the one who can respond appropriately and promptly to the flux of maintenance activities. Oftentimes technicians, as those at the sharp end of the operation, are faced with difficult decisions and limited information. To resolve the problem they have to draw on their theoretical knowledge to answer a practical problem – there are no official guidelines or procedures regarding these situations. The ethnography presented earlier in this thesis illustrates how this common situation manifests itself in
everyday operations. It is clear that technicians who are good at human factors ‘do’ human factors: they put it into practice. Those technicians are operating at Level 3. Why so is this knowledge level not mandated for human factors at all?

Summary

While regulatory efforts to effectively deal with the human factor in aircraft maintenance have not been a resounding success (as pointed out above), the willingness of regulatory bodies to tackle the issue has to be welcomed. EASA is continually making inroads upon the problem that is the ‘human factor’. Through the publication of requirements such as Part-66, and Part-145 in particular, the regulator is playing its role in strengthening the human factors message. The broad scope of the Part-145 requirement means that organisations must attempt to integrate human factors into their organisational systems and make a concerted effort to address human factors in a real and meaningful way.

When considered collectively Part-66 and Part-145, together with the other requirements, tell us important things about the ways in which the regulator views many important issues. Amendment 5 to JAR145, for instance, speaks to a growing awareness of the value of human factors training and the role it can play in an integrated safety management system. More interesting however is what the regulations tell us about the issue of competence and the way in which it is conceived of by the regulator. Part-66 of the EASA implementing rule relates to the issuing of aircraft maintenance licences for certifying staff. Specified in the requirement are all the modules which must be successfully completed in accordance with EASA Part-66 guidelines. Human factors is one such module and is decomposed into 9 different human factors topics which must be examined, and passed (assessment is by examination of knowledge), before the trainee is issued with any of the four aircraft maintenance licences. The Part-66 regulations also set out the knowledge levels to be demonstrated by applicants in the assessments. The nine human factors topics relate to things like social psychology, performance shaping factors, human performance limitations, human error and communication. The regulations go into some detail in each of these 9 topics and list all the knowledge areas which must be
covered in each topic. The assumption is that technicians who follow a human factors training curriculum based on this framework will be knowledgeable about each of these topics and will be well prepared to deal with human factors issues if, and when, they present themselves in the operational environment.

Amendment 5 to JAR 145 was the first time regulations used the term competence in relation to human factors. The requirement stated that organisations must establish and control the competence of personnel. In relation to human factors, competence is considered to relate to an understanding of the application of human factors and human performance issues. While this was the first time the regulations explicitly referred to human factors competence, it was not the first time that a notion of human factors competence had been advanced by the regulator. If one interrogates Part-66 in detail it is clear that the requirement is informed by a model of human factors competence. In defining the types, and levels, of human factors knowledge which maintenance personnel will need in their job it is clear that this conceptualisation of competence focuses almost entirely on knowledge – the ability to apply this knowledge is afforded little attention in relative terms. To this end, the next section of this chapter looks more closely at human factors training and human factors knowledge.

Review of state of the art in human factors training

What is Human Factors Training?

‘Human factors’ is one of many terms which describe the non-technical knowledge, skills, attitudes, and behaviours which relate to work in safety critical systems. Training in non-technical skills is given different names in different industrial domains. Cockpit Resource Management or CRM was an early term to describe human factors training aimed at personnel in the cockpit. This term was altered to create Crew Resource Management when the benefits of training for all on-board crew were realised: somewhat confusingly it retains the same acronym CRM. The translation of CRM training courses to aircraft maintenance has often been called MRM - Maintenance Resource
Management; the term used in anaesthesics is ACRM - Anaesthesia Crew Resource Management. The term ‘human factors’ is used mostly in engineering, energy and transport industries, but similar approaches are used in other professions such as medicine and surgery. Perhaps a useful distinction can be drawn between professions where the primary activity of the profession is social interaction, such as teaching or sales, and those where there primary activity is physical, such as maintenance or surgery. In the former professions the learning of social and interpersonal skills has long been an intrinsic part of the professional training, such as learning teaching skills and doing teaching practice. In the latter professions the critical role of social, psychological and organisational processes as determinants of the quality of the work has been recognised later and has been introduced into professional training relatively recently.

Notwithstanding the difficulties in establishing an agreed nomenclature for non-technical skills there exists a growing interest in what, in this thesis, shall be referred to as ‘human factors training’. The list of industries currently conducting human factors training include the nuclear energy, airline, chemical, oil, process operations, technical communications, engineering, fishing, construction and medical industries. The aviation industry has trained pilots, cabin crew, air traffic controllers, ground handling staff, aircraft technicians and managers. In the field of medicine human factors training has been used particularly with operating theatre staff - surgeons, anaesthetists, surgical nurses and anaesthesia nurses.

While the content of human factors training programmes varies depending on the occupational group, the industry, the philosophy of the training designers, and so on, the following list indicates the range of topics typically covered:

- Communications
- Human performance limitations
- Human error
- Team work
- Leadership & resource management
Typically, human factors training takes the form of special courses across all industries. Almost all human factors training courses take place after technical and professional training and it is almost always a separate module rather than being integrated into technical training. Indeed even those organisations who have taken the leading edge in the development and implementation of human factors initiatives have tended to marginalise human factors training where it has been seen as an ‘ad-hoc’ training device with very little impact.

Now that the regulators are making inroads upon the human factor issues training is increasingly been seen as a way in which human factors can be embedded in organisational systems. For some aircraft maintenance companies human factors training is just another training requirement to be satisfied; for others it represents a new tool with which to tackle deeply entrenched organisational problems. Much of the existing training in the industry consists of discrete one- or two-day courses for maintenance personnel aimed at raising their awareness and knowledge of human factors. The assumption is that raising awareness and imparting knowledge should be sufficient to impact behaviour in the operational setting. This assumption is most clearly demonstrated in JAR 66, which details the curriculum for human factors instruction. Human factors is treated simply as a body of knowledge which technicians must know, in the same way that they should know about aerodynamics or aircraft structure.
But bringing about effective change in operational behaviour is a much more demanding task than the mere application of knowledge. Skills need to be learned and developed – such as communication skills, decision making ability. Attitudes and values may need to be changed – such as willingness to take responsibility for safety and admit mistakes, willingness to work as a team. Developing skills and having a lasting impact on attitudes and values cannot be achieved in the space of a short training course. Human factors is something that not only has to be ‘known’, it has to be ‘done’.

Many companies are increasingly operating in difficult economic environments. The effects of the global downturn in the aviation industry following the 9/11 disaster are still being felt by many maintenance companies. Cost-cutting and rationalising are common across the industry and training is often considered to be a costly adjunct – something which does not create revenue and consumes a lot of resources. How, then, can the need for effective human factors training be reconciled with the operational and economic realities that restrict the time that personnel can be released for training?

**Human Factors Training**

What follows in this section is a review of the current state-of-the-art in human factors training. The next section deals with research projects which are attempting to broaden the scope of human factors training through the use of virtual reality technology.

The reviews and critiques which appear in these two sections rely on the author’s professional experience of the training courses and research projects. The STAMINA training course is featured below and the author is one of the approved trainers on this course. With over 4 years of experience in using the STAMINA course to train industry personnel to become human factors trainers, the author is very familiar with the course. The section following this deals with a research project called AITRAM. This was a development project aimed at producing new technologies and approaches to human factors training. The author was also involved in this project in his capacity as a
researcher. Again, the author is very familiar with the development and implementation of the AITRAM technologies.

While the author’s involvement with the STAMINA course and the AITRAM research affords a comprehensive insight into these two human factors training efforts it is to be acknowledged that the possibility exists for personal bias to enter into the analysis. The author is aware of this possibility and explicitly acknowledges it. That said, every effort was made to attenuate this possibility and present a clear and frank evaluation of both STAMINA and AITRAM.

The STAMINA Training Approach

Of all the human factors training courses, one course in particular has attempted to tackle the issue of human factors in a way which sets it apart from others. The STAMINA project consortium consisted of human factors experts and aircraft maintenance organisations and the training course specified and developed during the course of the project is regarded as the state-of-the-art in training in maintenance human factors. From the outset the intention was to develop a training course which would deliver significant improvements in safety. To achieve this the usual conceptualisation of human factors training as a brief ‘fix-it’ had to be challenged and progressed to adopt a more comprehensive and sustained approach.

The STAMINA course is well regarded in the aviation industry. Evidence for this can be found in the UK CAA’s support for the training course – it often recommends the course to organisations who are seeking to develop training courses. The philosophy of STAMINA holds that mere compliance with regulations is inadequate. While the STAMINA core materials cover the JAR 66 syllabus, the focus is more on enhancing safety, reliability and efficiency. The training program pre-dates amendment 5 to Part-145 but was already recommending human factors training for more than just certifying staff. This was perhaps the most critical element of the comprehensive STAMINA approach to human factors training: targeting the entire organisation, not just the
technicians at the sharp end. It is this aspect of the STAMINA training philosophy which sets it apart from other maintenance human factors training courses.

Essential to the STAMINA approach is a judgement that training solutions which emphasise mere compliance with the regulations could ultimately be counterproductive to the fundamental cause of human factors. To think that the problems are restricted to the ‘hands-on’ personnel and that solutions can be restricted to just this level represents a very limited view of human factors, according to the STAMINA approach. Maintenance work is intimately affected by decisions and actions of supervisors, shift and contract managers, planners, technical writers, and organisational management. These are the personnel who set the context for the work of the technicians. They also need human factors training which addresses their particular roles.

**STAMINA – The course**

The STAMINA training course is an integrated human factors training solution for aircraft maintenance organisations. The training is built around the STAMINA core course. This course comprises a comprehensive set of human factors training materials that can stand alone as a core human factors training course. The course has four main modules: The Individual, The Task, The Team, and The Organisation. This framework for conceptualising maintenance human factors represents the structure of the course. Each module, then, contains topics relating to that aspect of maintenance human factors. The core course (covering these four modules) is designed to be completed in 3 full days. In practice many organisations call for the course to be compressed into 2 full days and one half day to meet operational constraints associated with releasing large numbers of workers for long periods.

The STAMINA training materials draw together generic human factors knowledge with the findings of focused research in the maintenance domain. The training methodology involves active learning in an attempt to initiate a process of learning that will continue on the job. Aircraft maintenance is an activity which involves a lot of social interaction,
and so this is reflected in the STAMINA training course through the extensive use of group exercises and discussions. In this way the training sets up a group dynamic that can be carried over into the every-day work context. Thus, the skills, attitudes and values learned in training can readily be translated to the operational context. Classroom exercises, tasks, and role-plays are used to provide the opportunity to introduce trainees to the skills and strategies that they can use in their every-day work. Presentations by the trainer are kept to a minimum and participative learning techniques are championed in the course (through the inclusion of group exercises, role plays, individual exercises, games, videos, and group discussions). Classroom learning is supported by hand-outs which explain topics in more detail.

The core course also forms the basis for individual courses aimed at other occupational groups. Three critical roles are specifically targeted by STAMINA training: managers, supervisors and also the trainers who will train human factors. Additional modules have been developed to address the specific needs of these different trainee groups. This reflects the STAMINA philosophy which emphasises the blunt end of the organisation and the sharp end. While middle and senior management do not have day to day contact with maintenance personnel, the organisational context that they set for the technician has a major influence. This influence encompasses both the general safety climate and the impact of specific decisions and policies – allocation of resources, policies regarding personnel involved in incidents, training, incident and accident investigation and information flow. Supervisors play a vital role in setting the immediate social context in which the work is done – at the level of the work team. As well as fulfilling specific roles such as allocating tasks, the supervisor establishes the working style of the team – group or individual decision-making, openness to suggestions, problem-solving style, responses to errors. The supervisor’s behaviour can affect whether human factors training becomes an ongoing learning experience for a technician, or a set of naïve idealistic notions.

The STAMINA approach advocates addressing operational realities in the training. The premise is that the particular difficulties of the organisation and the industry as a whole need to be addressed for the training to be effective in transferring knowledge, skills and
abilities from a training domain to the workplace. In particular the following need to be addressed and discussed. Training that ignores or avoids these ‘hot’ issues of the working environment will readily be perceived as purely wishful thinking. To this end the STAMINA course covers topics such as:

- Barriers to safe performance – such as time pressure and confusing procedures.
- Role of management – the presence of a manager at the training, who is prepared to listen, to acknowledge deficiencies and discuss relevant issues, is very useful.
- Operational double standards – for example, technicians may be put under pressure to meet deadlines but feel that they will be blamed if an incident results from cutting corners.

STAMINA pushes another agenda which sets it apart from other human factors training courses. It rejects the assumption that raising awareness and imparting knowledge should be sufficient to impact behaviour in the operational setting. STAMINA acknowledges that bringing about effective change in operational behaviour is a much more demanding task than the mere application of knowledge. The philosophy acknowledges that skills need to be learned and developed – such as communication skills, and decision making ability. Attitudes and values may also need to be changed – such as willingness to take responsibility for safety and admit mistakes and a willingness to work as a team.

A Critique of STAMINA

The STAMINA training course is popular with the industry and regulator alike, and it is certainly a step in the right direction. It attempts to put human factors in context and through the use of the ‘Individual’, ‘Task’, ‘Team’, and ‘Organisation’ framework it certainly helps to situate human factors issues. In addition it is clear that the aspirations of the STAMINA training course are advanced and well-thought out. But there is the issue of whether or not the course, in practice, falls short of the aspirations.
STAMINA claims to conceptualise human factors as being more than just a body of knowledge but when the curriculum is critically examined some inconsistencies are exposed. Chapter 2 highlighted some common human factors problems which technicians encounter on a frequent basis: issues such as routine violation, poor documentation, poor training, poor communication and inadequate staffing levels. The STAMINA training course deals with many of these issues in a compartmentalised way: routine violation is an ‘Individual’ problem; poor documentation is a ‘Task’ problem; poor training is an ‘Organisation’ problem; poor communication is a ‘Team’ problem. Each of the four modules in the STAMINA training (Individual, Task, Team, and Organisation) takes ownership of certain human factors issues and explains the genesis of the problem, how it presents itself and sometimes makes weak attempts at suggestions to overcome the problem. Also there is the comment that in the ‘Organisation’ module in particular, the persons undergoing the training are not those responsible for the organisational aspects of their operation. Offering organisational solutions to human factors problems to technicians is clearly not an effective means of bringing about change. In this way it is clear that, despite the aims, the STAMINA course doesn’t actually reflect the way in which human factors problems manifest themselves in the real world. As illustrated in Chapter 2 the contradictory pressures and potential conflicts (e.g. safety vs efficiency) which technicians deal with demand a broader awareness of the task and the situation. The STAMINA course uses some active training methods: such as role plays and case studies. But the course stops short of using these methods to transfer any human factors skills. Instead the active training methods are used to illustrate important points about high-profile accidents and incidents. No skills are transferred in the training and trainees do not get to ‘practice’ human factors.

Another criticism relates to the duration of the course. Three days is a comparatively short time period. Human factors, as a discipline, encompasses many facets of aircraft maintenance activity. It is not possible to adequately explore these issues in a real and meaningful way in such a compressed period of time. This criticism does not uniquely apply to the STAMINA course – all human factors training courses operate under similar constraints. The industry, operating as it is, in a turbulent environment, is unwilling to
commit more time to human factors training. Nor is it willing to explore other arrangements where training could be spread out over a longer time period.

A final criticism relates to the knowledge-based approach to training embodied in the STAMINA course. Ultimately, the training course is flawed because it fails to move beyond knowledge and awareness. STAMINA champions an approach to human factors where training should be about more than just making technicians aware of a body of human factors knowledge. But the training itself fails to tackle human factors issues in a way which will bring about changes in behaviour. The training does not, in any way, attempt to develop practical skills which trainees can use to deal with human factors issues in the operational environment. For example, human error is covered in the ‘Task’ module and the focus is on understanding the Reason (1990) model of accident causation and different types of error rather than on how technicians can better perform their work such that errors do not occur. The STAMINA training course predefines categories of knowledge which are assumed to be beneficial to performing maintenance tasks. But, in no way does the training manage to adequately develop practical human factors skills. Because of its focus on knowledge the training fails to adequately represent the complexity of human factors problems as described in Chapter 2 and cannot deliver upon that which it promises.

The criticisms herein levelled at STAMINA apply equally (if not more so) to other maintenance human factors training courses, such as those offered by Galaxy Scientific Corporation and Dupont Safety Resources in America (more details can be found at www.galaxyscientific.com and www.dupont.com/safety) and the CAA and Baines Simmons in the UK (see www.caa.co.uk and www.bainessimmons.com for details). STAMINA is in no way unique in that it fails to target practical human factors skills. Nor does it stand out in terms of its short duration. Indeed there may be an element of interrelatedness between these two criticisms: the development of high-level practical skills is not something easily achieved in a short period of time.
The AITRAM Training Solution

The AITRAM project represented an attempt to integrate human factors and technical training. This pioneering project used a virtual reality environment to attempt to integrate the two types of training and developed a prototype which awaits commercial development. This project used virtual reality technology in an attempt to achieve the integration of human factors and technical training in a practical context in the maintenance human factors field. The project hoped to go some way to redressing the marginalisation of human factors and the perception that it is not part of the core job of a technician. So, the aim was to remove human factors training from the purely theoretical level and to get trainees dealing with actual situations and getting feedback on their human factors, as well as technical, performance. The project aimed to develop a training solution which would be used in practical training to give technicians the chance to practice performing maintenance tasks in a low-jeopardy environment. The idea was that technicians would use the virtual reality system developed in the project to learn how to perform tasks and to gain experience in dealing with the human factors issues associated with each task. As this was a development project a number of tasks were selected at the outset to be used to develop the demonstrator system. The tasks were chosen on the basis of their suitability to be represented in virtual reality.

The task of integrating human factors and technical training presented major challenges. The first was to integrate the human factors elements into the training in a way that was convincing to the trainees, and engaged them in the learning exercise. This can go a long way to helping to change the existing culture of the company from one which is primarily technically oriented to one which is equally skilled at managing the human aspects of the operation. Human factors training, when integrated into practical technical training, offers particular gains in this respect.

The second and most demanding challenge was to define the actions that represent good and bad human factors practice. In order to integrate the human factors and technical training, the project set about decomposing the selected maintenance tasks into their
constituent elements. Inherent in each task was a set of human factors issues, as defined by the human factors experts involved in the project. These, together with human factors issues which are enduring features of the socio-technical system in which maintenance is performed (and as such relate to all maintenance tasks), were then to be represented in the training technology. In this way the human factors training was related to practical problems and in developing the technology to reflect this it was necessary to pre-define and make explicit how best to handle these problems from a human factors perspective. In essence the VR solution demanded that specific human factors-related actions be defined as best practice.

The AITRAM project produced a demonstrator version of the VR training tool but the project did not achieve its goal of integrating human factors and technical issues in this system. Notwithstanding the efforts of the human factors researchers and practitioners, the task of defining human factors best practice proved itself to be beyond the capabilities of the industrial partners and the human factors experts. For the industrial partners it was impossible to come up with agreed statements about best practice human factors actions – what was considered appropriate in one organisation was frowned upon in another. From the human factors perspective the most significant challenge was to simplify and crystallise deeply entrenched human factors issues into specific actions which could be defined in the virtual environment.

This failure of the AITRAM project to integrate best practice human factors principles into technical training relates closely to one of the main findings of Chapter 2: the profoundly social nature of the task of maintaining aircraft. It was this social aspect of performance which presented many of the difficulties experienced in the AITRAM project. Aircraft maintenance tasks can be either individual tasks (i.e. designed to be performed by one technician working alone) or group/team tasks (i.e. designed to be performed by two (or more) technicians working together). Both types of tasks were difficult to represent veridically in the virtual environment technology. In team tasks the very nature of social relationships makes it difficult to define all the parameters of behaviour for each of the actors in the virtual environment. There is a complex story
behind the actions of every person. All action is, in some way, informed by the context. People make sense of this context, develop an intention to behave and, ultimately, act in a social environment. Again, it proved impossible to define and specify these processes in a technologically veridical way. Indeed, social psychologists have been unable to concretise this process and the intention/behaviour debate continues to this day. The representation of communication between technicians in group cases also presented difficulties. Individual tasks proved troublesome for a different reason. Because the trainee will interact with the system on their own there is no outward way of understanding why a person behaved in a certain way. The focus, thus, is on the mind of the individual and this cannot be easily tapped into (save asking questions after the fact). In terms of the technology of the AITRAM training solution this was a less than optimal method of representing individual tasks and was abandoned.

In general terms the AITRAM project failed to achieve its objectives. It seems that while theoretical human factors training can hide behind general principles, the requirement to specify and define explicit actions which correspond to best practice guidelines proved to be beyond the capabilities of both the maintenance industry and the human factors community. Moreover, the profoundly social nature of maintenance activities represented challenges to the developers in terms of veridically representing social action in a technological system.

**Human Factors Training: Summary**

This review of human factors training highlights the way in which human factors has come to be central to the reliable and efficient operation of aircraft maintenance organisations. It is clear that human factors training has made some progress; but there is still some distance to be travelled. It is clear that for human factors training to be effective it must target not just knowledge and awareness, though these are important, but the skills necessary to translate that knowledge into effective and safe performance of maintenance tasks.
The STAMINA training course is the state-of-the-art in terms of human factors training. More than being the most advanced and enlightened approach to human factors, it embraces the principles of change at an organisational level that are so critical to ensuring the success of managing the human factor. This means that STAMINA training can be considered the first step on a long ladder that leads to the reconciliation of organisational goals that were for too long competing: those of safety and efficiency. Unfortunately, it has been shown to be deficient in many important ways and has failed to move beyond a knowledge-based model of human factors training. The AITRAM project has similarly failed to meet its main objective. On this occasion the lack of success is attributed to the inability on the part of both the maintenance industry and the human factors community to agree upon and define best practice human factors principles relating to specific tasks and specific contexts, and to adequately represent the social aspects of maintenance tasks.

This review has served to highlight the potential of human factors and what it is capable of contributing to maintenance organisations. Moreover, regarding human factors training, it has underlined the desire to 'get it right', and drawn attention to the difficulty of making this aspiration a reality.

**Review of Practical Training**

The review of practical training detailed here represents two separate research efforts. Each piece of research involved observations of practical or on-the-job-training which were supplemented by interviews with trainers and trainees. There is one difference between the two pieces of research: one was conducted in maintenance organisations and the other in a manufacturer organisation. The maintenance organisations and the manufacturer that participated in this research are all EASA Part-147 approved training organisations. There are important differences between the companies, however. One maintenance company, Company A is the maintenance division of a large national carrier. Company B, on the other hand, is a large third-party maintenance organisation while Company C is the maintenance division of a medium sized low-cost carrier. The manufacturing company (Company D) is a large manufacturer of commercial aircraft and
has unrivalled training facilities; including sophisticated simulators and mock-ups. It also has a larger budget for training and more resources.

Observations were conducted in Company B and interviews were conducted at Companies A and C. The observations of practical training and interviews conducted at the manufacturer (Company D) are presented later in the chapter in the section entitled ‘Review of manufacturer-provided practical maintenance training’.

**Analysis of on-the-job-training (OJT) – Company B**

**Introduction**

*OJT* is the term used to describe practical training in the aviation maintenance industry. OJT is mandated by the aviation authorities for certification: all technicians must complete practical training if they are to be issued with an aircraft maintenance licence. The regulators acknowledge that classroom training is a necessary, but insufficient, component of training technicians to maintain aircraft. There is recognition that theoretical training based in the classroom needs to be supplemented by training in which the technicians have actual contact with the aircraft. In this way, OJT is intended as dedicated practical training whereby all technicians get some experience in performing maintenance tasks during their professional training.

**Methodology**

This research was conducted in company B. The analysis of OJT consisted of semi-structured observations of the practical training sessions. For the observations the researcher assumed the role of participant-observer. The researcher sat in on training as a trainee but it was understood by all concerned that the researcher was merely observing and gaining some operational experience of the training. The researcher endeavoured to be as unobtrusive as possible.
Four sessions of Airbus A330 OJT were observed. Each session was led by a different instructor and comprised different trainees. This meant that any analysis of the delivery of training or of the trainees would not reflect the particularities of just one trainer or one group of trainees. While no claims can be made about the representativeness of this sample it does provide an overview of the state of OJT at one maintenance organisation. The observation focussed on the following four areas (See Appendix B for the observation schedule):

1. Trainee Participation:
   - Motivation
   - Participation/Interest

2. Training Methods:
   - Delivery methods

3. Training Message:
   - Role of procedures
   - Role of technician
   - Dealing with bottlenecks
   - HF knowledge/practice
   - Focus: system/procedures/task

4. Organisational Issues:
   - Access to aircraft
   - Assessment of OJT

Results On-the-Job-Training (OJT)

The results from the four observational studies are presented in aggregate form. Four sessions of A330 OJT were observed at a ‘third-party’ maintenance organisation. Each one of four training groups comprised 4 or 5 trainees and one trainer. The duration of the active training sessions ranged from approximately 1.5 to 4.5 hours (excluding time taken to secure a session on an aircraft).

The observations gathered data on the following topics:

- Trainee Participation
- Training Methods
- Training Message
- Organisational issues
Trainee Participation

Motivation

All trainees showed signs of being highly motivated. Trainees continually asked questions of the trainers. Most of these questions seemed to be directed at points of clarification. The researcher felt that there was considerable evidence of a genuine motivation to learn. It was clear that trainees were driven to learn by more that just regulatory requirements – they seemed to want to further their knowledge and understanding of the aircraft’s systems.

This motivation to learn manifested itself on one occasion when the trainer was called to attend to a matter outside of the flight deck where the training session was being held. The trainees worked as a team and continued to complete the task they were working on prior to the trainer’s departure. When the trainer returned the trainees had completed the task. While the sessions were characterised by light-hearted banter there was a palpable sense of motivation and commitment to the training tasks in all groups observed.

Participation and Interest

In all groups observed participation was very high. All trainees were interacting with the trainer. The trainees were very anxious to impress the trainer with their level of knowledge when asked a question. The trainers had no difficulty in engaging the trainees. The level of participation and interest may be connected to the sense of camaraderie which had developed in the groups (each group having spent 8 weeks of training together). Trainees would help each other when it was needed. If, when asked a question by the trainer, a trainee didn’t know the answer, one of the fellow trainees would immediately offer help or the correct answer. These cohesive group dynamics greatly impacted upon the training atmosphere.
Training Methods

Delivery Methods
The methods of training delivery were constant across all groups. Within each training session various techniques were used, such as demonstration, the use of scenarios and description. OJT is mandated as part of training to ensure technicians have practical experience in task performance in a training environment: i.e. a low-jeopardy situation without commercial pressure. In the OJT sessions observed, there was very little evidence that this occurs in reality. Time constraints meant that it was not possible for all trainees in the group to have practice on performing the task. Often only one technician would get practice at doing the task; the other technicians would have to watch their fellow trainee doing the task. More often than not, however, none of the trainees were able to practice the task. Demonstration was the most frequently used training method: the trainer would merely run-through the task with the trainees. There was never sufficient time for all trainees to gain operational practice of performing the task; at best one technician out of the group would practice while the others looked on.

Training Message

Role of Procedures
The explicit training message in all sessions observed emphasised that procedures are the rules governing task performance and should be followed. Trainers seemed to stress that procedures needed to be followed. However, for the most part, little reasoning was given as to why procedures are important and why they should be followed: they just should.
Token statements such as “procedures must be followed” are often seen to be perfunctory and empty and more erudite trainees may well seek to find any implicit training messages that can be used to qualify those explicit training messages of which they are unsure.

In the training sessions observed the researcher perceived that there was an implicit training message being transmitted. It was implied in one particular training session that sometimes it is necessary to work around procedures in order to get the job done. This training message acknowledges some of the operational realities of aircraft maintenance.
as described in Chapter 2: procedures can sometimes slow you down and there are ways to do the job without following procedures to the letter.

What is the trainee to make of these opposing training messages? There is an explicit training message promoting the importance of procedure following (yet providing no basis for this recommendation), and an implicit training message acknowledging that procedures cannot always be followed if the job is to get done. One message seems to say that the end justifies the means whereas the other message champions the means over the end. In these instances the trainers were undermining the importance of procedures and presenting a mixed training message to trainees. Trainees are thus left to come to their own conclusions as to the appropriateness of procedure following.

This duplicity inherent in the message relating to the role of procedures was echoed in another trainer’s attitude to the training schedule. When asked by a trainee if they needed to cover a certain task specified in the training schedule the trainer replied “sure you saw the other boys do one last week. Yeah? Ok...” The trainer seemed more concerned about moving quickly through the training than covering the required curriculum. This is further evidence of the ambivalence about the role of procedures: avoiding delays is sometimes more important than following the procedures in every respect.

Role of the Technician
The role of the technician was not a topic that was dealt with in any great detail, if at all, in the sessions observed. On occasions where technicians’ duties and responsibilities were mentioned, the explicit message was that the role of the technician is to follow the procedures, and to work through the task methodically and quickly. Implicit in the training was the notion that the role of the technician may involve some juggling of tasks. The training seemed to say that some amount of flexibility is required when dealing with, for example, tight schedules. The role of the technician was addressed on some occasions, for example when the trainer would discuss possible scenarios in which the trainees might find themselves once they were back at work. In these instances the trainer
emphasised that the technician's role is to do the job – the most important thing is getting the task done.

**Dealing with Bottlenecks**

The issue of dealing with bottlenecks (problems with organisational systems which stop progress) was not given any consideration whatsoever in the training observed. None of the groups touched upon the topic, perhaps due to limited time.

**Human Factors Knowledge / Practice**

Mention was made of HF practice in two sessions; though it related more to occupational safety than 'true' human factors.

The first instance related to testing the air-conditioning system test. This task involved some IT system-based tasks on the flight deck which leads to a gush of air being emitted from an outlet valve under the belly of the aircraft (which could cause injury to any persons standing nearby). In order to prevent this, a watch person was sent out to ensure that no bystanders were near the outlet valve. A similar situation occurred with another group when they were performing a thrust reverse check on the engine. They ensured nobody else was near the engines as panels would move and could cause injury.

With the third group the issue of human factors was never mentioned. No practical examples of human factors were evident either as all the tasks were flight deck based and did not involve any tests affecting the exterior of the aircraft. It was not possible to assess how human factors issues are regarded in these instances.

**Focus of Training**

This category was used to describe any particular emphasis of a training session: was there a prioritisation of procedures, or getting the job done on time, for example? Across all three groups observed there was no coherent focus of the training. In one group the focus on procedures was quite explicit. In another group the focus was most definitely on
the task and the skills necessary to perform it. Given this situation it is difficult to come to a considered judgement as to the focus of the OJT as a whole.

**Organisational issues**

**Access to aircraft**

The company are a ‘third-party’ maintenance company and do not own their own aircraft. The training takes place on customer aircraft. This causes considerable difficulties in terms of scheduling OJT on ‘live’ aircraft. No components can be disassembled as part of OJT on live customer aircraft as they are scheduled to be back in service soon afterwards. Third-party maintenance organisations are grateful that their customers allow them to conduct OJT on their aircraft and are wary of doing anything that will jeopardise the relationship they share with their benevolent customers. Securing a session on an aircraft can take as long as 2 hours and this cannot be planned-for in advance. The trainees follow the trainer around as he tries to gain access to an aircraft. When conducting the observations for this study many hours were spent waiting for maintenance work to finish so that the training sessions could begin: then began the competition for access between the various training groups. Much of the time allocated for training was spent waiting for an aircraft to come in and then queuing to get access.

**Assessment of OJT**

The curriculum for OJT comprises a long list of procedures/tasks that have to be covered. Each trainee has a training record for which they take responsibility. This record consists of a table listing all the tasks trained in OJT together with two columns: one for the trainee to sign, and another for the trainer to countersign stating that the task or procedure has been trained. Trainees wait until all their training (covering an 8-10 week period) is over to approach their trainers for their countersignature on the training record. The signatures on the training record of both the trainee and trainer signify that the task has been trained and that the performance on the task was adequate.
Trainers cannot possibly be expected to remember the names of all trainees who have received training on a particular task. The assessment system is therefore trust-based: the trainers trust that the trainees will present accurate and valid training records for countersigning. There is no real system in place to ascertain if the trainee has in fact been trained on a particular task. The trainer must simply trust his trainees. This assessment system is not very rigorous, largely as a function of the length of training and operational constraints. A laissez-faire approach to the management of the assessment, such as this, opens the system up to potential abuse.

A further problem relates to the fact that many of the procedures have only been described, some have been demonstrated, and those that are practised, are often only practised by one or two members of the training group; the others having to make do with observing a colleague practice the task.

**Interviews**

Interviews were conducted with trainees and one trainer to supplement the observational data. The interviews took place in two different maintenance organisations: Companies A and C.

**Methodology**

Interviews were conducted at Companies A and C. A total of 3 groups of trainees were interviewed, two groups in Company A, and one group in Company C. In Company A the interviews were held in small groups (four or five respondents in each group). In Company C two trainees were interviewed along with one experienced trainer. All trainees were just completing their Level 2 OJT. Semi-structured interviews were used to elicit information on the following topics (trainers and trainees were asked questions about the same topics) (See Appendix C for full schedule):

- Perceptions of the objectives of OJT
- Difficulties encountered by trainees and/or trainers
English was not a first language for any of the respondents. They did, of course, understand technical English but there were some difficulties in conversing fluently about the research topics. In these instances the contact person in the company (who had fluent English) interpreted. This meant that the transcripts were quite disjointed and required much editing for sense to be made of the dialogue. The results presented below represent the important and illuminating aspects of the interview results and are presented in aggregate.

Results

Trainee Interviews (Companies A and C)

Course Duration and Content
The technicians expressed genuine concern that the OJT courses are too short and that this limits the amount of knowledge they can take from the course. It is apparent that they want to understand the system not just on a superficial level, but on a more detailed level: "the course is OK but there is not enough time to go deep into the system" is how one trainee put it. Trainees were concerned that they would be inadequately trained when they finished Level 2 training: they were not confident that the course imparted the knowledge and expertise which they felt was necessary to do the job. Questions were raised about both the training manuals and the level of time dedicated to certain chapters in the training curriculum. They felt that there was not enough theory in Chapter 49 for them to come to a comprehensive level of understanding of the contents. Concern was also expressed that an inadequate amount of time was allocated to Chapters 70-80 as they were completed in one day.

Opportunity to Practice
The technicians feel that there is insufficient opportunity to practice tasks. They are, at best, given only one opportunity to practice a task in training before they are called upon
to perform the task in a real-life work environment. Trainees proposed a more favourable scenario whereby students start a course, cover all the relevant theory, and then embark on a dedicated period of practice after you have studied the chapter. They feel that eight weeks theory and only two weeks practical training does not adequately prepare them for the demands of the task.

The composition of the training groups interviewed was quite varied. Some of the trainees were experienced aircraft technicians gaining another licence, others had experience in other mechanical/technical fields such as car mechanics and were training for the first time on aircraft, while others still were complete novices to the mechanical/technical field of work. The novices in the groups felt most strongly about the insufficient provision of time to practice what was learned in theoretical training. They felt that it is particularly important for those who are new to the technical and mechanical work environment to have ample opportunity to practice and familiarise themselves with the performance of such tasks.

'Proving Competence to Yourself'
Trainees pointed to the fact that they perceived that their working-style may change to some extent following training. They felt that, being aware of the inadequate opportunity to practice, they may approach a task a little more cautiously than if they were confident of their ability to perform the task. They believed that the only way to achieve this self-assurance is to have proven to yourself, through practice, that you can actually perform the task to the required level: one technician put it thus; "you have to prove your competence to yourself". They add that though most trainers are sufficiently approachable for trainees to request additional help, it did not alter the situation regarding the lack of practice.

Planning of Training Sessions
The final issue that trainees mentioned as being problematic relates to planning of training sessions. In Company C all OJT is scheduled during nightshift as it is not possible to train on live aircraft during the day: line maintenance is a dynamic and fast-
paced type of aircraft maintenance. The company cannot afford to schedule training on aircraft on the line when the aircraft are being turned-around between scheduled flights – the turnaround time is an important determinant of an airline’s efficiency and profitability. Performing OJT on line maintenance would add another variable to the already chaotic nature of line maintenance: thus OJT is scheduled for nightshift when the pressures are reduced. Unfortunately the night-time training can be difficult for those trainees that are unused to working at night.

**Trainer Interview (Company C)**

**Commercial Pressure**

The experienced trainer stated that Company C operates under very high commercial pressures and as a consequence believes in dispensing with training in an efficient manner such that the trainees can be returned to active service as quickly as possible.

**Training Group Composition**

He expressed concern that single OJT courses could be attended by various grades of trainees: in one group for example there might be three trainees - one with 15 years maintenance experience, another with 5 years maintenance experience, and the third one has no experience of maintenance. This presented difficulties for trainers in this company as they felt they could not lead the group as a cohesive whole: material could be too advanced for some trainees and too basic for others.

**Conclusions – OJT Analysis**

**Limitations of the analysis:**

There are some limitations inherent in this analysis. Chief amongst them is the fact that the observations were conducted in one maintenance organisation, while the interviews were conducted in another two maintenance organisations. Ideally, the observations and interviews would have been conducted in all three organisations. Unfortunately all three organisations were unable to provide limitless access to training sessions. Time constraints meant that it was not possible for any one organisation to facilitate both
observations and interviews: as a consequence only one data collection method could be employed in each organisation. Language issues played a role in deciding which method to use in which organisation. English was used as the teaching language in OJT in only one organisation. This organisation was, thus chosen for the observations as the researchers, as English speakers, would have been unable to observe OJT in any of the other two organisations.

Notwithstanding these limitations the data seem to suggest that the three organisations share some common ground, suggesting that the findings of this analysis of OJT reflect the reality of the industry inhabited by these three organisations.

Summary

The observations of OJT call attention to some serious shortcomings of practical training in aircraft maintenance. Access to aircraft, provision of opportunities for practice, double standards in relation to procedures, and assessment of training all proved to be areas in which the training seems to be failing the trainees.

One of the main difficulties relates to gaining access to aircraft. The training sessions are arranged primarily around the availability of aircraft. If a trainer cannot locate an aircraft that is not already in use by another training group (a common occurrence) the training session cannot go ahead. Once access has been gained, the problems continue. There is constant competition for time on the aircraft and trainers feel under pressure to move through the training as quickly as possible. In addition, there is constant interruption from staff involved in cleaning and servicing the aircraft.

Another problem relates to the lack of opportunity for trainees to practice a task. Trainees often had to make do with being shown how to perform task, but for the most part only one trainee was guided through the task. As such, the trainee performing the task was informed what actions to execute in order to complete the task while the other trainees watched. In these instances the other trainees are not given the opportunity to practice
given the time constraints. The provision of practice is something which is very important in any training program, and this situation is altogether unsatisfactory.

The double standard in relation to the role of procedures was something which was experienced in all groups. There was an explicit training message stating that procedures are to be followed in all circumstances, but when trainers used scenarios to explain how to perform a task in a real operational setting there emerged an implicit training message that said that there are times when you have got to get the job done and procedures get in the way. The blame for duplicitous training messages does not lie solely with trainers: trainers operate in a wider organisational setting which creates situations where the use of procedures is optional and where there may be quicker and better ways of doing the task. In all groups there was an implied notion of timely task performance being something which the organisation rewarded.

The observations have also raised serious concerns over the method of assessment that is in use. As it stands trainees sign their training record as having completed a whole series of tasks, and the trainers then countersign the document. This means that although the trainee has often merely seen a task completed, he is now certified to perform the task. In addition, the method of individual assessment is trust-based: there is no sure way of ascertaining if a trainee has in fact been trained on a particular task; the trainer must have faith in what he is told by the trainees. The assessment system is clearly open to abuse because of its informality.

Review of manufacturer-provided practical maintenance training

Introduction

Manufacturer-provided maintenance training is a critical operational input for airlines buying new aircraft. The training provided by a manufacturer provides key technical information which is required by maintenance technicians to perform their job. For an airline which is in receipt of a new generation aircraft this type of training is the first
stage in the training process and airlines (or indeed independent maintenance companies) require dedicated maintenance training from the manufacturer if they are to buy, and operate, a new generation aircraft. Maintenance organisations which do not possess the capabilities to provide type training in-house also rely on the training provided by manufacturers. The type-training courses provided by the manufacturer are on three levels for each aircraft type – General Familiarisation, Level 2 and Level 3. In addition they provide human factors training. The courses comprise both a theoretical and a practical component. The theoretical lessons are supported by Computer-Based Training modules, while the practical training is carried out on Training Devices (the 3D and 2D simulators) and on real aircraft.

Practical training sessions are conducted when all theoretical aspects of the topic have been covered in class. There are two different types of simulators: a 2D simulator and a 3D simulator. The 3D simulator is a large physical mock-up of an aircraft flight-deck. It reproduces the flight-deck to a high degree of fidelity and has operational avionic displays and instruments. The focus is on instrumentation: display configuration and troubleshooting tasks (there are no removal and installation tasks in this training). The 2D simulator represents a simplified version of the 3D, but maintains an information layout consistent with a flight-deck environment. It does not reproduce all switches and dials and doesn’t have operational electronic displays but does have working flight controls.

Given the differing functionalities of the two training simulators it is unsurprising that they are used for different training purposes. 2D simulator sessions focus mainly on troubleshooting. Trainees are provided with a PFR (post-flight-report) by the instructor. Trainees have to use the troubleshooting manual to perform the training task and they have to input into the simulator the task number of each task completed to progress on to the next part of the procedure. This is how assessment is organised: trainees cannot conclude the session until they have correctly input each task number. Once they have successfully input the correct task number they are deemed to have passed the training session. 3D training sessions on the other hand focus more on scheduled maintenance tasks that appear in the AMM rather than troubleshooting tasks: tasks such as operational
checks on components removed and installed. The 3D simulator has a higher level of physical fidelity than the 2D simulator and the operating systems can be set by the trainer with system faults for the trainees to detect and rectify.

This research was conducted in the training department of an aircraft manufacturing company. The maintenance training department consists of about 75 staff – 40 instructors (who provide the training), 20 courseware developers, 10 curriculum instructors (who develop the curricula, etc. for the course) and 5 members of senior management.

This study provides an insight into another aspect of maintenance training. Having a deeper understanding of the nature of this type of training affords a more systemic view of the state of practical training in maintenance: a life-cycle view from the manufacturer through to the maintenance organisation. Notwithstanding the differences between manufacturers and maintainers in terms of their training budgets, facilities and content of training, the results of the observations and the interview highlight some important issues which mirror those found in training provided by maintenance organisations.

**Methodology**

Three sessions of practical training were observed in Company D (see Appendix B for the observation schedule). All sessions observed (over a 3 day period) comprised the same group of trainees. It was not possible to gain access to more than one group of trainees as management wanted the research to be as unobtrusive as possible. That said, each training session was led by a different trainer (each of whom specialised in one aspect of training: 2-D or 3-D simulator).

The observation data were supplemented by a semi-structured interview with the Senior Training Manager (see Appendix C for interview schedule). The manufacturer was not willing to allow the researcher to have any access to the trainees for interviews. The company was adamant that the customers should not be approached during the active research tasks.
Results

Observations of simulator training

The observations of training gathered data on the same topics as were addressed in the observations of OJT reported earlier in the chapter. They are as follows:

1. Trainee Participation
2. Training Methods
3. Training Message
4. Organisational issues

Trainee Participation

Trainees tend to be more enthusiastic about the simulator sessions than the classroom training. Oftentimes during the observations there were light-hearted arguments amongst the technicians about who gets to perform which role. Trainees are brought through a number of checks by the instructor and all trainees seem very involved in the session – they seem to relish the opportunity to practice the tasks that they have learned in theoretical training.

Training Methods

The trainer assigns the task to be carried out and the trainees negotiate the allocation of the three roles used in training sessions. One trainee ‘reads’ the task procedure; another ‘does’ the task; the final trainee ‘monitors’ the performance. Then, in turn, they rotate their roles for successive tasks. The training activities are observed by the instructor while the trainees are working on the task. When the task is completed they are debriefed and the instructor will sign-off the task as proof of good performance during the training activity. An obvious limitation of the training centres upon the fact that not everybody gets the opportunity to practice the task; one does, one reads the instructions and one just watches. This means that only one in every three trainees has performed any particular task as part of the training. While the training does take place in a simulator (which has
more fidelity than a classroom) the trainees were being moved on through tasks very quickly by the trainers and were being quizzed by the trainers. Quizzing trainees on topics assesses their knowledge of the topic but it does not give them a working understanding of how to do the task: this is what practical training should be providing and is failing to do.

Training Message

The training process is very proceduralised and the content is extremely standardised. Trainers are not free to add much to what appears in the extensive training manuals. The explicit training message seems to suggest that procedures should be followed while the implicit training message focuses on the task and getting the job done. The constraints under which the trainers operate means that the training was quite hurried. The focus was on moving quickly through the manual and getting the job-done: this amounts to a task-focused training message.

Organisational Issues

The simulator training sessions are conducted with 3 trainees per simulator. The training is delivered under time and resource constraints: trainers have gruelling schedules and there is high demand for the training simulators. As such, during the training sessions three trainees are in the simulator at a time – this is termed the “one does, one reads, one monitors” methodology in the organisation. The training may have been more effective had there been more opportunities for trainees to practice the tasks followed by a practical assessment.

The problems with assessment noted in the observations of practical training in maintenance organisations are mirrored here. In some ways the assessment system for practical training that exists in the manufacturer could be viewed as a pro-forma exercise – it seems to be just a formality; the trainer merely signs that the trainee has completed the simulator session. A training log is kept and signed by the trainer (and the trainee) to verify that the trainee has understood the task. In practice, it would of course be
impossible to actually assess the trainees in a fair way: if the trainee is lucky s/he will have performed the task, but more often than not their experience of the task amounts to nothing more than having observed the task or maybe having it described to him/her.

**Interviews**

One interview was held with the Senior Training Manager. He provided a general perspective on the organisational aspects affecting the training of maintenance technicians. Specifically, he talked about the training department and its organisation, the training system design and specifications, the systematic issues affecting the training design, and the delivery processes.

**Interview results**

The Senior Training Manager pointed to many organisational and bureaucratic problems that hinder the effective delivery of maintenance training to the customers. He asserts that in order to improve the quality and effectiveness of their training, the organisation should seek answers to the following questions from their customers (primarily the airlines):

(i) “What do your technicians need to know about this aircraft?
(ii) “What is it you actually do: what are your best practice guidelines for task performance?”

His two major concerns are as follows:

**The organisational weaknesses**

Much dissatisfaction was expressed with the organisation of the training department. The issuing of approvals (see below) and the lack of a standard training system across all courses are evidence, he believes, of an ineffective organisation. The training department runs eight different type training courses (for different types of aircraft). As it stands each course is different in terms of training materials and design: therefore requiring different training approaches. Furthermore he asserts that the systems in place in the organisation at present reflect western cultures but are not very suitable for other cultures; Russia and
China in particular (both are important considering the growth in civil aviation in these countries).

The 'approval committee'

One of the main challenges he cites is in relation to the updating of the training course contents and materials. Before a modification is made to any aspect of the course contents or materials it has to be approved by an internal 'approvals committee'. The overly-bureaucratic nature of day-to-day business in the organisation means that it can take up to six months to get the approval to proceed with the modification. In the meantime training continues and trainers become frustrated that they have to continue using materials or teaching content that they know to be out of date/obsolete.

Conclusions

It would seem that the deficiencies noted in the observations conducted are echoed in the concerns of the senior training manager. The system, such that it is, is deficient but is working and there is no impetus to change it. While everyone is aware of the deficiencies of the training that the company offers there is an industry accepted belief that it is better than the training offered by this manufacturer's main competitor. A number of trainers spoke, unofficially, about customer satisfaction surveys. These trainers intimated that customers continually report satisfaction levels of 80% and don't cite very many limitations of the training when questioned. The trainers attribute these high scores to the low expectations trainees have when they begin the training – most trainees know what to expect and consequently don't express dissatisfaction.

The biggest failing in the whole training program is that the most valuable opportunities to deliver effective training (i.e. training with the potential for an optimised transfer of training from the learning environment to the working environment) are squandered. The simulators, as training devices, have an advantage over real aircraft when conducting practical training: mistakes can be easily put right in low-jeopardy situations such as these and there are no safety consequences associated with letting inexperienced trainees
explore the system. Simulators present ideal opportunities for trainees to practice tasks and deepen their understanding of how things work through trial and error. Time constraints in training scheduling at this manufacturer meant that these opportunities for good operational practice were squandered. Only one in three trainees will have practical experience in doing a particular task; and even that practice was constrained by time.

**Summary – Review of Practical Training**

Practical training is an important component of the training provided to a trainee seeking his/her type certification. This training can be provided by maintenance organisations or by the manufacturer directly (provided they are Part-147 compliant). The review of practical training detailed herein illustrates that while there is much to differentiate the training departments of a maintenance organisation and a manufacturer there is little that separates them in terms of the difficulties they face and the shortcomings in the training they provide. Table 8 (over) compares some of the findings from the research in both settings: the maintenance organisation and the manufacturer organisation.
Table 8: Overview of main findings of reviews of practical training in maintenance and manufacturer organisations

<table>
<thead>
<tr>
<th>Observations</th>
<th>Maintenance organisation Practical Training</th>
<th>Manufacturer Practical Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trainee Participation</td>
<td>• All trainees were motivated and actively participated in the practical training sessions.</td>
<td>• Trainees interested and enjoy opportunity to put things into practice</td>
</tr>
<tr>
<td>Training Methods</td>
<td>• Demonstration was the most frequently used method</td>
<td>• Standard format: one ‘reads’, one ‘does’, one ‘monitors’.</td>
</tr>
<tr>
<td></td>
<td>• Insufficient opportunities for trainees to practice</td>
<td>• Insufficient opportunity to practice</td>
</tr>
<tr>
<td>Training Message</td>
<td>• Mixed messages regarding the role of procedures: they should be followed but sometimes getting the job done is more important</td>
<td>• Important thing is getting the job done</td>
</tr>
<tr>
<td>Org. issues</td>
<td>• Gaining access to aircraft a huge difficulty</td>
<td>• Access to training simulators (constant competition)</td>
</tr>
<tr>
<td></td>
<td>• Inadequate assessment methods</td>
<td>• Ineffective, pro-forma assessment</td>
</tr>
<tr>
<td>Interviews</td>
<td>Trainees:</td>
<td>Senior training manager:</td>
</tr>
<tr>
<td></td>
<td>• Not prepared for real life operations</td>
<td>• Internal bureaucracy leads to delays in updating courses and a lack of standardisation across all courses trained at the organisation</td>
</tr>
<tr>
<td></td>
<td>• No opportunity to practice</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Concern about doing new task for first time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trainer pressurised to deliver training quickly</td>
<td></td>
</tr>
</tbody>
</table>
Table 8 shows us that the observations of practical training (or OJT) in both settings found that trainees are highly motivated during this type of training. They actively participate in the training sessions and seem to relish the opportunity to put things into practice. Demonstration was the most frequently used training method and this speaks to the operational constraints which render time-consuming practice on tasks an impossibility. It is interesting that this is an issue for both the maintenance organisation and the manufacturer. Undoubtedly the manufacturer has more resources at its disposal: the training school is large in comparison with that of most maintenance organisations and the presence of simulators precludes any problems gaining access to aircraft. This should put the manufacturer at an advantage when compared with a third-party maintenance organisation. The observations show that this advantage has not been translated into improved training: both sets of observations show that there is competition for training resources and it is not possible to allow all trainees to practice all tasks: at best a task can be practised by one in three trainees.

In terms of the training message the observations at the maintenance organisation showed that there were incompatibilities between the explicit and implicit training messages. This is particularly true when speaking of the role of procedures. ‘Procedures are there to be followed’, the trainer would say in general terms. But when the trainer shifted his attentions to scenarios that may present themselves in real life the message about procedures was less certain: in this context procedures are something that could get in the way of doing the job. As is often the case in maintenance the reluctance of the organisation to tackle the issues means that the trainees are sent mixed messages and have to come to their own judgements. Similar mixed messages were reflected in training relating to the role of the technician: explicitly the technician’s role relates to getting the job done. Implicit in the training was the belief that there needs to be some flexibility in performing maintenance in difficult operating circumstances.

From an organisational perspective the single biggest issue relates to gaining access to aircraft and/or training simulators. The manufacturers, together with the maintenance organisations, faced problems with competition for the training simulators and aircraft
and overburdened trainers. The assessment systems in both maintenance and manufacturer organisations are not very rigorous. The pro-forma exercise that is the assessment of training can be largely attributable to operational constraints: there is not enough time for the trainers to allow each trainee to practice the task and properly assess whether a trainee can perform the task or not.

The interviews with trainees and trainers in the maintenance domain and the senior training manager in the manufacturing company confirm the findings of the observational studies. Trainees felt that the courses were not preparing them for the job that needed to be done. There was not enough time to really take in the detail. They also feel that there are insufficient opportunities for practice. One technician made the point that "you have to prove your competence to yourself". He believes that the lack of practice will mean that when they return to work they will be cautious when first performing one of the newly-trained tasks. The fact that they were not able to assure themselves of their ability in training means that there is some anxiety about performing the task for the first time in a real operational setting.

The trainer seems to experience some anxiety also: he reports a feeling of commercial pressure to deliver training as quickly as possible. This is compounded by the mixed composition of training groups which provides difficulties for trainers in terms of pitching a course at a group with varied background knowledge and expertise. Trainers seem to be well aware of the deficiencies of the training (they are technical personnel after all) but are powerless to improve the situation. The statements made by the senior training manager in the maintenance organisation paint a bleak picture: even those at senior management levels feel powerless in a system that seems to thwart every attempt made to improve operations.

On-the-job training is mandated by the aviation authorities. Classroom training alone is considered inadequate to prepare technicians for the demands of the job of maintaining aircraft – there is a perceived need for them to have actual contact with the aircraft.
However, the constraints under which this training is carried out raise serious questions about the effectiveness of such training. Three major constraints are as follows:

1. **Time**
   The quantity of tasks to be covered in a training course means that there is minimal time for each task. There is not enough time for each trainee to practice, or be assessed on, a task.

2. **Availability of aircraft and simulators**
   This issue is more acute for some companies than others, and imposes different constraints:
   - Third-party maintenance organisations which do not have their own aircraft, depend on the goodwill of their clients to allow access to their aircraft for training.
   - Training can be very inefficient in its time use. Time is often wasted waiting for aircraft to become available, getting to the location, and negotiating access with the technicians doing the transit checks, and with flight crew, cabin crew and ground crew.
   - When access is gained, tight time constraints prevail.
   - This process can be stressful for both the trainer and trainees and detracts from the training.
   - Some organisations carry out training at night which reduces the time pressure on the training, but introduces difficulties of fatigue, and adjustment to night-work.

3. **Opportunity for practice**
   Many of the tasks cannot be carried out in training because of the risk of making the aircraft unserviceable, creating a delay, or the monetary cost of carrying out the task. The first time that the technicians will carry out a large majority of tasks will be in a real operational situation when they may be under time or other pressure.
These three points illustrate the difficulties faced by organisations as they attempt to provide practical training to their technicians. The training that takes place under these constraints relies heavily on description or, at best, demonstration of procedures rather than opportunities for each of the trainees to practice. In fact the training is not really on-the-job training. It is more like an extended field trip, which provides an overview of the tasks and procedures that the technicians may encounter. The real on-the-job training starts when they start working on the aircraft for real. It is then that they have to draw together their theoretical knowledge with the documented procedures for that task. The first time they do this will be time-consuming and inefficient, and prone to ‘expertise errors’. In order for this training system to work, the company is dependent on the willingness, experience, expertise and competence of their technicians to compensate for the limitation of the training. Technicians have often been characterised as having a “can do” attitude – willing to have a go at a job, even if the time constraints are severe, the appropriate tools are not available, or, in this case, their training has not been thorough. In these situations it is the professionalism of the technicians which ensures they succeed in getting the job done safely, efficiently and reliably.

The focus of the OJT is on the specific tasks and maintenance manual procedures. The role of procedures and the role of the technician in relation to those procedures are not deliberately addressed. The implicit, and occasionally explicit, messages in the training relating to the non-technical aspects of the work tend to reflect the normal operational practice of the company. With most companies this entails an ambiguity with regard to the role of procedures – technicians are expected to follow the official procedures, but it is recognised that sometimes there are more efficient and better ways to do the job. They widely use their judgement to fulfil the intent of the procedure, rather than following it to the letter; this is the genesis of unofficial procedures. Unofficial documentation (e.g. a “black book”) is common. Similarly human factors are not deliberately addressed in the training. Competence in managing the demands of the task, communication and working as a team, dealing with fatigue, low lighting, etc., is assumed to be part of the trainees existing expertise, and is, in this sense, beyond the remit of OJT.
The training weaknesses are reflected in the weaknesses in assessment. Trainees are assessed as having been trained in a task, even though they may only have observed it being done, or had it described to them. Section 2.2 of Appendix III to EASA Part-66 states that: “The practical training element must consist of the performance of representative maintenance tasks and their assessment, in order to meet the following objectives:

(a) Ensure safe performance of maintenance, inspections and routine work according to the maintenance manual and other relevant instructions and tasks as appropriate for the type of aircraft, for example, troubleshooting, repairs, adjustments, replacements, rigging and functional checks such as engine run, etc., if required.
(b) Correctly use all technical literature and documentation for the aircraft
(c) Correctly use specialist/special tooling and test equipment, perform removal and replacement of components and modules unique to type, including any on-wing maintenance activity”.

The training did not consist of the performance of maintenance tasks and their assessment: not in any real or meaningful way. There were efforts at training the performance of maintenance tasks and subsequently assessing this performance. There, however, one word in this requirement which may alter our interpretation of the training sessions observed. That word is “representative”. Training should cover the performance and assessment of representative maintenance. In this case it could well be argued that the regulations are ambiguous and create a situation which supports the informal aspects of training documented in this chapter.
CHAPTER SUMMARY

This chapter provides an overview of training practice and informs about the extent to which human factors training addresses real human factor issues. In conducting the review of training the issue of human factors competence presented itself on a number of occasions. Before summarising these issues it is necessary to conclude the review of practical training by reconsidering the findings of the observations and interviews.

All that has been reviewed in this chapter points to a number of problems with practical training which apply equally to maintenance organisations and manufacturers. Problems with access to aircraft and simulators are common right across the industry, as is a willingness on the part of senior management to dispense with the training as quickly as possible in an effort to get technicians back on the shop floor. More than this, the observations and interviews have highlighted how it is that practical training fails to embrace human factors and misuses what amounts to an ideal opportunity to illustrate the complex interrelatedness of human factors and technical issues. Many training practitioners believe that practical training can be an ideal conduit for the introduction of human factors best practice. The observations showed that the role of procedures is still something which is being grappled with; even in practical training. Chapter 2 highlighted instances which suggested the existence of a fundamental ambivalence about the role of procedures amongst maintenance technicians. The indication from the observations of practical training is that this ambivalence extends to the training community. While the trainer espoused the principles of safety and airworthiness there is an implicit message that this does not always mean that procedures have to be followed precisely: sometimes it is enough to follow the intent of the procedure. It seems that the reluctance of the organisation to tackle the issues means that the trainees are sent mixed messages through the trainers and have to come to their own judgements. Clearly there are important deficiencies in the way in which human factors are portrayed in practical training. But what about the ways in which human factors are represented in dedicated human factors training?
The chapter starts out by reviewing the history of human factors regulation in aviation maintenance. The regulators have been making slow, but determined efforts to instantiate human factors training as part of an integrated safety management system. In Europe, EASA Part-66 was the first attempt to regulate the 'human factor'. This requirement specified all the modules which must be successfully completed in order to receive a certifying aircraft maintenance licence. Human factors was included as one of these modules. Human factors knowledge was categorised according to 9 different topics, each of which must be examined, and passed (assessment is by examination of knowledge), before a trainee is issued with a licence. The Part-66 regulations also set out the knowledge levels to be demonstrated by applicants in the assessments. Later, with the publication of Part-145, organisations had to provide human factors training for all types of personnel involved in maintenance operations for the first time.

Part-145 succeeded in pushing the 'human factors' agenda by forcing organisations to embrace human factors and seamlessly integrate it into the fabric of the operation. The legacy of the earlier Part-66 requirement is more difficult to evaluate. It is true that Part-66 served to instantly validate the cause of human factors and marked a turning point in the treatment of human factors issues. But the details of the Part-66 requirement present some difficulties which remain unresolved. Primarily, the problem relates to the way in which the regulators have conceived of human factors. The regulator views human factors competence in terms of a pre-defined list of knowledge areas which, when understood by trainees, will see them through the types of situations which were detailed in Chapter 2. This focus on pre-defined categories of knowledge betrays a rationalist conception of competence.

The limitations of the STAMINA training course are related to a similar problem. Inherent in each of these is a model of human factors competence that also relies on rationalistic perspective. Working from first principles they have set out to define in advance all the pieces of information which a technician must know in order to be human factors competent. By using reason to understand the role of a technician this approach prioritises a priori knowledge. This means that there is no recourse to the real world
experience of the technician. So, by relying on theoretical knowledge of a technician’s job the regulations and the STAMINA project have set out, implicitly, their models of human factors competence. It is clear that these models are deficient. They are overly simplistic and cannot account for realities of maintenance operations as reflected in Chapter 2.

STAMINA and AITRAM, in particular, tell us some important things about human factors competence. The development of the STAMINA training course pre-dates the ‘thick description’ of aircraft maintenance proffered in Chapter 2. In this way the course was developed, not from an empirical understanding of the activity, but rather a rationalist approach focusing on what, theoretically, is required to do the task. It is clear from the review of the STAMINA course that featured earlier in the chapter that the course is, in many ways, aspirational. It seeks to achieve many things but fails to achieve them. The course is based on ‘knowing about’ human factors rather than ‘doing’ human factors. The course has a naïve rationalistic view of human factors and it is clear that this approach cannot account for the richness and complexity of the social life of maintaining aircraft as depicted in Chapter 2. The AITRAM project was equally ambitious but failed to instantiate human factors in the training system. That which had been assumed at the outset to be a demanding, yet feasible, task proved, ultimately, to be impossible. The rationalistic model of human factors intimated that human factors issues could be represented in the training system but it quickly became clear that human factors are not just issues that can be packed up neatly. In the end, it seems that it was a simple explanation of a complex phenomenon.

The STAMINA training course and the AITRAM training methodology were developed by respected human factors experts from many different European countries. These human factors experts have vast experience in human factors in safety critical systems and the aviation maintenance in particular. The consortia which worked on the research projects which developed the training were comprised of some of the most innovative and successful researchers in human factors. What is interesting is that these two leading research projects have been unable to develop a successful and coherent notion of human
factors competence. The relative failure of these training courses poses the core theoretical and practical basis of the thesis. It seems that the difficulties of STAMINA and AITRAM seem to stem from the model of human factors (and human factors competence) which informs the research and its failure to account for critical aspects of aircraft maintenance activities. Clearly rationalistic approaches to competence and human factors which prioritise knowledge have failed. What is needed is a new approach.

The question of where this new approach might come from can be examined if we explore the issues of practical training in order to facilitate an alternative understanding of competence. It is clear that the system controlling practical training is not operating as a formal system. Rather it operates as an informal system: the normal everyday functioning of this system is reliant on many informal actions. Assessment seems to be quite an informal process. So too is the issue of gaining practice during the training sessions, and the issue of following procedures. But these informal practices are not to be attributed to the actions of individuals. The informality which characterises much of the training system manifests itself as a response to the contradictions and inadequacies of the formal system.

Trainers have expressed their concerns about the training process in the interviews. They operate in a pressurised commercial environment and have developed informal ways of reconciling the demands of their job with the context in which they find themselves. The assessment of training is one example of where the informal work practices show the inadequacies of the system. Informally, the assessment process relies on a trusting relationship between the trainer and the trainee. While this is less than ideal, the informal assessment better reflects the way in which the training is conducted and it could be argued that this unofficial action is what is keeping the system going. The trainer is in close contact with trainees for an extended period of time and exercises his professional judgement when deciding on an assessment outcome. While this is less than ideal due to its subjectivity it is apparent that these informal assessment procedures are not detracting from the value of the training – the lack of adequate opportunities to practice tasks is what seems to be most undermining the training.
It is clear that the deficiencies noted in the observations relate to trainers’ attempts to develop an informal method for overcoming the problems with the training system – and the provision of practice is one area of training which seems to be bearing the burden of the operational considerations. Time constraints mean that it is not possible for all technicians to gain practical experience of a task during training, even if the formal system expects and demands this. Instead the informal practices revolve around one trainee practicing a task while the others assist and/or observe. In this context the trainer and the trainees have developed informal methods to compensate for the deficiencies of the training system. But, in contrast to the informal methods of assessing competence (which appear to be working) it is clear that the informal methods of dealing with the problems of OJT and practical training are resulting in a less than optimal outcome. To paraphrase the comment of one trainee: there is no opportunity for technicians to ‘prove competence’ to themselves by practicing a particular task.

There are two main problems with practical training. Firstly, there is an industry-wide failure to provide adequate practical experience (a problem compounded by the informal practices of those struggling to operate in this context). Secondly, there is a conflict between the procedures and the real way of doing tasks in real life. In a sense, these two issues relate to different facets of the same predicament: the difficulty of representing the practical aspects of training. Training (whether it be technical, practical, or human factors) should be primarily concerned with the practice of how things are done: it is after all an intervention designed to result in improved performance of work tasks. The reviews of human factors and practical training in this chapter underlines that this goal is not being achieved in any meaningful way. The training system has some serious deficiencies and trainers and trainees do their best to fill in the gaps in informal ways. While these informal attempts to improve the system might work in some cases (assessment, perhaps) they are blatantly not working in others (the issue of practical experience).

What we do see in these informal attempts to cope with and improve the system is an incredible amount of social formation. It is almost as if the social relations of the
workplace are being recreated in the informal aspects of the training system. Training is generally acknowledged to be an intervention aimed at changing aspects of the ‘individual’. Boreham (2004) and Eraut (1998) argue that training policies (typified by the British system of National Vocational Qualifications (NVQs)) are traditionally very individualistic. This is certainly true of aircraft maintenance. But it seems that the informal training system de-emphasises the individual in favour of the group. Take the example of assessment. Trainers have insufficient time to deal with formal assessments of individuals so they use an assessment approach which is based on trust and which represents a group-assessment approach: the score attributed to any one technician is a function of the performance of the group rather than any one individual. Similarly, the inability to provide practical experience for all technicians forced technicians to work closely together as a team. The ambiguity about procedures also betrays an implicit message which says that the decision of whether to follow procedures or not should be informed by the actions of others working in a similar situation. In this way it almost seems to suggest that the informal aspects of training (both good and bad) are enforcing a social definition on training systems which are, at heart, intentionally and fundamentally individualistic. In this way the informal mechanisms being used by trainers and trainees to overcome problems in the training system are actually serving to increase the psychological and organisational fidelity of the training sessions by imposing a social emphasis on the training. This is interesting in light of the findings of Chapter 2, where aircraft maintenance activities were found to be profoundly social.

Earlier, we have seen how it is that the lofty ambitions of STAMINA failed to be realised. In this sense there seems to be little which sets it apart from other human factors training courses. It is clear that, on the whole, human factor training needs to encompass more practical skills training. These skills should, in turn, be embedded in organisational practice such that trainees can return to work with skills which can tackle the human factors issues which are a feature of that organisation. Knowledge of complex problems and phenomena offer little to trainees – it might heighten awareness but it does not equip technicians to better handle practical manifestations of these issues when they are back in the operational environment. The ultimate aim of any training course should, therefore,
be to impact upon behaviour at work such that new work practices can be developed to deal with problem situations. Unfortunately, this aim will never be achieved by human factors or practical training in aircraft maintenance as they currently exist. This chapter has shown how difficult it is to represent practical competence in training.

These twin issues relating to practical competence and the profoundly social nature of maintenance tasks are neglected elements of the competence debate. The problems with training, by and large, arise from the lack of an adequate definition of competence. For this reason the next chapter (Chapter 4) deals with this issue.
CHAPTER 4
COMPETENCE AND HUMAN FACTORS

Introduction

Chapters 2 and 3 prefigured some of the discussion and detailed exploration of competence and human factors which is offered in this chapter. The review of human factors and practical training which featured in the previous chapter presented interesting findings which relate to these issues of competence and human factors. Specifically, it contrasted the aspirations of human factors training to impart practical skills to trainees with the failure to move beyond a focus on knowledge as the key to improving performance at work. The STAMINA course provided a stark example of the inadequacies of one particular training course and the way in which the failure to target human factors skills can be attributed to the inadequacies of the model of human factors competence that was informing the training course. In essence, the STAMINA course failed to construct a training approach which could account for the complexity associated with the performance of maintenance tasks as demonstrated by the findings of Chapter 2. The rationalistic focus on knowledge inherent in the STAMINA approach meant that other critical aspects of competence and performance were sidelined: in particular, the social aspects of maintenance activities.

The ethnography presented in Chapter 2 illustrated that the task of maintaining aircraft is an unpredictable, variable and complex activity where the multifaceted interdependencies within the organisation serve to further complicate matters. Unexpected problems can present themselves when a check is being conducted necessitating new parts, additional personnel and more time to complete the task. The maintenance personnel rely on their parts store to source the appropriate parts in a timely way. Parts and materials supply, however, operate in a wider context where they are reliant on manufacturers and couriers to get the parts in time. Oftentimes the complex interdependencies precipitate delays and difficulties which must be effectively
dealt with by the workers at the sharp end of the operation. Clearly managing the unpredictability and variety of aircraft maintenance activities in an effective way is a challenging and an adaptive task which involves juggling technical and non-technical demands to achieve a safe and efficient outcome. Rationalist approaches to human factors competence use reason to understand the role of a technician. These approaches therefore prioritise a priori knowledge and are based on a conception of aircraft maintenance activity which does not acknowledge the complexity of the environment in which technicians perform their work. Ultimately, rationalist approaches to competence are limited by the type of explanation which they offer.

Without acknowledging the social and environmental contexts in which work is performed it is impossible to come up with an adequate description or explanation of competence. Chapter 2 showed that maintenance tasks take place in a social space and the actions of the members of that social space have a direct, or indirect, impact upon the performance of any given task. The observations of training in Chapter 3 provide further evidence of the profoundly social nature of maintenance operations. In compensating for the deficiencies of the formal training process trainers and technicians developed informal ways of operating within the system. Interestingly, most of these informal practices served to re-create the social relations of the work environment in the training context. These findings, obviously, have some important implications for the development and specification of any model of competence which attempts to describe maintenance operations.

The observations of maintenance tasks demonstrated the requirement for flexible workers: ones who can rapidly respond to ever-changing circumstances and who can work together to make sure the job is done safely. It is only by being adaptable, industrious and flexible that technicians can get the job done. Indeed, this belief is reflected in the human resource management literature: workers who succeed are those who are knowledgeable, flexible and able to produce quality results (Meyer & Rowan, 1983; Keenoy & Anthony, 1992). Many now believe that as market forces become less predictable and the business markets more volatile the ability to develop committed,
flexible and effective employees is what guarantees survival (Bramming & Larsen 2000, Prahalad & Hamel, 1990; Hamel & Prahalad, 1994). Bramming and Larsen (2000) further suggest that developing competence will allow workers to achieve positive outcomes in a turbulent working environment. It seems, therefore, that the drive for competence is motivated by recognition of the centrality of flexibility to the safe and efficient functioning of the aircraft maintenance system.

Salaman (1995) contends that demand for specialised skills increases when organisations expand (tasks become more complex and specialised) or when they downsize (staff assume new roles). The net effect of this is that decision making becomes less centralised with more decisions being made at lower levels of the organisational hierarchy, leading to a consequent change in emphasis on leadership and processing skills. There is, then, a requirement for managers and those who are not managers but who are involved in decision making, to have a holistic view of the organisation. Given the economic difficulties in which many aircraft maintenance organisations find themselves it is feasible that Salaman's thesis has some resonance for the aviation maintenance sector as it stands right now. The changes being experienced by the aviation sector make it vulnerable to this less-centralised decision making. The ethnography from Chapter 2 and the training case studies from Chapter 3 certainly provide anecdotal evidence for this contention. Both studies provide evidence that those personnel at the sharp end of the operation are becoming increasingly involved in making decisions and judgement calls which have far-reaching ramifications. The ethnography and the review of training show that the decisions being forced on shop floor workers typically relate to non-technical or human factors issues. The critical issue, thus, relates to the competence of the workers in dealing with human factors issues.

Clearly the question of competence presents a particular challenge for the industry. There is much confusion about what constitutes competence and a review of the literature shows that there is currently a revolution of theoretical conceptions of competence. For the aircraft maintenance industry to adequately tackle the issue of
competence there must be agreement about what ‘human factors competence’ actually is and how it can be fostered and controlled. Eraut (1998), in frustration at the conceptual confusion surrounding competence, has proposed best practice principles for a treatment of the issue of competence. He suggests that it is most productive to engage with the issue by being clear about why the term competence is being used, stating the nature of the problem being addressed and by making explicit the theoretical assumptions upon which the discussion is based. This chapter attempts to satisfy Eraut’s (1998) requirements for a valuable discussion by presenting a review of the history of conceptions of competence, an interrogation of theories of competence and by attempting to propose a way forward which will aid the industry in effectively dealing with the competence issue.

**Competence: A Brief History**

The issue of competence at work has been of interest to managers and management theorists alike for almost a century. Taylor (1911), in explaining his studies of time and motion, proposed that the issue of worker competence was uppermost in the minds of all people at that point in time. In his book, *The Principles of Scientific Management* he argues:

"The search for better, for more competent men, from the presidents of our great companies down to our household servants, was never more vigorous than it is now. And more than ever before is the demand for competence men in excess of supply. What we are all looking for, however, is the ready-made, competence man; the man whom someone else has trained. It is only when we fully realise that our duty, as well as our opportunity, lies in systematically co-operating to train and to make this competence man, instead of hunting for a man whom someone else has trained, that we shall be on the road to national efficiency" (Taylor, 1911, p.6).
Working as an engineer, Taylor’s enquiring mind found much useful intellectual fodder in observing the different ways people accomplish work in factories. More specifically, he was interested in the nature of the differences between the least and most competent workers and the way they went about their work. His background as an engineer predisposed him to certain interpretations, and his now famous Time and Motion studies took as their starting point the scientific principles of the rationalistic tradition. He believed that the competence of these workers could be identified through the application of scientific laws and formulae. These competence descriptions could then be used by management to develop systematic training to achieve improvements in competence along with the consequent improvement in organisational effectiveness. His work began to focus the attention on the worker and make the issue of competence an important consideration for managers.

Taylor’s work on the time and motion studies were firmly based in the scientific principles of the rationalistic tradition and it would seem that his approach has set the agenda for competence research and practice for quite some time. Until relatively recently rationalistic approaches to competence have been dominant; and only in the last few years have other approaches, particularly the interpretative approaches, been afforded attention. Sandberg (2000) proposes Taylor as the founding father of the search for competent workers. While this may or may not be the case it is more interesting to note that little seems to have changed since his time: his insights date back almost 100 years but still hold much sway today. Competence has come to be something which managers pursue wholeheartedly. Through popular initiatives such as competency based training and performance appraisal the term ‘competence’ has entered into everyday parlance. Before reviewing the main theoretical accounts of competence it is incumbent upon us to consider some of the problems associated with the meaning of the term ‘competence’.
The Meaning of ‘Competence’

Bramming and Larsen (2000) invoke the linguistic philosophy of Wittgenstein in order to explore the meaning of the term ‘competence’. Wittgenstein (1953) writes about the meaning and semantics of words as used in everyday language in his book *Philosophical Investigations*. In it he uses a quote from St. Augustine’s *Confessions*, which echoes views stated in *Tractatus Logico-Philosophicus*:

"Every word has a meaning. This meaning is correlated with the word. It is the object for which the word stands" (§ 1).

While Wittgenstein frequently asserts that meaning and use are one and the same thing – from the use of a word you can understand its meaning – he disputes the universality of this statement from St. Augustine’s Confessions on the grounds that it holds true for only one particular aspect of language: nouns. Pointing at a table and saying ‘table’ is one way of teaching a child the meaning of the word ‘table’ – a process termed ‘ostensive learning’ by Wittgenstein. But what to do for words that are not nouns? Wittgenstein cites the words “this” and “there” as examples of this limitation. Pointing and saying the word (ostensive learning) will not teach the meaning of these words. “This” and “there” are relative terms and have no fixed meaning: their meaning is found in their use in a situation.

Wittgenstein supplements and improves upon St. Augustine’s theory of meaning by expanding it to one where the meaning of a word can be understood from its use in a situation: use in context. Wittgenstein states that “the meaning of a word is its use in the language" (1953, §1). The use of a word in a particular situation is what gives it meaning, he believes. Both context and use are important to understand the meaning of what is being said: there can be no one meaning for a word that is used in different circumstances. Thus, meaning relates to a word in a complex way, involving use and context in equal measure.
Wittgenstein's theory of meaning presents problems for researchers interested in theories of competence: if he is right in his contention it means that competence will mean different things to different people in different contexts. A cursory glance at dictionary definitions of competence would seem to suggest that this is indeed the case. The Oxford English dictionary defines competence as “the quality of being competent” and provides two definitions of competent:

- “Competent – having the necessary skill or knowledge to do something successfully”
- “Competent – satisfactory, though not outstanding: she spoke quite competent French” (italics in original)

Further evidence of the problems with finding an adequate and agreed definition of competence are to be found in Bramming and Larsen's (2000) paper. They derive three different meanings of the term competence from its most common forms of usage in everyday language and consider the concept of competence a ‘moving target’:

1. Competence as possessing the right to do something conferred by status or education (medical doctor)
   - I am competent to make this decision
2. Competence as the minimum expected standard for satisfactory performance
   - He is a competent baker
3. Competence as evidence of superior performance
   - She is a competent employee, in every way

(Bramming & Larsen, 2000; pp. 68-9)

In each of the three instances (directly above) competence is taken to mean something slightly different. In examples 2 and 3 there is very little distinction between the words used, though the meanings are different: example 2 refers to someone who is ‘good’ at what he does while example 3 refers to someone who is superior at what she does. The same words were used but the meaning was different because of the context; a fact
explained earlier by Wittgenstein (1953). Clearly the term ‘competence’ is not always used in a consistent manner or in reference to the same thing: to different people, in different contexts, ‘competence’ means different things. This is certainly true of everyday use of the term competence but as we will see in the next section an element of divergence characterises its use in theoretical considerations as well.

Rationalistic Approaches to Competence

Taylor’s work on the time and motion studies was firmly based in the scientific principles of the rationalistic tradition and it seems this approach has set the agenda for competence research and practice for quite some time. Job analysis is a contemporary technique used for the identification and development of competence and owes much to Taylor’s writings and his view of competence as an attribute-based phenomenon (Armstrong, 1991; Ferris et al., 1990; Gael, 1988).

The central tenet of rationalistic approaches is their conception of competence as an attribute-based phenomenon – a belief that competence relates to specific attributes, often expressed as knowledge and skills (Sandberg, 2000). Human competence, thus, is a set of attributes (knowledge, skills, abilities, etc.) which are used by workers to perform their work tasks. These attributes are held by rationalistic approaches to be context-independent in that the skill is seen as meaning something in itself and has an existence independent of context. The rationalistic conception of competence is closest to the meaning of ‘competence’ as used in everyday parlance.

The rationalistic research tradition is based on dualist ontology and objectivist epistemology (Sandberg, 2000). The rationalistic approaches to competence are influenced by dualist ontology in that the worker and the work are treated as two separate entities, and objectivist epistemology in that the work activities are conceived of as independent of the workers who accomplish them (insofar as there exists an objective, knowable work beyond the worker). Thus, advocates of rationalistic approaches see human competence as being composed of two independent entities: the
attributes possessed by the worker and the work activities (Sandberg, 2000; Bramming & Larsen, 2000). Put simply, rationalistic conceptions of competence define it in terms of an individual’s knowledge, skills, abilities, and attitudes and the activities (such as planning, managing and communicating) which are used to accomplish the work. This dual focus on the worker and the work has led to a number of different, but aligned, approaches to competence within the rationalistic tradition.


1. Worker-oriented
This approach holds that competence is associated with the attributes possessed by workers – the knowledge, skills and abilities/attitudes (KSAs) along with personal traits that are required to perform the work well. Sandberg writes that evidence of the enduring popularity of this approach can be found in the use of the term ‘competencies’. This term implies that what is of primary interest are worker attributes. This rationalist approach holds that competencies are context-independent.

2. Work-oriented
Work-oriented approaches are concerned with the actual work in attempting to identify and describe competence. Using the work activities required to accomplish tasks as the point of departure this approach then transforms these activities into personal attributes.

3. Multimethod-oriented
Multimethod approaches are slightly more comprehensive in their perspective. The approach of Veres, Locklear, and Sims (1990) typifies an example of a
multimethod-oriented method of identifying competence. In this case worker attributes were expressed in the form of KSAs which corresponded to work activities. These activities and the KSA profile were then compared to the actual work.

Definitions of competence proffered by Nordhaug (1993) and Boyatzis (1982) typify the rationalistic conception of competence. Nordhaug defines competence as “knowledge, skills and abilities that can be used to perform the work” (1993, p.69: translation by Bramming and Larsen). Boyatzis, in his study of managerial competence, defined competence as “an underlying characteristic of a person causally connected to effective or excellent performance in a job” (1982, p.21, emphasis in original). According to Bramming and Larsen the characteristic to which Boyatzis refers is a motive, skill, trait, self-image or body of knowledge and “comes with the person” (2000, p.70). They also state that the similarities between the approaches of Nordhaug and Boyatzis extend beyond the dual focus on individual and organisation. Both Nordhaug and Boyatzis suppose that the individual has some KSAs which are released in the work situation. The definitions of competence offered by the two authors hold that the worker’s KSAs are linked to the demands of the job. This is what Bramming and Larsen have termed the degree of ‘fit’ between the KSAs of the worker and the demands of the job. This is the underlying principle of job analysis and underlines the fact that Taylor’s influence extends to the current day.

**Rationalistic approaches: Implications for Aircraft Maintenance**

Taking a rationalistic approach to the specification of the competence required to perform maintenance tasks would result in a list of attributes (knowledge, skills, abilities) which workers must have in order to perform the work and/or a list of the work activities that are required to accomplish the task. Ultimately, all three rationalistic approaches to competence (Worker-oriented, Work-oriented, and Multi-method-oriented) have as their outcome a specification of KSAs which workers need to
to perform the work. While the point of departure for each approach is slightly different the destination is the same.

Listed below is a set of hypothetical KSAs that may be necessary to perform aircraft maintenance tasks. The method through which the KSAs were arrived upon was based on the worker-oriented approach. Based on the author's general experience of maintenance tasks a list of attributes was compiled which gives an indication of what is required to maintain aircraft. When considered as a whole these KSAs comprise a competence specification for maintenance technicians, which appears in Table 9 (over).

This competence specification serves an illustrative purpose: it allows one to explore exactly what a rationalistic approach can contribute to our understanding of competence as it relates to aircraft maintenance activities. The list of KSAs above reflects all those underlying characteristics which 'come with a person' and help them to perform maintenance tasks. The rationalistic approach to competence locates the abilities and skills within the individual. Thus, the logical conclusion of this theory is that once the individual has acquired these KSAs (through whatever means) their competence is assured irrespective of the situation.
Table 9: A hypothetical rationalistic competence specification for maintenance technicians

<table>
<thead>
<tr>
<th>Hypothetical Worker-oriented Competence Specification for Maintenance Technicians</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Knowledge of complex systems</td>
</tr>
<tr>
<td>• Knowledge of diagrammatic representations</td>
</tr>
<tr>
<td>• Knowledge and ability to plan and prepare all tools, parts, manuals needed</td>
</tr>
<tr>
<td>• Knowledge of complex and complicated maintenance manuals</td>
</tr>
<tr>
<td>• Knowledge of performance limitations</td>
</tr>
<tr>
<td>• Concentration skills for long and complex procedures</td>
</tr>
<tr>
<td>• Communication skills</td>
</tr>
<tr>
<td>• Leadership skills</td>
</tr>
<tr>
<td>• Multi-tasking skills</td>
</tr>
<tr>
<td>• Problem solving skills</td>
</tr>
<tr>
<td>• Team member skills</td>
</tr>
<tr>
<td>• Planning and preparation skills</td>
</tr>
<tr>
<td>• Ability to prioritise tasks</td>
</tr>
<tr>
<td>• Ability to deal with change</td>
</tr>
<tr>
<td>• Ability to anticipate problems</td>
</tr>
<tr>
<td>• Ability to recognise fatigue</td>
</tr>
<tr>
<td>• Ability to recognise stress</td>
</tr>
<tr>
<td>• Ability to maintain situation awareness</td>
</tr>
<tr>
<td>• Ability to learn by experience</td>
</tr>
<tr>
<td>• Ability to communicate and work in different teams</td>
</tr>
<tr>
<td>• Willingness to accommodate others</td>
</tr>
<tr>
<td>• Assertiveness</td>
</tr>
</tbody>
</table>

Accident data has shown that sometimes highly skilled and able workers are implicated in accidents and incidents (e.g. the Daventry accident). It is not just inexperienced technicians who make mistakes; there is evidence that the ‘best’ technicians can also make mistakes (Reason & Hobbs, 2003). This poses an important question: how is it that those individuals who possess the ‘required’ skills and abilities can perform in ways which would suggest that they are not competent?

Bramming and Larsen (2000) offer an explanation. They argue that the skills and the situation or task are very closely related. Most dictionaries define competence in terms of ‘having the ability to do something’. Bramming and Larsen argue that a definition
such as this is relative in that the *something* that you do is understood as the thing against which the skills and abilities are measured. So when attempting to assess whether someone is competent or not one needs to be mindful of the task or situation as well as the skills. They illustrate their point with the following example: consider setting someone the task of performing an appendectomy. Not a surgeon, but a professor of law. This person would be very unlikely to be "ascribed" (p.69) competence – even if this person is ascribed competence in the legal profession. Thus the skills and the situation or task are very closely related. Conceptualising competence only in terms of the skills which a person ‘has’ can lead to a myopic view of the issue. Clearly rationalistic approaches have their limitations. These are detailed in the following section.

**Criticism of Rationalistic Approaches to Competence**

Detractors of rationalistic approaches to competence find reason for criticism on the following grounds:

1. Inability to account for organisational factors
2. Focus on internal theoretical knowledge
3. Operationalisation of competence
4. Epistemological problems

Inability to account for organisational factors

Boyatzis’ definition of competence as “an *underlying characteristic* of a person causally connected to effective or excellent performance in a job” (1982, p.21, emphasis in original) epitomises rationalistic conceptions of competence at work. While Boyatzis claims to account for the needs of the organisation in his approach to managerial competence it is clear that, for him, the individual is in possession of the competence. The organisation is paid some lip-service but the conception of
competence does not account for the role of the organisation in developing or maintaining competence at work. Boyatzis’ research on managerial competence has been denounced by Bramming and Larsen (2000) and Jacobs (1989) on the grounds that it doesn’t take account of the specific context in which the manager performs. Many researchers are keen to point out that “work is not done in a vacuum” (Bramming & Larsen, 2000; p.78): it is done within an organisation which has its own culture, procedures, norms, technology, systems and a social make-up which is unique (Blackler, 1993; Blackler, Crump, & McDonald, 1997).

This thinking is in some ways nothing new. White, in the late 1950’s was writing about people interacting with their surroundings; all the time gaining knowledge as a kind of continuous competence building process, as it were (White, 1959). White (1959) defines competence as “an organism’s capacity to interact effectively with its environment” (p. 297). This definition emphasises the environment and context: an idea that, in some ways, was ahead of its time. It is only now that the dominant rationalistic approaches to competence are being challenged in a real way on the grounds of their individualistic approach which does not account for the role of the organisation in building and supporting competence at work.

Bramming and Larsen conclude from the literature that much of our understanding of competence centres on acquiring theoretical knowledge, while the general understanding of competence (as inferred from the usage of the term) is focused on performing a job – more to do with practical knowledge. This situation, they believe highlights a deficiency in understanding and we need to know more of how the organisational context determines competent actions (practice).

**Focus on internal theoretical knowledge**

Boyatzis (1982) and Nordhaug (1983), in their typically rationalistic conceptions of competence, highlighted the centrality of theoretical knowledge to the issue of competence, where theoretical knowledge can be taken to mean un-contextualised
knowledge about something. Bramming and Larsen argue for an expansion of this conception of competence arguing that competence is about both theoretical knowledge (know-what) and practical knowledge (know-how). Hutchins (1995) holds similar views:

"The emphasis on finding and describing "knowledge structures" that are somewhere 'inside' the individual encourages us to overlook the fact that human cognition is always situated in a complex sociocultural world and cannot be unaffected by it" (p. xiii).

Operationalisation of competence

The rationalistic definition of competence (as an attribute (or set of attributes)) has begun to attract criticism in recent years. Attewell (1990) and Norris (1991) argue that operationalising attributes in the rationalistic tradition results in abstract descriptions of competence which are simplified and narrow in focus. Rationalistic models of competence pre-define what competence actually is and these pre-conceived notions of competence serve to reinforce the researcher's own model of competence rather than allowing the researcher to capture critical insights into competence. Jacobs (1989), for example, casts doubt on Boyatzis' generic model of competence in management. His research, utilising Boyatzis' method, supports two conclusions: firstly, that the competencies required for management activities vary according to the activity, and secondly, that it is not possible to specify a set of generic management competencies that reflect the reality of management. Worker-oriented approaches to competence such as this produce descriptions of competence which are too general and abstract to be workable, although they may have high face-validity (a criticism which applies to the hypothesised competence specification for maintenance technicians detailed in Table 9 earlier in the chapter).

The two main rationalistic approaches to competence (of the three outlined by Sandberg - Worker-oriented, Work-oriented, and Multimethod-oriented) have been criticised for similar reasons. Focusing on the attributes of the worker (the worker-
oriented approach) is seen as being too general for practical use in that competence may emerge irrespective of the individual’s ‘competence’ profile, and that a competent person may simply fail for motivational or situational reasons, to use their KSAs. The work-oriented approach garners criticism for ignoring the fact that job attitudes and work characteristics are subjectively perceived (Sandberg, 1994). Employees doing the same job may perceive it in different ways (see the engine optimization study later in the chapter). Thinking of a task or job in this individualistic way, Bramming and Larsen (2000) argue, leads to the conclusion that each person’s way of doing their job is competent in their own mind. Each person then assumes that all other competent workers perform their work in the same way – even if the work is perceived by these people in fundamentally different ways. Sandberg’s (1994) study in Volvo shows that categories developed to describe work activities cannot provide insight into the competence involved in performing work when their focus is from the outside-looking in.

Epistemological problems

While dissatisfaction began to surface in the early 1990’s, deeper and more fundamental criticism of the epistemological basis for rationalistic approaches to competence has surfaced of late. The failure of rationalistic approaches to adequately capture and describe competence in a practical and valid way (see Boyatzis’ (1982) definition of competence) has led to a move towards interpretative explanations of competence.

The interpretative approach to competence supports the interpretation of work and competence by those who experience it: the workers. Exponents of this approach argue that ignoring the workers’ lived experience of work does not facilitate the development of a full understanding of competence at work. Sandberg (2000) and Bramming and Larsen (2000) are eminent and respected researchers in the field of competence and are also vociferous opponents of rationalistic approaches to competence. Their work on competence focuses on new definitions and understandings of competence and is detailed in the following section.
New Conceptions of Competence

Sandberg and Bramming and Larsen are critical of rationalistic approaches to competence. Their reasons for rejecting the rationalistic approaches differ slightly so it is not surprising that their suggestions for alternative conceptions and approaches to competence are different also.

Sandberg (1994, 2000, 2001) is critical of rationalistic approaches to competence because of the dualistic ontology and objectivistic epistemology which underlie these rationalistic approaches. The contention that competence can be reduced to a list of attributes (or KSAs) which the worker has, and which are related to work, is, for him, untenable. He proposes phenomenography as an interpretative approach to competence which allows researchers to access the workers' lived experience of work. This overcomes the problems of an understanding based on a dualistic ontology and objectivistic epistemology and facilitates an alternative understanding of competence. He argues that competence is less about lists of worker attributes and more about the way in which workers view, understand and conceive of their work. For Sandberg the basic meaning structure of workers' conceptions of their work is the basis, and foundation of human competence at work. That is to say that the workers knowledge, skills and other attributes which they use in doing their work are based upon their understanding of the work that they do. Sandberg's views on competence have important implications for competence development and assessment and will be discussed later.

While Sandberg and Bramming and Larsen are agreed on a shift in focus away from KSAs, Bramming and Larsen (2000) suggest a focus on the 'doing of the job' rather than workers conceptions of their job, as suggested by Sandberg. Bramming and Larsen's support for a change of direction in competence research stems from their criticisms and perceived inadequacies of the approach championed hitherto by theorists and practitioners from the rationalistic tradition. They argue that for management, given their perception of employee competence as the means to compete and survive in
a turbulent market, competence development is a strategic issue. The problem is that
the theoretical assumptions under which most management thinking operates have
been proven inadequate by researchers (Argyris, 1986, 1990; Bradley, 1991; Morgan,
1986).

Most organisational research has what Bramming and Larsen (2000) have termed an
‘essence’-based approach to competence – that is, analysis and development of
competence are based on the idea that an organisation or individual possesses
competence and thus can be measured as the core competence of the organisation –
with the end results of this measurement process being related to individualised and
organisational skills and abilities. Given the dominance of this ‘essence based’
approach in the literature it is not surprising that most organisations believe that
competence development is simply about filling the gap between skills demanded and
the skills possessed (Townley, 1994). For Bramming and Larsen (2000) this situation is
problematic. They argue that for these approaches to competence development to be
effective the environment would need to be stable, simple and easily controlled. In a
turbulent, competitive and reactive market the initial situation would have changed by
the time the skills and abilities gap had been specified, translated into training or
education, and rolled out in the organisation, thereby rendering the whole process
redundant and ineffective. Researchers such as Argyris (1986; 1990), Bradley (1991),
and Morgan (1986) have highlighted many problems with these outdated approaches to
competence. Bramming and Larsen summarise them as relating to three main issues: (i)
transferability – what is learnt in one context is not transferred to another; (ii) learning
and teaching – there is no certainty that what is taught is actually learnt; and (iii)
rationality – there is no ‘one best way’. These problems, they argue, set the agenda for
a re-conceptualisation of competence and a shift in focus, away from skills and
abilities, towards the ‘doing of the job’. They bemoan the lack of research focusing on
behaviour and argue for a more dynamic and relativistic concept of competence – one
where competent behaviour would be understood as being able to compromise between
the opposing interests in the organisation, being able to cope and perform (with or
without the skills or qualifications) in a way deemed competent by the ‘opinion
The emphasis, thus, is on a contextualised approach which accounts for the context in which the job is done and the way in which people form opinions about what is competent or not.

The separate contributions of Sandberg and Bramming and Larsen which facilitate moves towards new understandings of competence will be detailed firstly. Then a new conception of competence for the aircraft maintenance industry will be proposed based on these contributions.


‘Objective’ dualist approaches which describe competence as two things – a list of attributes which the worker possesses, and a separate list of the work activities – are rejected by Sandberg. Instead he argues that a more fruitful investigation of what constitutes human competence at work is to be achieved through a phenomenological approach which views the person and the world which they occupy as being inextricably linked as a result of that person’s lived experience of the world (Berger & Luckman, 1966; Husserl, 1970; Schultz, 1945, 1953). In a phenomenological approach to competence the work and worker are not treated separately and competence relates to the meaning which the work has for the worker in his/her experience of it (Dall’Alba and Sandberg, 1996).

The interpretative tradition has been used as a framework to guide a number of studies of competence. Dreyfus and Dreyfus (1986) as a result of their research on competence acquisition among pilots, drivers and chess players concluded that the attributes used to perform work were related to the situation irrespective of the level of competence acquisition. The knowledge and skills which workers acquired through training and practice were context-dependent. This finding is borne out by similar research in nursing (Benner, 1984) and other areas. Sandberg argues that this demonstrates a tacit dimension to competence (Polanyi, 1967). It is, he says, impossible to properly understand work from the outside looking in. Only when the perspective of the person
in the work situation is harnessed is it possible to come to an understanding of what competence is. He points to research by Brown and Duguid (1991) to lend support to this argument. They assert “that the ways people actually work usually differ fundamentally from the ways organizations describe that work in manuals, training programs, organisational charts and job descriptions” (p.40). This is certainly true of aircraft maintenance: one only has to remember back to the fourth task observation from the ethnography in Chapter 2 to find confirmation for this. Fielding (1988) and Schon (1983) provide empirical support for this claim.

The burden of evidence from the interpretative studies highlights the erroneous nature of rationalistic approaches to competence. Competence is not determined by a set of context-independent attributes possessed by workers, instead there is a context-dependent aspect to competence. The attributes, it seems are context-dependent as a result of the workers’ experience of their work. While the interpretative studies do cast some light on the issue they don’t explain why some people perform better than others. Sandberg (1994) conducted a study in an attempt to answer this very question. The primary aim of the study was to overcome the limitations identified within the rationalistic approaches by elaborating an alternative approach to competence which is not based on dualist ontology and objectivist epistemology. An interpretative approach, phenomenography, was put forward as an alternative to the rationalistic approaches and the extent to which this approach can render competence more apprehensible for managers was examined empirically through a competence analysis of a group of 20 engine optimisers at Volvo Car Company in Sweden.

In the study, interviews were used to generate descriptions of the optimisers' ways of conceiving the optimisation work. Three distinctive forms of competence in engine optimisation were identified: I) Competence as accurately optimising separate qualities of the engine according to requirements, II) Competence as accurately optimising interacting qualities of the engine in the right order, and III) Competence as optimising interacting qualities of the engine through a practical sense of the engine. The findings from this study demonstrate that human competence at work is not primarily

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constituted by a list of attributes which are possessed by the worker and externally related to the work, as stipulated by the dominant rationalistic approaches within human resource management. Instead, the workers' knowledge, skills and other attributes used in accomplishing the work are preceded by and based upon their conceptions of the work. Within each of the three categories of understanding there were specific structures of attributes which help the optimisers in their work. The results showed that the ways in which the work was understood by the workers informs those attributes that are related to various levels of competence in the task of engine optimising. Thus the more advanced the understanding of the nature of the work the more developed and advanced are the attributes that assist in performing the work.

Sandberg is saying that the KSAs required to perform the work are informed by the worker’s understanding of that work. The more sophisticated the understanding the more varied, numerous and complex are the skills and abilities that are required of workers to perform to the standard reflected in their understanding of the job. Thus understanding of the work is the most important determinant of competent performance. Sandberg’s findings point to a situation where different ways of understanding work interact to form a hierarchy of competence: the more advanced the understanding of the work the more competent the worker. The experience of workers performing the work informs their understanding of that work and it is this understanding of the work which prescribes the attributes necessary and organises them into competence when performing the work.

Sandberg (2000) finds support for his theory by exploring the question of why some people perform better than others. Rationalistic approaches would have us believe that an individual’s superior performance at a task is related to his/her possession of a superior set of attributes. Sandberg argues however, that variations on work performance are related ‘first and foremost’ (p.55) to differences in workers’ understanding of their work: those who perform better have a more sophisticated understanding of their work.
While this may well be true it doesn’t quite explain where exactly the attributes lie. The person still has to have the attributes, do they not? Or are they correlated with the understanding (the more sophisticated the understanding the more advanced the KSAs)? Sandberg addresses this issue in relation to collective competence. While he acknowledges the centrality of individual competence in performing any kind of work, he emphasises that ‘collective competence’ is the most important factor which influences an organisation’s performance.

In proposing an interpretative approach to collective competence Sandberg invokes Hutchins’ (1993, 1995) work on social and cultural cognition. Taking Hutchins’ cultural approach to cognition as a starting point Sandberg argues that in group activities such as maintenance there is a need for the members of this group to have a shared understanding of the work. Many organisational activities are ones in which there is a division of labour (Hutchins, 1995). This is true of aircraft maintenance: avionics work on electrical components, and craft workers work on metal sheet components, for example. Sandberg has said that individual competence is based on a person’s understanding of their work. Similarly, the collective competence of a group is based on the understanding of the work as shared by the members of that group. The shared understanding of the work is critical in ensuring co-operative interaction and is the basis for competent performance, he argues. Assuming this to be true, what, then, is this shared understanding? How does it come about, and how can it be developed?

Sandberg (2000) argues that sense-making is the critical process that determines workers understanding of their work. Adopting a cultural perspective assists in better understanding this process. Collective competence, from a cultural perspective, is related to the shared symbols that convey the meaning of the work with which the group members are involved. These symbols can be organisational stories, myths, norms and procedures which convey a sense of ‘how things are done around here’. New members of the group are initiated into this understanding through the use of these symbols and existing members have their understanding maintained through the use of these symbols. Sandberg uses the example of IKEA and its shared symbols as a
way of explaining the way in which shared symbols inform a group’s competence. The IKEA furniture company has a very strong corporate identity which is informed by nine propositions which are embodied in its broad understanding of the furniture business which is “to create a better everyday life for the many [sic] people”. The use of Swedish store managers in all 100 outlets in 20 countries has allowed the company to control the symbols that convey IKEA’s understanding of the furniture business. Sandberg argues that IKEA’s success can be attributed to the ongoing sensemaking of work that informs a strong shared understanding of the work which results in competent work performance.

*Developing Competence*

The interpretative studies cited show that the understanding which a person has of their work informs the attributes that they develop. Thus Sandberg’s interpretative approach to competence development is centred on developing competence through (i) changing the present understanding of the work, or (ii) developing the present way of understanding work. Rationalistic approaches to competence development focus on acquiring new attributes which are deemed appropriate for improved performance. These attributes, once selected, are then transferred through training to workers who don’t possess them. Sandberg, again, is unconvinced and proposes an alternative interpretative approach to competence development. There are two levels: Individual competence and collective competence.

*Individual competence development*

While Sandberg is critical of rationalistic approaches and their sole focus on attributes he does not dismiss training, apprenticeship and classroom teaching, all of which are development activities aimed at transferring attributes such as knowledge and skills. He does propose, however, that these methods can be used to achieve changes in workers’ understanding of their job. Encouraging reflection on workers understandings of their work during these training and teaching sessions would be, he proposes, an effective means for ensuring that understanding of the work grows and develops in line
with the new attributes which are required for more effective job performance. This ensures that the new attributes can be employed in a more developed and sophisticated understanding of the work rather than being lost on a more limited understanding of the work. ‘Reflected practicum’ sessions are seen by Sandberg to be the most effective way to achieve shifts in workers understandings of their work. Challenging workers to explain and resolve problem work situations serves to highlight for workers the limitations of their present understanding. Session facilitators then reveal alternative understandings of the work which facilitate the resolution of the problem. The attributes that allow such new understandings of the work are then detailed. Sandberg points out that the process of developing competence through shifts in understanding is not something achievable all at once. The changes that occur in workers understandings of their work are a result of multiple encounters between the worker and the work.

**Collective competence development**

Developing collective competence through shared symbols (as in the case of IKEA) is one way of developing competence within present understandings of the work. Developing collective competence by changing a collective’s understanding of their work is a different story. Relying heavily on the research of Edstrom, Norback and Rehndal (1989) (Swedish language research cited in Sandberg (2000)), Sandberg argues that the understanding of work which is held by a collective is often something which is not explicit. Instead it is implicit in the routines and systems of the organisation: ‘the way things are done around here”. Leadership is seen by Sandberg as a key tool in inculcating a new understanding of work. Through the use and communication of new shared symbols leaders can involve their workers in a sensemaking process. Moving from global symbols and concepts through to material changes in the everyday work environment a new understanding of work, and thus a new distinctive competence can be developed, he argues.
Overview of Sandberg's approach

Sandberg argues for interpretative approaches to competence. His postulations on competence are almost exclusively focussed on competence development. For him the dominant rationalistic understandings of competence are burdened by a dualist ontology and objectivist epistemology. Owing their origins to Taylor's (1911) studies of time and motion, rationalistic approaches view competence as being constituted by a specific set of attributes (knowledge, skills and abilities) which are used to accomplish work. Competence development from this viewpoint consists of transferring attributes to those workers who do not have them. Interpretative approaches, however, propose an alternative conception of competence: one where competence is related to ways of understanding the work. It is interesting that, despite the vehement dismissal of purely rationalistic approaches to competence, Sandberg’s conception of competence cannot entirely do away with the notion of KSAs. He focuses his efforts on the issue of ‘understanding’ and marginalises the role of attributes by declaring that competence is not first and foremost a matter of attributes, though they do play a part. Instead the way in which the work is understood by workers delimits certain attributes as being important to accomplishment of the work. Competence development in this approach consists of facilitating changes in workers’ understanding of their work.

Sandberg admits that competence development achieved through changing workers understanding of their work is something which is poorly elaborated and relatively unexplored in the literature. While he offers suggestions about how to achieve competence development through facilitating changes in workers understandings of their work it is apparent that interpretative approaches are still in their infancy when compared to the dominant rationalistic approaches. Research demonstrating the ways in which changes in understanding occur are needed in order to substantiate the claims Sandberg makes. A particular criticism would be that his elaboration of competence development methods is rather naïve: especially in relation to collective competence. He invokes the example of successful companies, such as IKEA, and attributes their commercial success, in the face of overwhelming difficulties, to effective leadership
and the judicious use of symbols but there is no real evidence to suggest that new understandings were achieved solely through symbols and that these in turn, are related to the subsequent success of the business.

The Contribution of Bramming and Larsen (2000)

Bramming and Larsen (2000) challenge traditional conceptions of competence and competence development; in particular the 'essence' based approach favoured in rationalistic takes on competence. They argue for a more contextualised approach where competence is seen as emerging from the practice of work - a dynamic process of interaction between actors and their tasks within a constantly changing context. They reject the idea that competence is something which resides in an individual and is then "released" as they act, and discredit the view that the competence of the organisation is a direct sum of all the competencies of the individuals.

In attempting to progress their revised conceptions of competence, Bramming and Larsen claim that dictionary definitions of competence (where competence relates to having the ability to do something) speak to the relative nature of competence. From this comes Bramming and Larsen's new definition of competence as something 'relational' - relational in terms of other performers or the job to be performed. They further propose a need to move away from essence-based approaches to competence and try to explore a notion of competence where it is viewed as something which emerges from the practice of work.

Promoting the contextual nature of practical knowledge as central to the notion of competence the authors propose a definition of competence based on the assumption that competence emerges in the doing. Defining the relationship between knowledge and competence the authors assert that competence emerges through enactment - in this sense competence is the outcome of handling knowledge in a work situation. Thus knowledge is important in terms of its actualisation - its use in a context. Context is important and central to the authors' definition in that competence is always relative to
the system in which the actualisation of knowledge occurs. This re-conceptualisation of competence means that competence cannot be seen as an essence – something that an organisation or a person has or possesses. That said, according to this new definition, a person can possess knowledge about how to do a job, but only when this knowledge is actualised or released in practice can we make a judgement about the competence of the enactment. Thus for Bramming and Larsen competence is something which is behaviourally revealed. Competence is a relative term for which there is no fixed meaning. It is only in the context of its presence in a situation that the meaning can be understood.

Bramming and Larsen state that most competence development work focuses solely on theoretical knowledge (know-what) but leaves unexplored the assumption that this knowledge relates to competent behaviour. They argue for a shift in focus away from theoretical knowledge and towards practical knowledge in an attempt to account for the complex nature of work. Their theory of competence as being the outcome of successful task performance delimits a certain understanding of theoretical knowledge and its role in task performance. For Bramming and Larsen the fact that it is not possible to know from the outside what is required to do a job well means that workers are not exclusively guided by theoretical knowledge. Instead competence is the output of successful handling of practical knowledge in a work situation. They say that taking practical knowledge (know-how) as their point of departure has allowed them to re-conceptualise competence as relational (competence is understood in relation to something (a job situation) or someone) and social (work is performed with, or in the presence of, others, and humans interpret the social world they inhabit). For Bramming and Larsen (2000), their “comprehensive” but “tentative” (p.85) model for competence development (detailed later in the chapter) is based on their assertion that competence is being able to perform work in a practical sense, situated in a social setting whereby the meaning of what is competent is emerging through interactions between the members of the organisation. Bramming and Larsen (2000) are mindful, however, of the judgement issue and acknowledge that ‘between the lines’ competence emerges when knowledge is handled well. The introduction of a judgemental or evaluative
aspect presents some problems for the authors which, through exploration of Bourdieu's body of work, they hope to solve.

For Bramming and Larsen there exist, outside the context in which the work is done, no objective standards about what is competent and what is not. Bourdieu (1990), in researching 'the social', asserts that the social is understandable from the inside but has an incomprehensible impermeability. That is, when you are in a situation you can understand what is going on but when you are not the constructor of the social your understanding will be limited in terms of your position in the social space and as you have not constructed the space you will not be able to see from where you observe, what you observe. Bourdieu introduces the notion of 'habitus' with the organisation as the social space in which the members of the organisation act and interact. In this sense the organisation is a community of practice: members of an organisation who formally and/or informally have some practice in common and interact with each other (Lave and Wenger, 1991) – a meaningful workgroup where people are dependent on each other for performing their share of a work process, if you will. In communities of practice, knowledge emerges and interpretations of what is sensible are supported. Through practical participation, the members of the organisation engage in a process of constructing an understanding of what organisational work and life in the organisation is all about.

"Work is not done in a vacuum" (P.78), Bramming and Larsen (2000) argue. Work takes place in organisations comprised of individuals (peers, subordinates, superordinates) who have a shared history and who employ technology to work together to achieve mutual goals whilst following explicit and implicit rules (Blackler, 1993; Blackler et al., 1997). Bramming and Larsen’s main contention is that “actions, and thereby competent behaviour, by individuals can only be explained and understood by relating the here and now concrete social setting/objective conditions of life in which the individual is situated with habitus to the objective conditions of life which created this habitus” (p.81).
Thus, relating this to the aircraft maintenance domains, if we are to explain and understand behaviour we have to somehow link the situational determinants of the task with the dispositions towards action acquired through experience (such as norms and workarounds) to the way people, through socialisation, make sense of the world they inhabit (objective conditions) which created the disposition towards specific action. Bramming and Larsen clarify: when someone acts or behaves in a particular way it relates to that individual’s history, their skills and abilities and the context in which they find themselves – so there is a sense in which there is an appropriateness in the given situation with the given people in the given organisation.

Bramming and Larsen (2000) propose a new definition where competence is:

“...the practical sense displayed through actions by individuals in a [sic] organisational working context, which (actions) in the same context are deemed competent by the community(ies) of practice in which the activity is taking place.” (p.82, italics in original)

Competence, then, has no independent existence apart from action; it is a label used to describe action in a context. For Bramming and Larsen competence is not a prior cause of action, as suggested by rationalistic approaches, but instead a subsequent description of action. Furthermore, the meaning of competence and incompetence is socially constructed and negotiated among the members of the “community of practice” – thus it is not an objective concept. Their definition of competence sees it as being the outcome of successful task performance and promotes a shift in focus away from theoretical knowledge towards practical knowledge in an attempt to acknowledge the complex nature of work. This conception of competence delimits a certain understanding of theoretical knowledge and its role in task performance. For Bramming and Larsen the fact that it is not possible to know from the outside what is required to satisfactorily perform a job means that workers are not exclusively guided by theoretical knowledge. Instead competence is a description of the output of
successful handling of practical knowledge in a work situation. The work situation is important as it contains the conditions for exhibiting competent behaviour.

**Overview**

The writings of Sandberg (2000) and Bramming and Larsen (2000) provide direction for new conceptions of competence. Sandberg’s interpretative approach to competence offers an alternative to the flawed rationalistic approaches. His study of engine optimisers illustrates that competence is not merely the sum of a set of context-free attributes such as KSAs. Rather, the workers’ experience of performing the work informs their understanding of that work and it is this understanding of the work which prescribes the attributes necessary and organises them into competence when performing the work. Instead of competence being solely about having the necessary skills and abilities as stated by rationalistic approaches, the interpretative approach championed by Sandberg emphasises the worker’s understanding of their work. Sandberg does not entirely dismiss attributes such as knowledge, skill and ability in defining competence: he merely argues that the workers’ attributes are preceded by and based upon their conceptions of the work.

Bramming and Larsen, in common with Sandberg, include attributes in their new approach to competence. They, however, take an attribute as their point of departure in their quest for new conceptions of competence. For them one attribute in particular is critical: knowledge. They argue that the majority of competence literature and developmental efforts erroneously focus on theoretical knowledge and do not question its relationship to competent behaviour. By shifting focus towards practical knowledge they are able to propose a different conception of competence where it is understood as social and relational. Competence is social in that work is performed in a social setting where the members of the social setting interpret their world and give meaning to it. Competence is relational in terms of other performers or the job to be performed: the example of the professor of law performing an appendectomy illustrates that competence can only be understood when compared to something or in comparison to
someone. For them competence is being able to perform work in a social setting where
the meaning of that competence emerges from the actions of the members of the
organisations. Thus, competence is a description of action in a context, where the
community of practice determine the actions to which the label ‘competent’ applies.

Having reviewed both viewpoints it is clear that Sandberg and Bramming and Larsen
agree upon the deficiencies of the rationalistic definitions and interpretations of
competence at work. There is agreement that competence is not reducible to simply a
set of attributes (or KSAs), although they do have a role to play. The two views differ,
however, about what exactly constitutes competence. Sandberg focuses on
‘understanding of the work’ and Bramming and Larsen focus on ‘competence as an
outcome of performance’. It seems that they know what competence is not (a list of
attributes) but there are divergent opinions about what it actually is. The interpretative
studies cited by Sandberg show that the understanding which a person has of their
work informs the attributes that they develop and use to accomplish that work:
evidence, Sandberg asserts, that competence is primarily concerned with the
understanding a worker has of his work. Bramming and Larsen’s work suggests that
competence is merely a label given to actions which are deemed competent by the
members of a community of practice in which the activity is taking place.

The northern European interest in competence (all three researchers hail from
Scandinavia) is closely related to the common perception in this region of the world
that they inhabit a competitive and turbulent commercial environment. The writings of
Bramming and Larsen (2000) and Sandberg (2000) acknowledge that as market forces
become less predictable and the business markets more volatile what is required, more
so than anything else, is flexibility. For Bramming and Larsen, together with Sandberg,
it is clear that human competence is the only thing to assist organisations in
successfully navigating through the turbulent changes and the demands for higher
production in increasingly competitive times. Competence development, thus, is seen
as a countermeasure to address the increasing demands from the environment. When
they come to discuss the practical applications of their theories of competence,
however, the papers by Sandberg and Bramming and Larsen seem to focus almost exclusively on competence development, at the expense of competence assessment.

The aircraft maintenance industry looks to competence literature for two main purposes: competence development and competence assessment. Many companies see competence development as the way in which they can achieve a committed and flexible workforce who can produce high quality results (Blyton & Turnbull, 1992). Given the current difficulties being experienced by the aviation industry it is no surprise that competence development is a hot topic. Regarding competence assessment it is clear that the aviation regulators are making inroads upon the issue of competence and they seem to be pursing an agenda of human factors regulations, the conclusion of which may well be a requirement for competence assessments.

Chapter 3 has highlighted how the theoretical models informing much of the research and development work in the area of aviation human factors are inadequate and limited in their focus. In light of the new approaches to competence championed by Sandberg (2000) and Bramming and Larsen (2000) it would seem to be appropriate to interrogate the models of competence which they propose in an effort to explore what they can offer to the discussion on human factors competence and assessment.

The efforts of Sandberg and Bramming and Larsen are clearly motivated by a desire to assist and improve competence development activities. Both sets of authors provide much guidance on the limitations of dominant rationalistic approaches and push the boundaries of our understanding through the specification of new conceptions of competence. They propose some ways of developing competence based on their theoretical surmising: these are presented below. Bramming and Larsen’s analyses of competence development, together with their proposed ‘social and relational’ model of competence, additionally provide much needed direction to competence assessment efforts.
Competence Development

Sandberg (2000) and Bramming and Larsen (2000) are critical of rationalistic approaches where competence development is believed to be a bridging task: closing the gap between skills possessed and skills demanded. The ‘fit’ is achieved through education and training but is burdened by its inability to operate in complex dynamic environments where situations, together with the skills demanded do deal with these situations, change quickly thereby ensuring that developmental efforts play a continual game of catch-up (Townley, 1994). As such Sandberg and Bramming and Larsen have detailed the competence development methods which relate to their conceptions of competence at work.

*Sandberg (1994, 2000, 2001)*

Sandberg states that the development of particular knowledge and skills takes place within a certain understanding of work and proposes two methods of competence development: changing the present understanding of the work, or developing the present way of understanding work.

Sandberg does not entirely dismiss training as a competence development tool for individuals, though he is critical of sole reliance of rationalistic approaches on training and learning as competence development tools. He argues that reflective practice sessions conducted during training can allow a worker’s understanding of his/her work to grow and develop in line with the new attributes which are required for more effective job performance. Sandberg is aware that this method of competence development will not see instant results: changes in workers’ understandings of their work are noticeable after multiple encounters between the worker and the work.

Sandberg is less transparent when suggesting competence development methods aimed at groups. Based, of course, on changing or developing workers’ understandings of their work he proposes the use of leadership and shared symbols as a way of involving workers in a sense-making process whereby changes in understandings of the work result in the development of a new distinctive competence.
Bramming and Larsen (2000)

Bramming and Larsen’s paper suggests a shift in the theoretical assumptions underpinning competence development and argues for a developmental process that accounts for the ways in which people make sense of and interpret the social space of their work. They propose a 4-step process to be guided by a skilled process consultant:

1. **Social verbalising**
   This involves getting the community of practice to agree among themselves the competencies required for their job – KSAs (these form what is termed a ‘wheel of competence’)

2. **Individual rating**
   Each individual rates themselves on each attribute according to their level of competence

3. **Social adjustment**
   The group discusses each individual’s competence rating and comes to a consensus

4. **Individual and social development**
   The group translate their agreement into plans for individual and group development (avoiding exclusive reliance on formal education and training as a means of developing competence)

Bramming and Larsen propose that this method of competence development works best in organisations composed of responsible workers who are eager to contribute to the organisation and are aware of the demands placed on the workers by the organisation and its work. The process takes the actual work in the community of practice as the point of departure and is reliant on dialogue and good communication.

In practice the fourth step in the process could prove to be a stumbling block: in order to implement the competence development plans the workers would need a mandate from senior manager. This may be a rather idealistic and naïve approach to competence development when it is acknowledged that in reality a true and meaningful partnership between workers and management is not easily achievable.
Competence Assessment

Bramming and Larsen (2000)
Bramming and Larsen argue that competence is behaviourally revealed: it emerges from the practice of work in a particular context. Competence has no independent existence apart from action. It does not reside in a worker, though it does emerge through the actions of a worker in a particular context. Bramming and Larsen also acknowledge the evaluative nature of competence. For them ‘competence’ is a label: a description of action rather than a prior cause of it (as claimed in rationalistic approaches). The meaning of this label, ‘competent’, is something which is negotiated amongst the members of the community of practice and is not an objective concept. Bramming and Larsen’s approach provides guidance on the appropriate way to assess competence: the behaviour of the worker in a context is the starting point, the members of the community of practice observe the work and through negotiation attach the label ‘competence’ to the actions and performance upon which they agree.

Sandberg (1994, 2000, 2001)
Sandberg argues that competence is revealed through exploration of workers understandings of their jobs: in his studies he used interviews to target workers’ understandings of their work. Following Sandberg’s approach would result in a competence assessment method which uses interviews to understand workers levels of competence. Over time, and based upon these interviews, a researcher may be able to construct a psychometric scale which would discriminate between workers according to their conceptions of work: thereby assessing their competence. Logistically this is a demanding task and if it were achievable, which is altogether uncertain, it would still be burdened by one problem. A worker’s understanding of their job is merely an indicator of how they might perform; an intention to behave in a certain way.
A Synthesis of Competence Theories

Bramming and Larsen’s work, and that of Sandberg, is critical of rationalistic theories of competence. The two papers, outlined in detail in this chapter, make strident efforts to put forward alternative conceptions of competence which are not burdened by the failings of rationalistic approaches. Both papers however, stop short of proposing worked out theories of competence. Bramming and Larsen (2000) state that their interpretation of competence “allows for a more comprehensive, if still tentative, model for competence development” (p.85) but they never actually detail the model allowed for in their conception of competence. Sandberg (2000), similarly, is reluctant to specify a comprehensive model of competence based on his research findings. He acknowledges that competence development through manipulating changes in the understanding of work is poorly elaborated when compared to methods of transmitting attributes. Nonetheless, he is aware that further research is needed in order to explain the way in which changes in understanding occur and the relationship between these changes and enhanced competence at work.

The inability of Sandberg and Bramming and Larsen to present fully evolved models of competence relates to the complexity of the issues being studied. The ease with which rationalist approaches to competence can actually define and describe competence may well explain the dominance of these approaches but we have seen how these descriptions of competence are rather naïve and simplistic, failing, as they do, to account for the vagaries of working life. The contribution of Sandberg, taken on its own, may not amount to a model of competence. Similarly, Bramming and Larsen’s input to the competence debate does not explain every facet of the issue. That said, the two explanations of competence are not at odds with each other and when amalgamated each approach serves to supplement, rather than supplant, the other.

There are, it seems, three main perspectives on competence. Firstly, there is a purely rationalistic approach, as typified in Boyatzis’ (1982) conception of competence which produces a single explanation of competence against which comparisons are made.
Then there is an interpretative approach to competence as championed by Sandberg (2000). Finally, Bramming and Larsen (2000), in their approach to competence, invoke aspects of social constructivism and theories of practice. It is clear that these three approaches are ideologically incompatible. But strip away the ideology and it is clear that the three approaches have much in common.

All three explanations of competence have recourse to the attributes of knowledge, skills and abilities and it seems that it is the reliance on these attributes which forces some harmonisation between the different approaches. For example, Bramming and Larsen were unable to advance notions of competence which didn’t have recourse to attributes such as knowledge; similarly Sandberg’s approach has some reliance on KSAs. Bramming and Larsen, together with Sandberg, have been critical of rationalistic approaches to competence so how can they then include KSAs in their conceptions of competence?

In practice, invoking interpretative or social constructivist explanations of competence does not eliminate the centrality of KSAs to the issue. In criticising rationalistic models of competence they are criticising not the content of these models (KSAs) but the way in which these KSAs are arrived at and the way in which they are employed in the model of competence. Dekker (2005), in writing about rationalist approaches to human error, has defined the rationalist partiality which he argues is a defining feature of human factors as follows: “rationalist means that mental processes can be understood with reference to normative theories that describe optimal strategies” (p.77). This comment neatly illustrates the problem with rationalistic approaches to competence. They hold that there is an objective ‘one best way’ of performing: a normative theory which describes an optimal strategy. The problem with rationalistic explanations is not that they focus on KSAs (though the sole focus on attributes is limiting); the problem is that they propose a set of criterion KSAs with which to make comparisons. It is the method of establishing competence which is problematic, not the reliance of KSAs to explain competence. The assumption is that people behave like perfectly rational human beings and their competence is determined by their KSAs. But there is no such
thing as perfect rationality. Rather there is an imperfect, bounded, local rationality which is governed by people’s local understanding, their focus of attention, and their goals rather than a global ideal (Dekker, 2005). This re-conceptualisation links performance and the situational context. Performance is part of a localised setting in which it is enacted, and can only be understood in relation to this situational context, not in relation to some universal standard. In invoking notions of local or bounded rationality it is clear that there is more scope for integrating the three approaches to competence because there is a move away from the mental processes which determine how people act (‘the thinking person’) and an acknowledgement of the context which produces and accompanies these actions (‘the acting person’).

There are differences between the approaches offered by Bramming & Larsen and Sandberg. Sandberg shows that competence relates to workers understanding of their work and this is not something which can be quantified and specified in the easy way that skills and abilities can. Bramming and Larsen lead us to believe that competence is a label: an evaluative term agreed upon by members of a community of practice which is used to describe action in a particular context. Given the contextual nature of Bramming and Larsen’s interpretation of competence it is not possible to specify the criteria for competent performance before an action takes place. It is only when the actions occur in the context that the opinion-makers can judge whether, in that context, the actions can be deemed competent.

So, while there are some important differences between the three approaches to competence which have been detailed in this chapter, it seems that some reconciliation can be achieved between the competing explanations of competence. What we need is a promiscuous theory of human factors competence: one which can exist in all these worlds. We need to be able to explain, using the model, how it is that some tasks are performed competently and others are not. We understand, from Sandberg’s work, that competence relates to our understanding of work and we accept, from Bramming and Larsen’s work, that competence is an outcome of performance and relates to behaviour. There is no denying the centrality of attributes such as knowledge, skills and abilities to
the issue of competence. So, what is needed is an adequate definition of competence: one which can link KSAs to practice and performance, and which details the relationship between 'understanding' and 'competence'. The next section attempts to do just that.

**A Model of Competence for Aircraft Maintenance**

It is well documented that the worst mistakes are often made by the best and most experienced technicians: it is not just inexperienced trainees who make mistakes or errors which have serious consequences (Reason & Hobbs, 2003). A purely rationalist approach to error would hold that workers who possess the KSAs which make them 'good' technicians make errors because they departed from the standard or rational norm. The error occurred because the technician was deviant – he didn’t take enough time; he wasn’t bothered; he was negligent (Dekker, 2005). This approach epitomises the ‘Bad Apple Theory’ advanced by Dekker (2002). If we unpick this using a bounded rational approach it is clear that humans cannot work like perfectly rational decision makers. If an error or mistake occurred it was related to the person’s local understanding, their goals and knowledge: the things which govern human rationality. In this sense rationality has, what Dekker (2005) termed, an ‘interpretative flexibility’. By this he means that what is rational in a local sense is not rational in a global sense. Bounded or local rationality allows for an interpretation which does not subscribe to the ‘old view’ of human error. When the error or mistake was made the worker was doing what made sense to him at the time. Given his point of view, the focus of his attention, his knowledge of the situation and the objectives of his work group and organisation his actions were reasonable. In this sense there is no irrationality to an error or mistake.

Given what we know about the goals of maintenance organisations (fast turnarounds, more efficiency etc.) we can see how these goals can influence the rationality of those workers operating in this system. Breaking rules and not following procedures in this context may well be an indicator of a well-intentioned worker; someone striving to
provide that which the organisation wants. In this context the workers reasoning is influenced by the organisational environment and cultural norms such that his goals are aligned with the goals of the organisation (Dekker, 2005).

Looking back to the tasks observed in the ethnography presented in Chapter 2 this all seems to be making an important point regarding competence. The procedural violations and workarounds which were in evidence in these tasks (particularly the fourth task involving the cargo-door snubber) were primarily informed by the technician's view of the organisational goals (emphasising efficiency). In this context the technician's personal goals (to break rules and finish quicker) are an indication of a motivated worker. We have seen from Chapter 3 how it is that many formal systems in maintenance organisations fail to function properly and informal systems develop as a response. In this way the system goals and the personal goals become harmonised. The challenge for technicians is to manage, in practical terms, the informal aspects of an organisational process and system. Clearly competence in aircraft maintenance is not about just having knowledge, skills and ability. It is about managing safety and efficiency and the complexities, uncertainties, dilemmas and tradeoffs which are present in operational environments.

Chapter 2 described the social aspects of aircraft maintenance. We saw how all maintenance tasks, whether performed by an individual or a team, take place in a social environment characterised by social interaction; be it direct or indirect. In this context a performance failure could never be because of the actions of one person: what about the organisation, the systems and the processes which support maintenance tasks? The people who populate these systems also have a role to play in mediating the outcome of performance. In the same way that poor performance is not related to an individual, how can competent performance be related to an individual?

For aircraft maintenance, the answer is that it can't. Not entirely anyway. The profoundly social nature of maintenance tasks is clear from the task observations in Chapter 2 and the observations of training in Chapter 3. Competent performance in
Aircraft maintenance is not just about the performance and actions of one person. Certainly, some tasks are performed by one technician working alone. But this technician is working in a broader context: a socio-technical system in which the task processes and organisational structures create social interactions (sometimes indirect) such that the final outcome of a task relates not only to the performance of the sole technician but also to the inputs of those personnel who supplied parts, planned the task and managed the performance of it. The issue of competence in aircraft maintenance, thus, relates to the collective.

We know that there is more to the performance of maintenance tasks than just having the appropriate knowledge, skills, expertise or experience. There are other additional factors which mediate the outcome of the performance of an aircraft maintenance task. In order to adequately understand this peculiar phenomenon it is necessary to propose a model of competence which can account for the aspects of aircraft maintenance which were highlighted in Chapters 2 and 3. What we need in aircraft maintenance is a competence model which accounts for the social circumstances in which tasks are performed. This means that what is called for is a model of collective competence: a description of the ways in which social interaction transforms inputs into competent performance (the output). In general this move towards collective explanations of competence is something which is supported by Boreham (2004). He argues against the 'individualisation' of competence. He claims that in some contexts it makes better sense to think of competence in terms of the collective, rather than relying solely on explanations which prioritise the individual.

Selznick (1957) was amongst the first researchers to use the term collective competence. More recently Prahalad and Hamel (1990) have dealt with the issue of collective competence. In addition Leonard-Barton (1992) has reviewed much of the research on collective competence and she identifies a number of dimensions of collective competence. For her collective competence consists of an 'interrelated interdependent knowledge system' focusing on the knowledge possessed by employees, the knowledge and skills embedded in technical systems, the knowledge created and
controlled by the formal and informal managerial systems and the values and norms assigned to the various knowledge and skills of an organisation and its development. Similar to Leonard-Barton, Prahalad and Hamel conceive of collective competence as the company’s collective knowledge about how to co-ordinate diverse productions skills and technologies.

These approaches to collective competence offer little to the development of a model of collective competence for aircraft maintenance. Both of these approaches to collective competence prioritise only knowledge and do not account for the actualisation of this knowledge in a contextual situation, relying, as they do, on a dualist ontology (which divides collective competence into two entities; the collective who performs the work and the work itself) and objectivist epistemology (which views work activities as being separate from the collective that performs them). Moreover, the focus is too general to be useful in the context of aircraft maintenance activities. What is needed is a model of competence which bridges the conceptual gap between explanations of competence focusing on the individual and those emphasising a whole organisation. In the next section of the chapter just such a model of competence is presented facilitating a full exploration of the notion of competence as it relates to human factors and the performance of aircraft maintenance activities.

The hybrid model detailed below was developed drawing both from the interpretative studies of competence by Sandberg (1994, 2000), and also from Bramming and Larsen’s social and relational notions of competence (2000). The model reflects the ways in which maintenance is performed and incorporates KSAs as an integral part of the competence equation. Bramming and Larsen see competence as the behaviour which is able to compromise between the various coalitions and interests in an organisation and competence relates to being able to cope as deemed appropriate by the opinion makers, because of, or despite, the formal qualifications deemed necessary. Sandberg sees competence being first and foremost related to workers understandings of their work (as informed by their lived experience of it) and that the understanding of work delimits certain attributes which are necessary to perform the work. Thus, for
Sandberg workers KSAs are preceded by and based upon their understanding of their work.

The starting points of these two opposed approaches reflect another interesting dichotomy: between competence and performance. In his writings on linguistics Chomsky (1965) provides an interesting take on the issue. For him competence relates to the knowledge of language. Performance, on the other hand, relates to the use of that knowledge. He goes on to argue that performance cannot directly reflect competence. This is certainly true of language. False starts, deviations from rules and changes in plan characterise natural speech and looking at performance alone would give us a skewed impression of the person’s linguistic competence (or knowledge). Chomsky (1963) also states that descriptions of what an organism knows, and what it does, can be very different things. The difficulty he says is to determine the knowledge of language that a user has based solely on his actual performance (Chomsky, 1965). Observed use of language gives an indication of the mental reality of the person’s knowledge but it would be erroneous to go on this alone, he argues. While Chomsky was talking specifically about linguistics and grammar it proves useful in proposing a model of competence for human factors. In essence, Chomsky’s conceptualisation of the competence/performance dichotomy relates to the distinction between knowledge and its deployment (Smith, 2004). This distinction mirrors the differences between the starting points of the Sandberg and Bramming & Larsen approaches to competence. The ‘mentalistic’ aspects of competence are reflected in Sandberg’s approach and the ‘deployment’ of knowledge is reflected in the Bramming & Larsen approach. What is clear from Chomsky’s treatise is that competence and performance interact in complex ways. In acknowledging the validity of both approaches, the new model of competence proposed in the next section of this chapter can reflect this complexity. These two different opinions have different starting points in their quest to better understand competence but the model attempts to reconcile them in such a way that performance and competence in aircraft maintenance can be better explained.
A Model of Human Factors Competence

This model of human factors competence accounts for the social and collective nature of maintenance tasks and is grounded in the social reality of operations. Competence in aircraft maintenance is not just about an individual. To reflect the social processes of maintenance activities we need to go beyond individualistic conceptions of competence. From Chapter 2 we see that maintenance activities are not just about the actions of an individual, it's about the actions of individuals working together. These individuals may be working in different areas of the organisational system, and may interact only in indirect ways, but the performance output for these types of tasks is collective: it reflects the actions of all those who had an input.

This model has six key elements: Understanding of the Work, Attributes, Action, Performance, Context and Evaluation. A brief description is given below: a more complete explanation is detailed later.

1. Understanding of the work
   This is the basis of competence. Understanding is gained through the lived experience of work. This prescribes the KSAs necessary to perform the work.

2. Attributes (KSAs)
   This element refers to the knowledge, skills, abilities and attitudes which a worker uses to perform his work.

3. Action
   This refers to the enactment or actualisation of the KSAs. This is when knowledge and skill are externalised and expressed in behaviour.

4. Performance
   This refers to the actualisation of KSAs. This is where the work activities (or actualised KSAs) of one worker interfaces with the work activities of another.
5. Context
This element refers to the community of practice in which the performance takes place.

6. Evaluation
The use of the label ‘competent’ is negotiated by the members of the community of practice.

The model is outlined in Figures 4 & 5 (over). The model allows for two modes of performance: maintenance tasks performed by a single technician and maintenance tasks performed by two or more technicians working together. To clarify the nature of the difference between these two types of performance two figures are used to illustrate the competence model: one relating to individual tasks and the other relating to team tasks. In reality the second diagram is merely a variant of the first one; the only difference being the mode of performance (individual or team). The two diagrams do not represent two different theories – one is merely an abstraction of the other – and are included for purposes of clarity more than anything else.

The model is of a bounded system: the dark blue line of the exterior box illustrates that this model of performance and competence relates to a specific context. This context, with its community of practice, norms, values, attitudes and beliefs, is critical to the other elements of the model. The model depicts individual workers (shown as square boxes in the diagram) and illustrates that internal to each person is their shared understanding of their work and the attributes (KSAs) which are informed by their understanding of the work and which they later use to perform work. All that takes place within a square box represents the mental life of the worker. In the diagrams there are two types of square box: boxes circumscribed by a full red line (indicating that the individual is a technician) and a box circumscribed by a dashed orange line (indicating support staff not directly involved in production activities). Support workers have an indirect impact on the performance of maintenance tasks. They are not directly involved in maintaining aircraft but their work does have an input to the performance of maintenance tasks (albeit indirectly). The model of competence reflects
the influence of support workers such as planners, managers, documentation writers, task designers, parts suppliers, re-fuelers, and so on and represents them in the model. It should be noted that the diagram represents a simplification of the maintenance process and only one support worker is included in the diagram. This is not meant to be representative of reality – the diagram has merely been simplified for illustrative purposes. Action relates to the actualisation of an individual’s attributes and is indicated in the diagrams as a purple arrow (a dashed line is again used to indicate the indirect nature of the work of support staff). This actualisation of the KSAs results in performance which is represented as a green octagon. Evaluation, then, refers to the appraisal of performance whereupon a label may be attached. The meaning of competence is something which is negotiated by the opinion-makers in the community of practice in their specific context.
Figure 4: A Model of Competence for Aircraft Maintenance Tasks performed by a Pair of Technicians
Figure 5: A Model of Competence for Aircraft Maintenance Tasks Performed by a Single Technician
Explaining the Model

Understanding of the Work

This element of the model is based on Sandberg’s explanation of competence at work. Sandberg’s approach is based on a prioritisation of the ways in which workers understand their work. He asserted that changes in competence can be brought about by changing the way in which workers understand their work. For Sandberg the workers’ understanding of their work relates to the basic meaning structure of workers’ conceptions of their work and is the basis and foundation of human competence at work. A worker gains his/her understanding of work in their lived experience of the work in a constant sense-making process which prescribes the attributes necessary to perform the work competently. Sandberg’s findings also point to a situation where different ways of understanding work interact to form a hierarchy of competence: the more advanced the understanding of the work the more competent the worker. In aircraft maintenance, because of its social nature, it is important that the understandings of the workers contributing to the performance of an operation or task should have a shared or complementary understanding of the work.

Knowledge Skills Abilities (Attributes)

Bramming and Larsen, together with Sandberg, are critical of rationalistic approaches to competence which view it as merely a list of attributes. This does not mean that attributes have no role to play. It is telling that, despite the vehement dismissal of purely rationalistic approaches to competence, Sandberg’s conception of competence cannot entirely do away with the notion of KSAs. While Sandberg’s model is based on ‘understanding’ and marginalises the role of attributes by declaring that competence is not first and foremost a matter of attributes; knowledge, skills and abilities cannot entirely be dismissed. The way in which the work is understood by workers delimits certain attributes as being important to the accomplishment of the work. Or, put another way, the attributes (or KSAs) required to perform the work are informed by our understanding of that work (Sandberg, 2000). The more sophisticated our understanding of the work the more varied, numerous and complex the skills and
abilities that are required of workers to perform to the standard reflected in the workers understanding of the job. Attributes, Sandberg proposes, are context-dependent as a result of the workers’ experience of their work. The experience of workers performing the work informs their understanding of that work and it is this understanding of the work which prescribes the attributes necessary and organises them into competence when performing the work. For these reasons the model includes attributes such as knowledge, skills and abilities.

Action
This element relates to the actualisation of the attributes. This element of the model defines the relationship between attributes and competence. Bramming and Larsen’s conception of competence sees it as something which emerges through enactment. This approach views competence as the outcome of successfully handling knowledge in a work situation. Attributes such as knowledge are important in terms of their actualisation – their use in a context. Defining the relationship between knowledge and competence the authors assert that competence emerges through enactment - knowledge is important in terms of its actualisation or its use in a context. ‘Action’ is an important component and is included in the model for this reason.

Performance
This element refers to the place where the actualisation of attributes interfaces with the work activities of other occupational groups in an organisation. It is here that the organisational context can mediate the actualisation of a worker’s attributes. Things like planning, scheduling, manpower issues and the availability of parts and tools play a part at this stage. It is here that the worker would try to manage the compromise between the opposing interests in the organisation.

Evaluation
This element refers to the act of ascribing competence (in the form of a label) to the performance of work. This activity, along with all the others in the model, takes place in a specific context: one where all members of the community of practice interpret
their world and give meaning to it. For Bramming and Larsen (2000) competence is something which is behaviourally revealed: competence emerges in the doing of work. Competence is a relative term for which there is no fixed meaning. This meaning is negotiated by the members of the community of practice with reference to the context. Competence in these terms relates to being able to perform work in a social setting where the meaning of that competence emerges from the actions of the members of the organisations.

Context
Context is central to Bramming and Larsen’s conceptions of competence in that competence is always relative to the system in which the actualisation of knowledge occurs. Competence is a description of action in a context, where the community of practice determine the actions to which the label ‘competent’ applies. Competence is a relative term for which there is no fixed meaning. And it is only in the context of its presence in a situation that the meaning can be understood. For Bramming and Larsen there exist, outside the context in which the work is done, no objective standards about what is competent and what is not. Work happens in organisations which are made up of individuals (peers, subordinates, super-ordinates) who have a shared history and who employ technology to work together to achieve mutual goals whilst following explicit and implicit rules. It is in this community of practice that people develop their understanding of their work. Only in accounting for this specific context can the members of an organisation make an informed decision about competent performance. This is especially true of the work of an aircraft maintenance technician.
Chapter Summary

The model outlined above reconciles Sandberg’s interpretative perspective on competence with Bramming and Larsen’s social and relational model of competence and provides the basis for a new approach to competence in aircraft maintenance. In so doing the model also provides an overall account of the important issues such that the dichotomy between competence and performance makes sense. The new model incorporates knowledge (what Chomsky terms competence) and performance and for the first time a model of human factors competence is presented which attempts to account for the variety and complexity of issues and problems which were detailed in Chapter 2.

Chomsky proposes that performance can never directly reflect competence. This is certainly true of language. But it applies equally to the performance of any tasks. Normal performance is not a linear thing. There are changes in plans, restarts, and so on. This is certainly true of aircraft maintenance. In recognition of this fact this model of competence also includes aspects of knowledge and understanding. In this way the model includes aspects what Chomsky termed ‘competence’ (the knowledge) and ‘performance’ (the use of that knowledge). In practice this means that the model can explain an error, for example, from two perspectives: one where the error arises from the person not knowing how to do something (what Chomsky termed competence) and another explanation where the error is caused by a contextual problem (what Chomsky would term performance). In this way we are avoiding the problems associated with a single focus and we can offer evaluation based on what an organism knows and what it does.

Of course the evaluation is influenced by the person offering the explanation and this is why the ‘Context’ element of the model is so important. It has been argued that there is a tacit dimension to competence (Polanyi, 1967). It is impossible to properly understand work from the outside looking in. The members of the community of practice observe the work and through negotiation attach the label ‘competence’ to the
actions and performance upon which they agree. Only those persons who operate in that particular context can make an informed evaluation about what is, or is not, competent.

The next chapter, Chapter 5, explores an instantiation of the model of human factors competence advanced herein. The key question which needs to answered is whether the model can account for the reality of maintenance operations as described in rich detail in Chapter 2.
CHAPTER 5
EXPLORING THE UTILITY OF THE MODEL

Introduction

The model of competence advanced in Chapter 4 builds upon the approaches to competence reflected in the work of Sandberg (2000) and Bramming and Larsen (2000). These researchers proposed approaches to competence which focused primarily on behaviour and enactment (Bramming & Larsen’s contribution), and workers’ understandings of their job (Sandberg’s contribution). The perspectives of Sandberg and Bramming and Larsen are, thus, slightly different. Sandberg’s perspective relates to the ‘mentalistic’ aspects of competence while the ‘deployment’ of knowledge is reflected in the Bramming and Larsen approach. Interrogating Sandberg’s interpretative approach to competence and Bramming and Larsen’s situated action approach to competence led to the specification of a competence model which purports to provide a better and more comprehensive explanation of the mechanisms of competence (particularly in the context of aircraft maintenance) that any of the models specified heretofore.

This chapter is chiefly concerned with exploring the extent to which the competence model advanced in this thesis provides a good account of the nature of the performance aspects of competence as they relate to aircraft maintenance tasks. The utility of the model is examined in two ways. The first involves the exploration of the utility of the competence model as instantiated in a performance assessment tool developed in a multi-disciplinary research project. The development of this performance assessment tool (termed the Operation Performance Audit (OPA)) was informed by the tenets of the competence model so it is possible to explore the work of the tool in an effort to see how the competence model benefits it in practice. The second way in which the utility of the competence model is explored involves using the model to re-examine one of the maintenance tasks observed in Chapter 2. If the competence model is appropriate and reflects the core issues then it should be able to explain critical aspects of the task.
observed in Chapter 2. One important question regarding the model relates to how well it can account for the finding that the way in which technicians perform their work in normal everyday circumstances differs significantly from the way in which the work is described in manuals, procedures and job descriptions. If the model can account for the patterns of behaviour which characterise these types of real-life maintenance scenarios then it clearly has some merit. This chapter is structured around two main sections. The first part of this chapter recounts the development and pilot implementation of the OPA tool. The results of the pilot implementation are then used in the second part of the chapter to explore the utility of the model, supplemented by a re-examination of a task observed in Chapter 2.

Assessing Performance

Background

The performance aspects of competence have been neglected up until recently – due in no small way to the dominance of rationalistic approaches to competence. The findings of Chapter 2 speak to the importance of the social aspects of maintenance tasks and the collaborative way in which they are performed. These social aspects of maintenance relate to the practice of human factors; to the performance of tasks in a social process. Not only that, we have seen in Chapter 3 how performance and practical aspects of competence are woefully represented in human factors and practical training. Bramming and Larsen (2000) were the only theorists to specifically address the performance aspects of competence. The OPA tool privileges the performance-related elements of the competence model and while it doesn’t allow us to explore the utility of all elements of the competence model it does allow us to explore the most under-explored aspect of competence: performance. Using a heuristic approach such as this may not allow a full evaluation of the competence model but it does give an important insight into one of the most critical elements of competence.
The OPA is included in the thesis not in order to validate the competence model advanced in the previous chapter, but to explore the utility of the competence model in explaining important aspects of performance. The OPA was developed as part of the ADAMS 2 project and was focused on developing a performance assessment tool for aircraft maintenance operations. ADAMS 2 was funded by the EU and the project aimed to develop tools and methodologies which would assist organisations in managing the human aspects of their operation. The focus was on safety and organisational systems and the OPA was intended to be used by organisations to assist them in understanding the pre-conditions for safe performance from an organisational and systems viewpoint. Because of this prioritisation of performance the OPA does not embody all elements of the competence model. The OPA does, however, represent an instantiation of certain aspects of the OPA. In particular, the OPA is included in this chapter in order to examine the way in which one should approach the assessment of competence in relation to the performance elements of the competence model.

As such, in relation to assessing performance, it is clear that ‘Context’, ‘Performance’, and ‘Evaluation’ are the key elements of the model. The prioritisation of Bramming and Larsen’s (2000) perspective should not automatically invite criticism from those who claim, like Chomsky (1965), that performance cannot directly reflect competence. His statement that it is erroneous to focus on performance alone is based on his conception of competence as knowledge. His definition of competence does not allow for a performance element and as such performance and competence (knowledge) are viewed as separate entities. In the model of competence advanced in this thesis, however, it is clear that there is no such dichotomy: competence and performance are not about fundamentally different things, they are merely aspects of the same thing. The ‘Context’ element of the model helps to demonstrate this.

The next section begins by reviewing some assessment methodologies in the aviation and medical domains before moving on to detail some of the drivers for an assessment of aircraft maintenance operations. The chapter then moves on to the OPA method for assessing the performance of aircraft maintenance operations.
Assessing Performance in Medicine and Flight Operations

High reliability industries such as power generation, flying and medicine have recognised the need to foster and train sets of behaviours which are associated with superior task performance but which are different from the actual technical execution of the task (Fletcher, Flin, McGeorge, Glavin, Maran, and Patey, 2003). These behaviours have been termed non-technical skills but are essentially re-branded human factors skills. CRM (Cockpit /Crew Resource Management) and ACRM (Anaesthesia Crew Resource Management) training courses have been designed to specifically target these behaviours and this was soon followed by the development of assessment methodologies designed to ascertain the effectiveness of these training courses in transferring skills to the operational environment.

Three methodologies in particular have been developed to identify and assess these non-technical skills or human factors skills. They are LOSA and NOTECHS in the flight operations domain, and ANTS in the medical field.

The NOTECHS (Non-TECHnical Skills) system for the evaluation of flight-crews’ non-technical skill was developed as a response to JAR training regulations (Flin, Goeters, Hormann & Martin, 1998). Its goal was to define non-technical skills and to formulate a method of assessing the proficiency of these skills in order to comply with the requirements for the assessment of non-technical skills under JAR regulation. When published, the JAR requirement did not specify an Acceptable Means of Compliance (AMC), and in response the NOTECHS system was developed. The ANTS (Anaesthetists’ Non-Technical Skills) system is an adaptation of the NOTECHS framework to the field of surgery and anaesthesia (Fletcher, Flin, McGeorge, Glavin, Maran & Patey, 2003). There are currently no regulatory requirements for anaesthetists to be trained in human factors but there is an increasing recognition of the need to train non-technical skills in the medical field. LOSA (Line Operations Safety Audit) is a different type of assessment methodology. LOSA encompasses an assessment of non-technical skills but it is more innovative in that it additionally facilitates an organisational approach to performance evaluation.
NOTECHS and ANTS are assessment tools which consist of empirically-established, structured skill taxonomies which are used to assess performance at work such that the efficacy of non-technical skills training can be established. These systems are built around 'skill categories', 'elements' and 'behavioural markers'. Behavioural markers are "observable, non-technical behaviours that contribute to superior or substandard performance within a work environment" (Klampfer, Flin, Helmreich, Hausler, Sexton, Fletcher, et al., 2001, p.10). These assist in structuring the assessment of worker performance such that the behaviour displayed in action can be easily compared to the non-technical skills and can be rated accordingly.

There are a number of problems with these approaches to assessing performance. Firstly, they are undermined by their limited attention. The primary interest of NOTECHS and ANTS is in establishing the efficacy of training. In focusing solely on the transfer of skills from the training to the operational environment there are many aspects of performance which are not considered or explained. The assumption behind these assessment systems is avowedly rationalistic – there is an inference that the only factors determining performance are those that relate to the individual and his or her skills. Assuming that humans are perfectly rational beings means that there is an assumption that people have unlimited access to exhaustive information about the world (Dekker, 2005), and the only factor influencing their performance is their skill-set. The NOTECHS and ANTS systems do not allow for the role of the environment in their approach to performance. In addition the focus of these assessments is on the individual. This, in some ways, reflects training and regulatory perspectives which traditionally have the individual as their unit of analysis (Boreham, 2004). Irregardless, the focus on the individual discounts the role of social processes in performance at work. The assessment systems do contain skills which relate to team-work and communication but they do not account for the way in which social processes can mediate worker performance in relation to other behavioural markers.

In existence for over eight years now, LOSA has proven its utility as an industry-ready tool (currently 15 airlines are involved in running LOSA programmes) and it is
recognised as a valuable new approach to safety, as evinced by ICAO's commitment to, and support for, the programme. Indeed, LOSA was the central focus of the ICAO flight safety and human factors programme for the period 2000-2004. LOSA (unlike NOTECHS) was not developed as a way of licensing individual aircrew. NOTECHS and ANTS are, in essence, training evaluation templates. LOSA, however, is concerned with safety at a broader level. LOSA, as an assessment tool, provides data on performance of two components: the crew and the system. In this way it informs about the functioning of the flight operations system and it evaluates aspects of the organisational system in terms of their impact on performance in flight operations.

This approach is informed by a model of Threat and Error Management (TEM) which has twin foci: the operating environment and the humans working in it. This conceptual framework for understanding operational performance in complex environments is concerned with the way in which performance is influenced by the environment in normal, everyday operations. Research has demonstrated the pervasiveness of minor errors and violations of procedures in highly skilled and professional aircrews (Klinect, Wilhelm & Helmreich, 1999). To a large extent the level of error and violation is situationally determined, diminishing markedly when the level of 'threat' in the operational environment is high, and increasing when the level of threat and demand is low. This has suggested the notion of an envelope of acceptable behaviour which fluctuates according to the perceived threat or demand in the situation. This analysis also prioritises the ability to recover, in a timely fashion, from a 'non-standard' situation (resulting from an error or violation) as being more important than the original error or violation itself.

The TEM model is an attempt to explain these occurrences. Threats are defined as "situations, events or errors that originate outside the cockpit" (Klinect, Wilhelm & Helmreich, 1999, p.683); errors are defined as "a crew action or inaction that leads to a deviation from crew or organizational intentions of expectations" (p.684). The TEM model is central to the success of LOSA and it allows the assessment to move beyond just collecting CRM performance data. Instead the tool can gather data about threats
which come from the environment, and errors which relate to performance, and the way in which they were handled by the crew.

The strength of the LOSA technique is that it provides the opportunity to capture, in a systematic way, the everyday practice and experience of operational personnel. This creates the possibility of adapting the procedural system to the operational reality, while for the first time creating transparency and accountability for actual performance standards. Because of this, LOSA has added very much to the aviation world and particularly within the human factors research domain it has contributed to a confirmed belief in the importance of research on normal everyday operations as a vital source of information on safety and efficiency. Moreover, in acknowledging the environment it has moved beyond the rationalistic perspectives of other assessment techniques. While LOSA does contain behavioural markers, the TEM model serves to give substance to the expressions of abstract skill which are a defining feature of them. While ANTS and NOTECHS base their analysis solely on behavioural markers, LOSA moves beyond this and acknowledges the role of outside factors in influencing behaviour. The next section details some of the considerations relating to assessing performance in aircraft maintenance before moving on to detail the development of the OPA.

**Assessing Performance in Maintenance**

There are myriad reasons why a maintenance organisation might wish to assess the performance of their operations. In general terms there are two main perspectives.

They are:

- Quality: safety, efficiency, reliability, quality
- Personnel and licensing: skills, abilities, selection in, selection out, training, issuing licences

**Quality**

The desire to ensure safe standards in maintenance is an important reason for assessing performance of work tasks. In a safety critical industry such as aviation maintenance it
is vital to have a way of guaranteeing that work is being done properly and safely. An assessment of performance would give organisations a better insight into the realities of their operation and would highlight any problems with the quality of the output of the operational processes. The main motivation here would be to control and improve the safety, reliability and quality of operations.

**Personnel and Licensing**

Performance assessment could also serve a human resources and personnel purpose. Organisations have to make important decisions regarding career progression; such as which applicant is selected for a particular job, and which is sent for training. Oftentimes these decisions are made based on methods which invite bias and prejudice. In the absence of a formally developed method of targeting the variables upon which the decisions are made there is a reliance on intuitive decisions where it is impossible to establish the true nature of the relationship between the criteria and the individual. Assessments of performance provide a more reliable and valid method for discriminating between job candidates and making decisions about the training needs of their workers. Similarly, in terms of licensing it is advantageous for licensing authorities and regulators to be able to use performance data to inform their decisions. In theory regulators already use assessments of performance (albeit in low-jeopardy training contexts) to decide upon the issuance of licences. The assessment of practical maintenance training should include an assessment of performance but Chapter 3 showed how, in practice, this rarely happens.

Interpolating these drivers for an assessment of performance in aircraft maintenance one can see that the critical issue relates to the use to which data generated by an assessment of performance would be put. The outputs of the assessment process can be categorised in an alternative way: in terms of those upon whom the assessment reflects. Would the data be used to reflect on the performance of an individual or a group?
Clearly, an assessment of performance which serves the needs of personnel and licensing functions informs on the performance of an individual. The focus is on establishing the performance of one particular worker in order to make decisions about which personnel should be awarded a licence, promoted, trained and so on. Assessing performance from a quality perspective suggests a shift in focus. Generating data on the performance of an individual worker would not reflect the real way in which maintenance tasks are performed. Chapter 2 has shown how the performance of maintenance tasks relies upon co-operation and social interaction. In gathering performance data to ensure the safety and quality of maintenance work it is important that the data reflect the way in which the work is done. In this sense performance assessments focusing on quality and safety would be best served in gathering data about team or group performance.

The tool described in this chapter (the OPA) was developed to assess performance from a quality perspective. This means that the priority was not the performance of an individual but the performance of teams or groups of people who work together to maintain aircraft. In the aviation industry desires to improve quality are often closely related to desires to comply with regulations. As we will see below the regulator has a large input into quality systems which operate in maintenance organisations. Unfortunately, the regulator seems to be operating under an individualist approach to the performance of maintenance tasks. More than anything else this reflects the fact that traditionally the ‘unit’ with which the regulator deals is the individual: licences are given to individuals not to teams. The ‘individualisation of performance at work’ is something which Boreham (2004) attributes to education and training policy. In order to overcome this bias and in recognition of the way in which regulatory bodies look to advances in research to assist in the formulation of policy it was decided to demonstrate the assessment of performance of maintenance tasks from a new perspective: one emphasising groups, teams and communities.
Quality Audits in Aircraft Maintenance

Aircraft maintenance is a highly regulated industry where maintenance organisations are continually subjected to audits and approvals by aviation authorities covering both quality and operational requirements. Each organisation is required to have a quality system which monitors all operational activities. The quality department in an organisation uses direct auditing, on-site inspection, routine visits to component workshops, statistical trend analysis, quality investigations, incident investigation, disciplinary measures in order to monitor the quality of the work. Quality departments are responsible for ensuring that a satisfactory system of sampling checks is in place to ensure that the documentation and facilities comply with the regulations. These checks (audits) culminate in an audit report which is sent to managers in the company and to the aviation authorities.

These audits have an important role to play in establishing compliance with minimum safety standards. There are two types of audit: internal and external (by either the regulatory authority or the customer). Internal audits usually consist of product audits (e.g., of aircraft or a component), facilities audits (e.g., tools, testing equipment), maintenance error audits (e.g., outcome of an incident investigation), paperwork and documentation audits. In an average company this can result in up to 200 audits per year. The auditing process, almost always, focuses primarily on documentation. It usually involves an assessment of relevant paper work and documentation, informal interviews, checks on training records and certification levels, checks on manpower, serviceable equipment, tooling, and housekeeping. Sometimes site visits are used to audit the physical resources and infrastructure, although actual work behaviour is never audited or sampled.

Traditionally there is a clear demarcation between assessments of an individual and an operation. Individual assessments (of the kind used in training) usually focus on knowledge assessment and are taken to be measures of competence. Individual assessments thus, are seen as a way of determining competence, while audits are seen as a way of determining the quality of the system. Most commonly audits and
assessments gather data that is not closely connected to actual performance. Audits normally concentrate on the documentation which records the work carried out, rather than on how that work has actually been carried out. Assessments concentrate on the technical and human factors knowledge rather than on how that knowledge is implemented in practice.

The differentiation between assessments of individuals and audits of systems is an artificial one which serves to perpetuate the misnomer that aircraft maintenance tasks are performed by individuals. They are not performed by individuals working alone. They are performed by groups of individuals working together (sometimes indirectly) to achieve a common goal. Until such a time that the differentiation between individual and system is abandoned no real progress can be made in relation to the issue of competence as it relates to aircraft maintenance.

In order to overcome this problem the OPA proposes an alternative level of analysis which is unburdened by the problems of individualistic conceptions of knowledge and competence at one end and global abstract notions of systems at the other end. Located somewhere between these two is the idea of an operation: a task, a job. This, it is suggested, helps to bridge the gap between individual assessments and quality audits, and to avoid problems associated with the nomenclature.

From a quality perspective it is preferable to move the focus away from an individual and his/her knowledge while at the same time focusing on the work itself. The implication of the analysis in Chapter 4 is that assessments or audits need to be oriented much more closely to task performance. Task-oriented assessment, however, has proven logistically difficult for the industry as illustrated in the assessment of practical training in Chapter 3. Taking an approach which emphasises individual performance will not represent the realities of organisational life so an operation or a task was chosen as the level of analysis in the OPA. The following section details the development and pilot implementation of the OPA before moving on to address the
extent to which the competence model informing the tool provides a useful framework for addressing the performance elements of competence.

**OPA Development**

*Introduction*

The main objective of the OPA methodology is to gather safety information about normal maintenance operations in a structured way. It is based on two guiding principles: that the key to improving safety is understanding normal operations and that performance is an important characteristic of competence (Bramming & Larsen, 2000). These notions inform the OPA such that the operational aim of the tool is to understand and gather data on three aspects of aircraft maintenance: (i) the contextual situation within which the task was performed; (ii) the behaviour of the workers, and; (iii) the outcome of the task.

The main types of information gathered by the OPA tool are centred on answering a fundamental question; that of "how did the work go?" This provides a unique type of information to quality systems and, as a diagnosis, it informs about performance (good or bad) from a human factors viewpoint.

The OPA is informed by the model of competence advanced in this thesis. The tool is an instantiation of the competence model and reflects aspects of the model in an indirect way. Rather than explicitly building a tool around the structure of the competence model from the front-end, the elements are reflected in the various aspects as background issues. This is detailed later in the chapter. The overriding concern in the development and specification of the OPA tool was to make a tool which made sense to those for whom it was intended (technicians and quality personnel) and which was usable. In this sense the tool is structured with the user in mind, and uses industry-standard terminology rather than psychological terms.
Borrowing heavily from LOSA, the OPA is both a tool and a methodology. The tool consists of a protocol for observing normal maintenance tasks in real situations. This protocol is modeled on the LOSA form but has been adapted for aircraft maintenance activities (see below). Moreover, the OPA is a methodology – it is a way of organising and selecting what to observe, how to gather information and how to bring this all together for analysis and recommendation generation. The OPA borrows from LOSA again – the success of LOSA is attributed by its developers to the strengths of its methodology and the ten characteristics which set it apart from other safety initiatives. These characteristics are detailed later in the chapter. Much of the success of LOSA can also be attributed to its ability to provide information on the performance of an operation as well as worker performance; something which the OPA also builds upon.

**Adapting LOSA for Aircraft Maintenance**

The experiences of LOSA provided a unique learning opportunity for the development of the OPA. The developers of LOSA identified that the successful implementation of LOSA in an airline was attributable to a number of key factors. The researchers have specified a number of these operating characteristics that they believe to be critical to the success of LOSA. Given the similarities in approach between LOSA and the OPA it was important that the ten defining characteristics of LOSA (underlined) were applied to, and adapted for, the OPA (in italics). (See below)

1. **Observations during normal operations** – *an OPA collects safety data about what normally happens in maintenance, it does not evaluate individual technicians.*

2. **Joint technician/management sponsorship** – *support for the OPA must cut across all levels of the organisation and more specifically must have the support of both management and front-line staff if it is to succeed.*

3. **Voluntary participation** – *participation in the OPA is voluntary: employees are free to decline to be observed. In these instances the observers walk away, no questions asked.*
4. **De-identified, confidential and safety-minded data collection** – all data gathered is anonymous and confidential. Trust is critical to the success of the OPA. If technicians do not trust the project they may act in ways that are not normal – something which would undermine the data. Results of the observations are presented at operation or fleet level; individuals are never identified.

5. **Targeted observation instrument** – the OPA tool is specifically designed to target factors which affect performance in normal operations and is based on years of collaborative research with maintenance organisations.

6. **Trusted and trained observers** – the selection of observers that are trained in human factors and the use of the OPA is crucial to the success of the audit. Observers must be trusted by both management and workers from the shop floor.

7. **Trusted data collection site** – experience has shown that in order to convince employees of confidentiality the data should be sent to a trusted data collection site. Researchers from Trinity College, Dublin manage all data and results.

8. **Data verification roundtables** – all data generated by the OPA are subject to quality checks by qualified personnel (shift leaders, technician representatives etc.) to ensure that the observer has not incorrectly logged an entry.

9. **Data-derived targets for improvement** – analyses of the data gathered by the OPA audit will show strengths and weaknesses of the operation. The data are interrogated for patterns which can be improved upon. These improvements then become targets against which future OPA audits are compared.

10. **Feedback of results to front-line operators** – once an OPA program is completed the results are fed back to the technicians (in aggregate) along with the management plan for improvement.

The ten operating characteristics listed above refer to the LOSA and OPA methodologies rather than to the tools. In essence these operating characteristics are specifications for a comprehensive management system which administers all aspects of the implementation of the tool in an operational context. In concept, adapting this for the maintenance domain was easily achieved and the requirements for the management of the process were specified in advance of the OPA pilot implementation detailed later in the chapter. In practice however, operational issues and pressure for
resources in the end-user organisation constrained the implementation and setting-up of a formal management system (this is detailed later in the chapter).

The adaptation of the LOSA tool to the aircraft maintenance domain presented another challenge. The LOSA tool was developed specifically for the flight operations domain and adapting it for use in aircraft maintenance forced a number of changes. These changes were necessitated by fundamental differences between the activities of flying an aircraft in the sky and maintaining one on the ground. ICAO, in attempting to advise maintenance organisations on the differences between CRM and MRM training, has catalogued some of the differences between flight operations and maintenance (ICAO, 2003 (Doc. 9824)). They are detailed in Table 10 (over).
### Table 10: Flight Operations and Maintenance Operations: Some Critical Differences

<table>
<thead>
<tr>
<th>Topic</th>
<th>Flight Operations (CRM)</th>
<th>Maintenance Operations (MRM)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Human Error</strong></td>
<td>Flight crew errors are often classified as active failures as the consequences are usually immediate</td>
<td>Aircraft maintenance technician errors are usually classified as latent failures, when public safety is considered</td>
</tr>
<tr>
<td><strong>Human Factors Training</strong></td>
<td>CMR training emphasises psychomotor aspects because of the immediate effects of mental workload, reaction time, etc.</td>
<td>MRM training emphasises the system’s perspective of maintenance operations. It stresses social and organizational factors.</td>
</tr>
<tr>
<td><strong>Communication</strong></td>
<td>Flight operations communications are mostly “face to face” within the cockpit and immediately interactive with air traffic control (ATC).</td>
<td>Maintenance operations communications are mostly “non-face to face” via technical manuals, work cards, service bulletins, advertisements, etc. Hence, the aircraft maintenance technician is deprived of the non-verbal cues that are present for flight crews.</td>
</tr>
<tr>
<td><strong>Team Composition</strong></td>
<td>Flight crews tend to be homogenous by nature. Crew members generally have similar education and experience to each other.</td>
<td>Aircraft maintenance technicians tend to be diverse in their education and prior experience both from each other and from flight crew.</td>
</tr>
<tr>
<td><strong>Teamwork</strong></td>
<td>Flight crew team size is small and all members are located in the same small working space.</td>
<td>Aircraft maintenance technicians tend to work in large teams on disjointed tasks spread over a large hangar area. There is also multi-team activity where each team has its own responsibilities.</td>
</tr>
<tr>
<td><strong>Situation Awareness</strong></td>
<td>The flight environment changes quickly and sets the scene for active failures.</td>
<td>The maintenance environment can be hectic, although it changes slowly relative to flight operations. Aircraft maintenance technicians must have the situational awareness to extrapolate the consequences of errors over hours, days and weeks.</td>
</tr>
<tr>
<td><strong>Leadership</strong></td>
<td>As with teamwork, the leadership skills required in flight operations focus mostly on intra-team behaviours (i.e. “how to lead the team”) as well as “followership” skills. Interteam interaction is somewhat limited during flight.</td>
<td>In maintenance organisations, supervisors or team leaders are frequently intermediaries between many points of contact in different departments or sections. Aircraft maintenance technician leaders must therefore be skilled not only in intra-team behaviours (for their own teams) but also in handling team “outsiders” (personnel from other shifts, departments or work groups, etc.). These “outsiders” also vary widely in experience, mannerisms, etc.</td>
</tr>
</tbody>
</table>

[Adapted from ICAO (2003) Doc 9824]
Table 10 (previous) highlights some of the important differences between aircraft maintenance and flight operations. Chief amongst these are communication, team composition and teamwork.

Maintenance workers deal with many support departments when performing their work, including planning, quality, parts, airline representatives, crew-managers and check managers. Communication with these departments is often indirect, involving the use of documentation, such as service bulletins, AMMs, task cards and order forms. When compared with flight crew communication the differences are obvious. Flight crew communications are limited to the crew themselves and air traffic control (ATC) and for the most part this communication is verbal and direct. Regarding teamwork, while both maintenance and flight deck personnel all work as part of some type of team the nature of that teamwork is different. The flight deck has a defined team which is quite rigid in terms of membership (a first officer, a captain, and ATC), maintenance operations on the other hand are characterised by flexible work teams, the composition of which changes frequently and without advance notice. Thus, the teamwork required on the flight deck is focused within the crew (intra-team work), maintenance operations require a different approach – one emphasising teamwork between teams (inter-team work).

Maintenance personnel, it is clear, work in a way which is more closely integrated in the organisational structure of the maintenance organisation. The work of flight crew, on the other hand, is characterized by the boundaries of an aircraft in flight and the limited channels of communication that are available (between the flight deck and ATC) when working remotely from the organisation. This tight coupling of maintenance personnel and the maintenance organisation invites an element of unpredictability and variance in terms of the social structure which supports the work and conditions under which the work is performed (McDonald, 2005).

This evidence suggests that there are important differences between maintaining aircraft and flying them. In adapting a flight operations auditing tool and methodology
for the maintenance domain this must be borne in mind. LOSA focuses on a single flight in its efforts to describe human activity in a system. A single flight (and its constituent elements; take-off, cruise, landing, etc.) is the unit of description in auditing performance in flight operations. As discussed above the work of maintaining aircraft takes place in a more complex context that does the work of flying aircraft. The development of the OPA, thus, forced choices about the natural unit of description for aircraft maintenance operations.

Unit of Description or Analysis

As discussed earlier in the chapter, the purposes of an analysis play a critical role in informing the focus of that analysis. The OPA is driven by quality reasons: the tool aims to ensure safe standards in maintenance by auditing performance. So, what level of performance description is the most appropriate for looking at the role of human activity and system effectiveness in a maintenance operation? If a single flight is the natural unit of activity in flight operations what is the natural unit of performance in aircraft maintenance?

In flight operations the natural unit is arguably a single flight. Every flight consists of a number of phases: preparation and aircraft checks, taxiing, take-off, cruise, descent, approach, and landing. All flights, irrespective of distance, duration, aircraft type, etc., follow this same sequence. Each phase in the sequence has its own internal structure of tasks to be performed by the flight crew and procedures governing these tasks. It is natural, thus, that this sequence of activities representing a flight is seen as the basic performance unit in flight operations.

In aircraft maintenance things are less clear-cut. There are two main performance units: one is a check, the other is a task. From a management perspective the significant unit of analysis is the check. As detailed in Chapter 1 aircraft maintenance is organised around ‘checks’ which specify the tasks to be performed and the intervals at which this work must be done (usually prescribed by flight cycles, or hours flown). Checks can
vary in length from a few minutes for a line maintenance check during an aircraft turnaround between flights to thousands of hours for a comprehensive ‘C’ check. Each check consists of individual tasks which must be performed but the number of tasks and time taken to complete varies considerably: ‘C’ checks can last several weeks and may require scores of specialised personnel. At another level (from a human factors perspective) it could be argued that the basic level of performance is the individual task specified by a task card and allocated to a technician or group of technicians to complete. Again, such a task might take from a few minutes to check and maintain an oil level to several work shifts with a team of technicians to dismantle inspect repair, reassemble and test a substantial component of the aircraft (McDonald, 2005).

The OPA takes the task card as its unit of analysis. The OPA is a tool which prioritises the performance of work in normal circumstances in an attempt to gather data about competence and the safety strengths and weaknesses of an operation. Focusing on a whole check was dismissed on grounds of pragmatism. It is not physically possible for an observer (or a group of observers) to examine and witness all elements of a check. The lengthy nature of maintenance checks precludes a thorough observation. Similarly, checks take place in large hangers with work undertaken over a large geographical area thereby hindering any attempts to observe all aspects of the work. The only feasible level of analysis for a performance assessment tool is that of task (as defined by a task-card).

De-composing maintenance tasks

Aircraft maintenance tasks are performed as part of a check process. The activities of a check have a natural sequence from the planning and scheduling activities to the final review meeting. The main activity is the completion of tasks (as directed by task-cards) that are specified in the check. There are many types of aircraft maintenance tasks: including routine task-cards planned for the check, non-routine task-cards raised during the check, and tasks involving additional work arising from airworthiness directives and other sources. Some of these activities require the supply of spare parts which may or may not be in stock, or necessitate the use of specialised equipment which may be
shared across different parts of the maintenance organisation or may even have to be
hired in. These varying activities will also require different levels of co-ordination
between different personnel – including check manager, airline representative, crew
managers, planners, parts supply, repair work-shop, licensed technicians, inspectors
and approved engineers (depending on the national system), and other unlicensed
technicians and apprentices (McDonald, 2005).

LOSA decomposes the unit of analysis (a single flight) in a temporal order according
to the sequence of flight set out in official procedures. The task begins with
preparation and aircraft checks, taxiing to the runway, take off, cruise, approach,
landing and ends with final taxiing to the destination stand. A similar approach was
taken with aircraft maintenance tasks. The OPA decomposes any maintenance
operation into three key stages:

1. Job set-up
2. Procedure
3. Close-up

This is based on the Airbus* classification system which is used in all documentation
produced by the manufacturer. Boeing documents decompose maintenance tasks in a
similar way. This is an appropriate method of decomposing maintenance tasks as it is
one which is deemed by the manufacturer to apply to all maintenance tasks (it appears
on all task cards), it is a system with which all maintenance personnel are familiar, and
it directs and structures the analysis in a consistent way. The main types of information
gathered by the OPA tool are centred on answering a fundamental question; “how did
the work go?” This information is sought from each of the three phases of maintenance
tasks: Job Set-up, Procedure and Close-up. The data gathered from each of the phases
of the task informs about the behaviours of the technicians working on the task. These
behaviours have been further classified into ‘Planning’, ‘Execution’, and

* Airbus uses an additional category (entitled ‘Reason for the job’) in its maintenance manual. This
category is included in the forms but is not considered a constituent element of the temporal order of
maintenance tasks and as such is not included in this categorisation.
'Review/Modify' behaviours. This classification is directly borrowed from LOSA and is included in the OPA because of the ease with which the concepts can be understood by technical personnel and the fact that the terms are relatively devoid of jargon.

But this is only part of the picture which the OPA tries to recreate. Context is as important as behaviour. In order to fully understand behaviour we must consider, and take account of, the context in which that behaviour occurred. Similarly, the outcome of behaviour is as important as the context in helping us to assess human and system performance. Thus, there are two further foci of the OPA (in addition to the behaviours). These are the contextual situation within which a task was performed, and the outcome of the task. So, in total there are three areas of a task which are of interest to the OPA:

1. The context in which the task was performed;
   Are documentation, tools, parts, equipment, etc. available and adequate? Are appropriately skilled workers are available, etc?

2. The behaviours of the workers;
   How do workers actually perform – what actions do they take?

3. The outcome of the task.
   Was the task performed on time? Were there any re-dos? Were there any quality or safety occurrences once the aircraft was released to service?

In order to ensure the OPA is user-friendly the tool uses simpler terms to describe two of these areas of interest. The context in which the work is undertaken is termed ‘Input Conditions’, and the outcome of the task is termed ‘Outputs’; the final category remains unchanged – ‘Behaviours’. These three foci are more easily understood and remembered using this terminology and are included to assist observers in remembering where it is that they should focus their attention when they are observing a task. The overall structure of the tools is depicted in Table 11 (below):
Table 11: Overall Structure of the OPA Form

<table>
<thead>
<tr>
<th>Foci of the OPA</th>
<th>Data Gathered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input conditions</td>
<td>Information</td>
</tr>
<tr>
<td></td>
<td>Expertise</td>
</tr>
<tr>
<td></td>
<td>Resources</td>
</tr>
<tr>
<td>Behaviours</td>
<td>Job Set-up</td>
</tr>
<tr>
<td></td>
<td>Planning Behaviours</td>
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<tr>
<td></td>
<td>Execution Behaviours</td>
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<tr>
<td></td>
<td>Job Procedure</td>
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<tr>
<td></td>
<td>Execution Behaviours</td>
</tr>
<tr>
<td></td>
<td>Review / Modify Behaviours</td>
</tr>
<tr>
<td></td>
<td>Job Close-up</td>
</tr>
<tr>
<td></td>
<td>Execution Behaviours</td>
</tr>
<tr>
<td></td>
<td>Review / Modify Behaviours</td>
</tr>
<tr>
<td>Outputs</td>
<td>Task Completion</td>
</tr>
<tr>
<td></td>
<td>Quality issues</td>
</tr>
</tbody>
</table>

The OPA form is structured around the contextual situation within which the task was performed, the behaviours of the workers, and the outcome of the task (i.e. the inputs, the outputs and the behaviours associated with task performance). This structure emerged from analyses of the LOSA form and from development activities undertaken at Company B. A number of maintenance tasks and checks were observed using the broad categories borrowed from LOSA. This work showed that the structural framework of the LOSA tool adequately represented the realities of aircraft maintenance, although some changes were needed: the behavioural markers had to be adapted to maintenance activities although the categories of behaviour (planning, execution, and review/modify) proved useful. Similarly the inputs and outputs needed to be changed in line with the ICAO document on the differences between CRM and MRM.
Behavioural Markers for Aircraft Maintenance

The OPA is based closely on the LOSA tool and methodology. While the OPA relies heavily on the LOSA methodology there are important differences between flight operations and aircraft maintenance which necessitated some development work before the OPA could be piloted. LOSA provided the structure and the framework for the OPA but the unit of analysis and its constituent elements together with the behavioural markers themselves needed tailoring to the aircraft maintenance domain.

The term 'behavioural marker' refers to "observable, non-technical behaviours that contribute to superior or substandard performance within a work environment (for example, as contributing factors enhancing safety, or in accidents and incidents in aviation)" (Klampfer, Flin, Helmreich, Hausler, Sexton, Fletcher, et al., 2001, p.10). Care was taken to define the behavioural markers in such a way that they describe both individual and group behaviours. The OPA is not an individual assessment method: it is concerned with non-technical skills and for the most part non-technical skills relate to the interface between people. The OPA assesses the safety and performance of maintenance operations by observing behaviour and relating that behaviour to the context in which it was performed, the outcome of the task and the threats and errors which may have occurred. In this sense, the behavioural markers themselves are not the most important aspect of the tool: they merely direct the data gathering in specific ways. The behavioural markers specified in the OPA forms (below) are just a collection of suggested behavioural markers which best-practice and experience suggest are related to exemplary performance of aircraft maintenance tasks. Ideally the behavioural markers would be research-developed; that is, developed and specified as a result of a dedicated research project. This was beyond the scope of the project which developed the OPA, so instead best-practice principles and research experience informed the choice of behavioural markers that appear on the OPA forms.

Three categories of behaviour were specified (based on the LOSA categories): 'Planning', 'Execution', and 'Review/Modify' behaviours. The phase of the task delimits certain categories of behaviour as set out above in Table 11. The exact
behaviours subsumed in each category vary according to the task phase. For example, there are slight differences between the ‘Execution Behaviours’ in the Job Set-up and Job Procedure phases (see the OPA forms later in the chapter for more details).

**Threat and Error Management**

As discussed earlier, the LOSA methodology differs from other methods of assessing non-technical skills in that it moves beyond behavioural markers and adopts the TEM model. This approach was adopted in the OPA. As such the tool gathers information about any threats that exist in the environment; any steps the workers took to minimise or reduce the threat; and the outcome of those actions. In the event that the threat leads to an error, or an un-associated error occurs, the OPA gathers information about the nature of the error, the actions taken to manage the error, and the final outcome. These data are gathered by the Threat and Error Management worksheets that are found at the end of the OPA forms.

**The OPA forms**

The finalised OPA forms used in the pilot implementation are presented in Appendix D.
OPA Piloting

Introduction
The main objective of this task was to pilot-test the implementation of the OPA in a maintenance organisation and gather information about the way in which maintenance was performed in a company. Following on from the initial development work a pilot implementation of the OPA took place in Company E. This company is a small European airline which has a small, but growing, maintenance operation. The pilot implementation of the OPA tool took place in Company E’s maintenance organisation over a four-month period.

Implementation Procedure

The OPA was designed to follow a sequence of general steps set out as follows:

1. Identify tasks suitable for observation
2. Observe tasks
3. Complete the OPA forms
4. Conduct a round table analysis (to ensure consensus)
5. Generate recommendations for improvement

Steps 1-3 comprise the data collection phase and should be repeated in line with the focus of the OPA strategy. Randomised strategies can be pursued in cases where a general indication of normal operations is required or specific strategies can be pursued when there is a specific reason for carrying out the OPA (e.g. choosing only tasks on certain aircraft types, choosing only tasks performed in certain hangars etc.). Data gathering is followed by analysis: represented by steps 4 and 5 above. In this phase quality, training and operational personnel review the data and propose solutions to simple problems.

Before the tool could actually be used in Company E, observers had to be selected and a period of training had to be conducted. These are detailed below.
Personnel

Two quality inspectors, both of whom were former maintenance technicians and were promoted from the shop-floor, were selected to act as OPA observers. They each had a couple of years of experience in the quality role but prior to this they had worked in technical roles in the organisation for over 10 years each. Both had previously received basic human factors training. This profile made them the most suitable observers for the pilot implementation. In ideal circumstances the observers would come from the shop-floor. Language and human factors experience in this instance, however, dictated the choice of observers. The organisation was only beginning to institute a human factors training programme and only a small number of personnel had been in receipt of human factors training. Of those who were trained, only three people had experience of ever maintaining aircraft, and of those three only two spoke English. These pragmatic issues were primary considerations in the choice of OPA observers.

Training

Both quality inspectors were trained in the use of the tool. The training took up one afternoon and covered the rationale and logic of the tool. The small number of observers meant that the training was conducted in an informal manner: more like a discussion rather than a lecture. The observers engaged in discussion about the role of such a tool. With the logic and rationale explained the training became more focused on the tool: the decomposition of a maintenance task, the categories of behaviour and the method of ranking. The methodology was explained and at the end of the training each observer completed a trial form before clarifying any ambiguities that remained. The first stage of the implementation involved the participation of the researcher (see below).

Observation

The implementation was conducted in a two-stage process. Initially the researcher/tool-developer acted as an observer (Phase 1). In Phase 2, a full implementation was initiated whereby the trained OPA observers used the tool without any support from the researcher/tool-developer. Table 12 (over) illustrates this:
Table 12: OPA implementation phase and observers involved

<table>
<thead>
<tr>
<th>OPA Implementation</th>
<th>Observers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>Researcher/tool-developer and end-user contact</td>
</tr>
<tr>
<td>Phase 2</td>
<td>End-user contacts alone</td>
</tr>
</tbody>
</table>

In the first stage the researcher/tool-developer was closely involved in guiding the end-user organisation in the use of the tool. This was necessary as it was the first time that the OPA tool was used in an end-user organisation to assess operational performance, and while the two quality inspectors had been in receipt of training in the rationale and logic of the tool it was felt that a transition period from training to practice would be beneficial to the trainees as they become acquainted with the methodology.

In the first phase of the implementation, the OPA forms were completed jointly by the researcher and the two trained OPA observers (both quality inspectors). This avoided any difficulties that may have arisen due to inexperience on the part of the observer. Two observers, the researcher/tool-developer (a human factors expert) and one of the quality inspectors (a technical expert), jointly ranked and assessed task performance. This arrangement was advantageous because the researcher/tool-developer had no real maintenance experience and lacked the ability to identify technical behaviours and the quality inspector (technical expert) has limited experience of the tool and needed guidance to work through it. This created a need for the researcher/tool-developer to work closely with the observers in the first stage of the implementation.

In the second phase of the implementation process the researcher/tool-developer was not involved in any aspect of data collection and the end-users were left to implement the tool and methodology without the involvement of the researcher/tool-developer.
Selecting Tasks

In the first phase of the OPA implementation it was decided to observe a range of maintenance tasks (non-routine/defect cards, routine cards, inspection cards) so as to fully test the tool’s ability to be used for all types of maintenance tasks. In order to understand the situational determinants of performance in each of these tasks it was further decided to observe the full range of tasks all from the same check. That way the analysis would explore the extent to which the tool could handle different activities all the while controlling for (and understanding) the external conditions which related to the context in which the task was performed. A night-time A3 check on a CRJ 200 lasting approximately 9 hours was duly observed by one of the quality inspectors together with the researcher: performance was jointly rated using the standardised OPA tool. The length of the check was such that it would allow the observers to see the whole check from beginning to end and understand the conditions under which the tasks were being observed in order to facilitate a considered understanding of individual tasks and situational determinants relating to the context in which the work was being done. The idea was that a number of tasks would be observed during the 9-hour check, and an OPA form would be filled out for each task. A number of different task-card types were identified as being suitable for observation in the days prior to the check. They were chosen in order to represent the range of different types of tasks that composed an A3 check. Thus, the strategy was to observe at least one of each task category type and if time allowed to observes multiples of the same task category type. This meant that routine and inspection task cards, together with defect/non-routine task cards would be observed.

Notwithstanding the careful planning and selection of the task-cards, work began on all the identified tasks at the same time – during the last four hours of the check. Given that each task had to be observed by both the researcher and the end-user observer it was not possible to observe all the tasks as planned. In fact, only one task was observed from beginning to end. This was disappointing but on a return trip to the maintenance company, some time later, three additional tasks were observed, making a total of 4 tasks which were observed collaboratively by the researcher and a quality inspector.
The second phase of the implementation did not involve the researcher in the observations. Important lessons had been learned about choosing tasks to be observed and the quality inspectors used an opportunistic sampling method to collect data. Over a two month period the quality inspectors took it in turns to look out for tasks that could be observed in their entirety. Over this period 5 forms were completed, making a total of 9 completed OPA forms. These forms were then returned to the researcher for analysis before a round-table session was held at the organisation to reach consensus on each of the completed forms.

Chaired by the researcher/tool developer, and attended by the quality personnel, the meeting sought to discuss each completed form and provided a forum for questions and queries to be answered, outstanding uncertainties to be resolved and final ratings to be agreed by all three. The final stage of implementation involved evaluation of the OPA tool. Two standardised evaluation protocols were used to evaluate the OPA. Both quality inspectors from Company E completed each of the forms. The evaluation results are documented in a separate report contained in Appendix E.

Implementation Results

Implementing the OPA (as discussed earlier) consists of two phases: gathering data and analysing data. In the data collection phase there were some operational difficulties which reduced the number of observations which could be conducted. Despite these problems a total of 9 OPA forms were completed: 5 forms completed by the end-user and 4 forms jointly completed by the end-user and the researcher/tool-developer (over two visits). The tasks observed were as follows:

Phase 1: Researcher/tool-developer & End-user forms

1. Lubrication of the thrust reverser tracks and ball-screw actuators
2. Cable adjustment in Cockpit
3. Adjustment of Spoiler Proximity Sensors
4. In-board and out-board Flap Installation
Phase 2: End-user forms

5. Removal of the engines
6. Engine Run test
7. Functional Check of Control Sensors
8. A2 Scheduled Check on LH & RH engine
9. Scheduled Borescope Inspection of LH & RH engine

The second stage of implementing the OPA (analysing the data and generating recommendations) was similarly beset with operational constraints, but these problems proved more difficult to overcome.

Firstly, the amount of data generated by the implementation was considerably less than was expected. It proved difficult to observe tasks from beginning to end in a busy operational environment. Technicians manage their tasks quite flexibly and tasks are not always completed in a linear way. The temporal sequence in which a task is completed is dynamic and influenced by many situational factors. A task might be started in the morning, then the technician is called away to assist on another job, he may return to the original task a number of times during the day; only to finish it towards the end of his shift. In these situations it is nigh on impossible to observe the task for the purposes of the OPA. In addition, there is evidence that the language barrier impacted upon the quality of the data gathered in the OPA. The forms have narrative sections at critical junctures in task performance which supplement the behavioural markers. These are included in an attempt to add some richness to the data – the qualities that are lost in data gathered in structured protocols. English was a second language for the OPA observers and while they are proficient in speaking the language unfortunately their unwillingness, and inability, to write detailed descriptions of the tasks meant that a crucial source of data was lost. This means that only limited conclusions can be drawn from the paucity of data.

Secondly, the implementation process was designed to conclude with the generation of a set of recommendations for improvement; unfortunately this stage was not reached
with the OPA. The organisation was unable to engage in anything more than a simple
analysis of the results and no recommendations or plans for improvement were
generated. The reasons for this are related to a lack of resources in the organisation,
and an unwillingness to embark upon a process of organisational change. This was
motivated by the company’s concerns about the unsettling effects this would have on
the organisation which was already experiencing a period of considerable growth and
change. In general terms the pilot implementation realised its goals – it did gather data
which can be analysed – but the data are limited and the analysis and recommendation
generation phase was not achieved.

The results of the OPA provide us with information about three aspects of the tasks
observed:

- the contextual situation within which the tasks were performed
- the behaviour of the workers and
- the outcome of the task

Regarding the context in which a task was performed the OPA tells us about the inputs
to the task performance. These relate to information, expertise and resources. The tool
gathers data on the information which supports task performance: are manuals and any
other official documents available and are they adequate? Many times, as experienced
in the tasks observed in Chapter 2, tasks are performed using manuals which are
deficient in important ways. The OPA also tells about the resources which were
available to workers at the time of performing the task. Were there any problems with
tools, parts, materials or equipment, for example? In addition the OPA provides a way
of documenting whether there was an adequate complement of workers to successfully
complete the task and if the workers had experience in performing the task before.

The OPA assesses the safety and performance of maintenance operations by observing
behaviour and relating that behaviour to the context in which it was performed, the
outcome of the task and the threats and errors which may have occurred. The
behavioural markers are only one way in which the behaviours of the technicians was
assessed. The threat and error management worksheets are a critical aspect of the tool as they manage to capture information about the behaviours of workers at critical junctures: where threats and errors conspire to compromise the safety of the system. As stated earlier in the chapter the behavioural markers chosen for the OPA represent one possibility. There are unlimited numbers and combinations of behavioural markers which can be used to gather data about performance. The behavioural markers specified in the OPA are based on the researcher’s interpretation of the maintenance task as informed by the research which is reported in this thesis and from the maintenance human factors domain in general. As such they reflect a generic take on maintenance tasks and may not adequately reflect the behaviours which are valued in a particular organisation. The point is that an organisation which wishes to use the OPA can, unilaterally, develop their own behavioural markers which reflect the practices of their organisation. While the logistical difficulties associated with an activity such as this are duly acknowledged, the possibility still stands.

Regarding the outcome, the OPA gathers information about four aspects of task performance. They relate to both quality and efficiency concerns. The first concern is whether the task was completed on time (an efficiency concern). Then there is the issue of whether there were any quality, or safety, issues which were noticed either immediately after the task has been completed or once the aircraft has gone back into service.

The data gathered by the OPA (and presented directly below) are based on a pilot implementation of a newly developed tool. The observers using the tool were engaging for the first time with the tool and it is likely that their inexperience has impacted upon the ratings given to aspects of performance. Similarly, the limited nature of the data (as discussed earlier) gives rise to a situation where it is difficult to draw out implications from the results of the OPA implementation. Nonetheless the results do give an indication of the way in which the tool can describe and represent human aspects of aircraft maintenance tasks and it is this aspect of the results that will be explored herein.
The Data

Owing to the limitations noted earlier in relation to the implementation of the OPA and the data gathered during implementation this section details, in general terms, the findings of the study. Rather than list the data gathered in relation to each task or conducting analyses of overall trends (as would be expected of a full-scale implementation) the results have been structured around the three foci of the OPA: Inputs, Behaviours and Outputs. Under these headings the general findings are then discussed (below). Of the nine tasks observed only one provided a sufficient amount of data to justify presenting the results individually. Following a discussion of the general findings this task will be explored in more detail as an illuminating example. In doing this we are better able to use the OPA data to draw conclusions about the utility of the competence model.

The OPA has three foci (listed below) and gathered information about the performance of the nine tasks observed in relation to each of them. They are as follows:

Inputs

The inputs to task performance relate to (i) Information, (ii) Expertise, and (iii) Resources. In all tasks observed the documents and manuals that were required for the task were all available and adequate. The same was true for all tools, parts and equipment which were required of the tasks. Regarding expertise, in most cases there was a sufficient number of appropriately trained personnel. It is clear, thus, that all inputs which an organisation provides for its operations were in place.

Behaviours

The behaviours of workers were targeted using the threat and error worksheets and also the behavioural markers. Regarding the behavioural markers, what is presented here is a synopsis of the behaviours which were ranked as being 'poor' and 'outstanding' by the observers. These are the behavioural markers which received the lowest and the
highest ratings. In this way we can see what were perceived, by the observers, to be the strengths and weaknesses in the workers performance.

**Behavioural Markers**

‘Document Usage’, ‘Anticipation’, and ‘Use of Procedures’ were the three main problem behaviours as determined by the frequency with which these behaviours attracted the lowest score. In 5 tasks ‘Document Usage’ was rated as poor, in 4 tasks ‘Anticipation’ was rated as poor, and in three tasks ‘Procedures’ was rated as poor. Clearly the observers were unhappy with the extent to which technicians consulted the documents and procedures in Company E. Similarly, there seems to be some dissatisfaction that in addition to this the procedures were not actually being followed. Anticipation was also cited as a weakness in task performance: technicians did not show evidence of anticipating problem situations and no contingencies were put in place for any unanticipated occurrences.

‘Evaluation of Plans’, ‘Checking’, and ‘Supervision’ were the three main exemplary behaviours (respectively) as determined by the frequency with which these behaviours attracted the highest score. In 5 tasks ‘Evaluation of Plans’ was rated as outstanding, in 4 tasks ‘Checking’ was rated as outstanding, and in four tasks ‘Supervision’ was rated as outstanding. Clearly the strengths of the operation in Company E relates to the ability of workers to critically evaluate their plans and consider their suitability in light of changing circumstances. The observers were suitably impressed with the fact that technicians were sure to check the work done to establish that it was complete and correct. Supervision was another aspect of task performance that was repeatedly cited as being outstanding.

**Threats and Errors**

Only two errors were noted in the nine tasks observed; no threats were noted. These two errors occurred on the same task (Task no.3) but were both noticed by a member of the work team and suitable measures were taken to correct the mistake.
The Outcome

All of the nine tasks observed using the OPA in Company E were completed in time and though two errors were noted there were no residual safety concerns. The two errors that occurred were noticed and were rectified, necessitating a small re-do. This re-work took no more that a few minutes and the aircraft were released back to service as per the schedule.

Overview

The results of the pilot implementation of the OPA are limited in a number of respects due to problems with the data collection phase. The findings themselves are not uninteresting (not least for the company concerned) but in terms of this chapter they bring little to the table. What is of more importance in this chapter is to ascertain the utility and effectiveness of the OPA in relating important human aspects of task performance. This can best be evaluated by looking more closely at one of the nine tasks which were observed and documented using the OPA.

Task No.3: An Illuminating Example

What follows (in the next seven pages) is a completed OPA form showing the data gathered in relation to a task observed in Company E. This task (task 3) involves the adjustment of spoiler proximity sensors on the aircraft wing and was chosen as an illuminating example because it was the only task which had complete error management forms and as such represented the most complete set of data in relation to a particular task.
OPA Observation Form

Input conditions

<table>
<thead>
<tr>
<th>Information</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PFR</td>
<td>Available? Y / N</td>
<td>Adequate? Y / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service Bulletin</td>
<td>Available? Y / N</td>
<td>Y</td>
<td>Adequate? Y / N</td>
<td></td>
</tr>
<tr>
<td>AMM/ IPC</td>
<td>Available? Y / N</td>
<td>Y</td>
<td>Adequate? Y / N</td>
<td></td>
</tr>
<tr>
<td>Troubleshooting Manuals</td>
<td>Available? Y / N</td>
<td>Y</td>
<td>Adequate? Y / N</td>
<td></td>
</tr>
<tr>
<td>Wiring Diagram Manuals</td>
<td>Available? Y / N</td>
<td>Y</td>
<td>Adequate? Y / N</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expertise</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Job allocated by? (Supervisor? Check manager?)</td>
<td>Team leader</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>When (if ever) task was last performed by personnel?</td>
<td>Last month</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adequate number of personnel?</td>
<td>Y / N</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skill set of personnel appropriate?</td>
<td>Y / N</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have personnel received OJT on task?</td>
<td>Y / N</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional personnel were drafted?</td>
<td>Y / N</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resources</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tools</td>
<td>Available? Y / N</td>
<td>Y</td>
<td>Adequate? Y / N</td>
<td></td>
</tr>
<tr>
<td>Parts</td>
<td>Available? Y / N</td>
<td>Y</td>
<td>Adequate? Y / N</td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td>Available? Y / N</td>
<td>Y</td>
<td>Adequate? Y / N</td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>Available? Y / N</td>
<td>Y</td>
<td>Adequate? Y / N</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task Type</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-routine</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scheduled</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unscheduled</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrective</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preventative</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reason for the Job / Job Introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrative: Please provide a brief description of the reason for the job...why is it being done?</td>
</tr>
<tr>
<td>Engineering order - Manufacturer recommended the modification. The operator chose to include it on the C check that the aircraft is undergoing. It's a good opportunity to do this kind of work.</td>
</tr>
</tbody>
</table>
Behaviours

Job Set-up

Narrative
Please justify behavioural ratings. Tell exactly what happened in general terms.
What was done well? What was done badly? How were threats, errors and significant events handled?

Overall average performance. Planning was poor though - they didn't get correct tools. Failed to anticipate any unexpected occurrences, had to visit stores three times (they could have anticipated this at the beginning), this took a lot of time. Use of documents was good - looked at the AMM regularly (had to use IPC on computer later on).

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Poor observed performance had safety implications</td>
</tr>
<tr>
<td>Marginal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Marginal observed performance was barely adequate</td>
</tr>
<tr>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Good observed performance was effective</td>
</tr>
<tr>
<td>Outstanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Outstanding observed performance was truly noteworthy</td>
</tr>
<tr>
<td>Not observed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Not observed</td>
</tr>
</tbody>
</table>

Planning Behaviours

<table>
<thead>
<tr>
<th>Plans Stated</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational plans and decisions were defined</td>
<td>Plans were communicated and acknowledged - everybody understands operational plans and what will be happening</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task Priority</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Importance of task re: efficiency/safety criticality is communicated and acknowledged</td>
<td>Everybody knows importance of the task (e.g. task is the lead item on the check)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task allocation</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tasks and activities are communicated and acknowledged</td>
<td>Everybody aware of their role and responsibilities and “knows what to do”</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Anticipation</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategies for anticipation of problem situations are prepared</td>
<td>Possible delays/problems are identified and contingencies are in place</td>
</tr>
</tbody>
</table>

Execution Behaviours

<table>
<thead>
<tr>
<th>Tools/doc/parts/materials procurement</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tools etc. have been sourced in a timely way</td>
<td>Tools etc. are available and ready to be used</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supervision</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management personnel actively supervised subordinates</td>
<td>Managers asked about progress and offered advice</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Document usage</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant documents were used to support task performance</td>
<td>Operatives/management actively consulted documents during task</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Monitoring</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operative personnel actively monitored their own performance and that of workgroup members (if any)</td>
<td>Keeps track of task supports (docs, tools, parts) and checks progress to see what is done and what is yet to do</td>
</tr>
</tbody>
</table>

253
fob Procedure

Narrative
Please justify behavioural ratings. Tell exactly what happened in general terms. What was done well? What was done badly? How were threats, errors and significant events handled?

Docs were used to guide task performance (though they didn’t follow procedures step-by-step). This job was excellent in terms of inquiry, assertiveness and evaluation of plans. Supervision and monitoring was excellent. A junior technician who had much experience of this task noticed and highlighted two mistakes: 1. spacer between nut and bolt was incorrectly aligned 2. lockwiring was incorrectly applied (wrong direction). The junior technician highlighted the mistake of a senior technician quite readily. The team also asked other staff if the lockwire was correctly applied. Plan to redo some of the work was developed when they noticed their mistaken application of the spacer.

<table>
<thead>
<tr>
<th>Execution Behaviours</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Document usage</td>
<td>Relevant documents were used to support task performance</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Procedures</td>
<td>Relevant procedures were followed to support task performance</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Supervision</td>
<td>Management personnel actively supervised subordinates</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Operative personnel actively monitored their own performance and that of workgroup members (if any)</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Review/Modify Behaviours</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inquiry</td>
<td>Questions were asked to investigate and/or clarify plans</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Assertiveness</td>
<td>Critical information and/or solutions were offered confidently</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Evaluation of plans</td>
<td>Existing plans were reviewed and modified when necessary</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>
Job Close-up

Narrative Please justify behavioural ratings. Tell exactly what happened in general terms. What was done well? What was done badly? How were threats, errors and significant events handled?

Unfortunately it was not possible to observe this part of the task for operational reasons.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>Marginal</td>
<td>Good</td>
<td>Outstanding</td>
<td>Not observed</td>
</tr>
<tr>
<td>Observed performance had safety implications</td>
<td>Observed performance was barely adequate</td>
<td>Observed performance was effective</td>
<td>Observed performance was truly noteworthy</td>
<td>Not observed</td>
</tr>
</tbody>
</table>

**Execution Behaviours**

<table>
<thead>
<tr>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring</td>
</tr>
<tr>
<td>Operative personnel actively monitored their own performance and that of workgroup members (if any)</td>
</tr>
<tr>
<td>- Keeps track of task supports (docs, tools, parts) and checks progress to see what is done &amp; what is yet to do</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>Checking</td>
</tr>
<tr>
<td>Operatives ensure work is done in accordance with procedures and best practice guidelines</td>
</tr>
<tr>
<td>- Operatives check their own work to ensure it is complete and correct</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>Inspecting</td>
</tr>
<tr>
<td>Managers inspect work done to ensure it is complete and was performed correctly</td>
</tr>
<tr>
<td>- Managers visually inspect work done &amp; verify verbally that it was done according to procedures</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

**Review/Modify Behaviours**

<table>
<thead>
<tr>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inquiry</td>
</tr>
<tr>
<td>Questions were asked to investigate and/or clarify plans</td>
</tr>
<tr>
<td>Workers not afraid to display a lack of knowledge and lose face</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>Assertiveness</td>
</tr>
<tr>
<td>Critical information and/or solutions were offered confidently</td>
</tr>
<tr>
<td>Workers spoke up without hesitation when necessary</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>Evaluation of Plans</td>
</tr>
<tr>
<td>Existing plans were reviewed and modified when necessary</td>
</tr>
<tr>
<td>Decisions and actions were openly analysed and considered to assess suitability in light of changes</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>Outputs</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td><strong>Task was completed on time?</strong></td>
</tr>
<tr>
<td><strong>Was there any re-do?</strong></td>
</tr>
<tr>
<td>The Spacer had to be realigned and the lockwire had to be re-applied in the right direction</td>
</tr>
<tr>
<td><strong>Were there any quality issues noticed once task was completed?</strong></td>
</tr>
<tr>
<td><strong>Once task was completed and aircraft released to service were there any quality and/or safety issues of which you are aware?</strong></td>
</tr>
<tr>
<td>Error #</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>1</td>
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<td>2</td>
</tr>
<tr>
<td>Error #</td>
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<td>---------</td>
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<tr>
<td>1</td>
</tr>
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<td>2</td>
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</table>
Task 3: Interpreting the data

The data gathered by the OPA in relation to Task No. 3 is used here to answer one fundamental question: how well does the OPA represent the essential features of performance? This is a critical question in that the OPA represents an instantiation of the performance elements of the competence model advanced in the previous chapter. In answering the question about the OPA’s ability to represent and explain the realities of performing maintenance tasks we can ascertain the extent to which the performance elements of the competence model offer a well-founded representation of the issue.

In practice, if the OPA can represent the realities of maintenance operations described in Chapter 2 then it tells us that the performance aspects of the competence model reflect the way in which work is actually performed. In addition it tells us something about the value of the OPA tool. There is an issue relating to the extent to which the OPA’s description of performance is related to the model informing the tool, or whether it is a function of the tool itself. In reality, this is a moot point. A tool can only be as good as the model informing it and we have already discussed the problems associated with the pilot implementation of the tool. In this sense, what is of interest is not the data per se but the types of data gathered and what they tell us about the performance of maintenance tasks.

Firstly, we must expose the ways in which the OPA represents the performance aspects of the competence model. In the model of competence advanced in the previous chapter performance was construed as an essential aspect of competence. Advancing a model of competence without a performance element means that one can offer only mentalistic explanations of competence. The model of competence developed in this thesis holds that there is a social and relational nature to competence and this is manifest in the performance of work. We saw in Chapter 2 how maintenance tasks are profoundly social – technicians, planners, managers and others working together (formally and informally; directly and indirectly) to achieve a common goal. The competence model holds that performance is social and is informed by the context. In an effort to represent this, the OPA targets inputs, behaviours and outputs. By adopting
this framework it facilitates an exploration of the situational determinants, the actions of those workers operating in a community of practice, and the output of their work. The TEM worksheets also represent this aspect of the competence model – recognising that people perform as informed by their context. The social nature of performing maintenance tasks is also reflected in the OPA’s level of analysis. Rather than gather data on individual performance the OPA focuses on the performance of a team or group of workers who collaborate to perform a task. The evaluative aspects of competence are reflected in the ratings which are given to behavioural markers and the assessments that are made in the threat and error management sections of the OPA forms.

The completed OPA form presented above gives us the opportunity to use one particular task as an illuminating example whereby a number of pertinent questions can be answered. The issue here relates to how well the OPA is able to describe and capture the human aspects of task performance in aircraft maintenance. In particular, how well is the OPA able to represent the complicated and intractable issues which characterise aircraft maintenance? Does the OPA do a better job of representing human factors performance and competence than did the ethnography in Chapter 2? In answering these questions we are able to explore the utility and value of the competence model.

The task

Task No.3 (Adjustment of Spoiler Proximity Sensors) was a service bulletin task – a modification ordered by the manufacturer. The task was included in a scheduled check and was not subject to any time constraints or commercial pressure of any kind. It is a group task comprising both senior and junior technicians and mechanics. It was not possible to observe the final ‘Close-up’ section of the task though it was possible to get information about the output of the task.
**Inputs**
The inputs to the performance of the task were satisfactory in most respects. All tools, parts, equipment, and materials were available and adequate. The same was true for the documentation which supported the task. The only deficient input related to the expertise of the workers. While all technicians were appropriately trained and certified to carry out their work, none of the technicians had received OJT in performing this task.

**Behaviours**
The behaviours of workers can be looked at in a temporal manner. For ‘Job Set-up’ the overall behaviour was average. Anticipation was rated as ‘poor’ because (the narrative section tells us) they failed to anticipate some additional tools for which they could have prepared. But the use of documents (including the IPC (illustrated parts catalogue)) was rated as ‘good’. For the ‘Job Procedure’ phase behaviour was rated more positively. Assertiveness, Evaluation of plans and Monitoring, for example, were rated as ‘Outstanding’. The narrative section and the TEM worksheets inform us that two errors occurred but were noticed and brought to the attention of the supervisor. The narrative also tells us that in this phase of the task procedures were not followed “step-by-step”, though official documentation was used to guide task performance. Interestingly, the use of procedures was ranked (in the behavioural marker section) as being ‘good’. As stated earlier the ‘Job Close-up’ portion of the task was not observed for operational reasons.

In terms of the TEM worksheets we can see that two errors were reported. One error related to a misaligned spacer that was placed between a nut and bolt. The second error related to the application of lockwire which was tightened in the wrong direction. The error worksheets detailed that the errors were committed by the senior technician and it was a junior technician who noticed and readily highlighted the mistake of a senior technician. A plan to redo the erroneous work was developed when the work group noticed the mistaken application of the spacer and the incorrect application of the lockwire.
Outputs
The task was completed as per the schedule but there was a small re-do because of the errors described above. There were no other quality issues and the aircraft was safety released to service.

Overview
The performance data gathered on this task present a description of an almost archetypal aircraft maintenance task: there were a number of problems with performance; the system supporting the operations had some deficiencies; but, somehow, the work gets done. The OPA data also demonstrate that the performance of a maintenance task is not about technicians working alone it is about a co-operative synergy where people work together. Getting down to the critical issue regarding the tool’s ability to assess and describe the performance of maintenance tasks, the OPA has shown that it is quite capable of gathering rich data. Let us examine the evidence.

The task detailed in the OPA protocol highlights two particularly effective aspects of the OPA tool: the narrative and threat and error management sections of the form. The narratives at the beginning of each phase of the task serve to provide some important background information regarding the evaluation of the individual behaviours. In this way it allows us to create an accurate account of what actually happened and provides information about the context in which the behaviours emerged. The threat and error management forms, on the other hand, allow us to gather information about the mistakes which characterise normal human performance and the threats coming from the environment which conspire to degrade performance.

The narrative and threat and error sections of the OPA form are central to the effectiveness of the overall tool. This can be demonstrated in reference to the task detailed above. The ratings attached to the review and modify behaviours were all in the ‘Outstanding’ category (a rating of 4). This tells us that workers (as determined by the observer) were assertive and questioning when they had a concern and that plans were appropriately reviewed and changed in light of changes in circumstances. This is
all well and good but without the background information provided by the narrative section and the full description of the error we would not be able to properly understand what happened in this task. Using pre-defined categories which are then ranked is obviously limiting (even if there are reasons relating to reliability and comparability which call for their inclusion) but when combined with these background descriptions the data is suddenly ‘rich’ and the picture becomes clear. We can see that a mistake was made, but more importantly, it was noticed and the work-team voiced their concerns and came up with a plan to rectify the problem.

The model of competence talks about the importance of context and it is clear that the narrative and TEM sections of the OPA allow for this. The strength of these aspects of the tool is that they allow us to systematically understand the behaviours which were observed in terms of the situational determinants of the ‘here and now’ (as experienced by the technicians) such that the behaviour can be understood in terms of the sense it made to the worker in the ‘there and then’.

The Performance element of the competence model relates to the interface between the actions of workers (in terms of actualised KSAs) and various functions of the organisational context in which the work is performed. Oftentimes, in the maintenance domain in particular, this interface involves the management of compromises between opposing interests in the organisation. In this instance the OPA seems to have exposed some of the contradictions which characterise maintenance operations in general and which impacted upon the performance of the task observed. In the ‘Job Procedure’ phase of the task, the narrative section stated that procedures were not followed step-by-step, but in the behavioural marker section the item relating to the use of procedures was ranked as ‘good’. This ranking was discussed with the observer afterwards and it was suggested that it is common to workaround certain steps of the procedure for this particular task. It seems that in this particular organisation there are a set of system goals which prioritise efficiency over safety and in this context the use of procedures in the performance of this task corresponded quite well with the system goals – hence the ‘good’ rating. On this occasion, in this community of practice, this behaviour is
considered an effective way of managing the compromise between safety and efficiency.

Another interesting episode occurred during the ‘Job Procedure’ phase of the task. The performance of this task attracted a high score for monitoring because a technician picked up on two errors that had been made by another technician. The technician who made the mistake was unfamiliar with the task (never having performed it before) and he had not received practical training on the task. This technician was the most senior technician working on the task and was leading the group because of his level of experience. The technician who noticed the mistakes was a junior (non-certifying) technician who had seen the task performed many times before although he had never been formally trained in how to perform the task either. This occurrence highlights the ways in which the training system fails to produce properly trained technicians who are equipped to perform tasks in operational circumstances and echoes the findings of Chapter 3. It also serves to dispel the myth that the most experienced technicians are necessarily the ‘best’ technicians. Again, this illustrates the ways in which the OPA assists in understanding behaviours in terms of the contextual situations which created them. By using the OPA, not only is it possible to see how a problem manifests itself, it is also possible to understand why it occurred and observe the ways in which it was resolved.

Overall we can see how the performance, context and evaluation elements of the competence model are so closely related and intertwined. A perfect example of this interrelatedness is the ‘good’ rating given for the use of procedures on a task which was characterised by procedural violations. The utility of the performance elements of the competence model is neatly demonstrated here, in that it allows us to unpick these issues and understand how it is that they interact in operational scenarios. If we recall one of the tasks from the ethnographic observations detailed in Chapter 2 (task no.4, the final one detailed in the chapter) we can further examine how the performance aspects of the competence model assist us in better understanding procedural violations. The task was an Operational Check of a Cargo Door Snubber and the
observation showed how the technician engaged in procedural violations: breaking rules and using unofficial equipment; not using specialised equipment called for in the procedures, and so on. The ethnographic approach facilitated an analysis of the context in which the task was performed and this made it clear that the specialised equipment specified in the procedures was never used in this organisation—the company didn’t even own it. The procedures were inadequate and misleading and the task was badly designed. Luckily, the ethnographic approach facilitated this analysis of the context such that the actions of the technician could be better understood. The technician was not breaking rules for no reason. He had good reason to do so and his actions made sense to him at the time. To the outside observer, without access to these types of information, his behaviour takes on another meaning. Without recourse to the factors informing workers’ behaviour it is not possible to properly understand their actions.

The strength of the ethnographic approach is related to the fact that it was able to uncover the local rationality under which the technician was operating. He had to complete a task but the (indirect) actions of other workers were creating problems: the task was badly designed, the manuals were incorrect, and the tools were not available. So, in performing the task the technician had to contend with performance failures relating to the manufacturer, the designers, and the management of the company. Ordinary performance assessment techniques fail to take account of the fact that performance is embedded in, and systematically connected to the situation in which it takes place. The OPA, however, is different. It directs observers to gather information about inputs to the situation and encourages background information regarding the context and work situation to be used to situate the understanding of the actions of workers. This characteristic of the OPA is directly informed by the performance elements of the competence model. The OPA is a simple tool but the data it can gather and the descriptions it can offer rival those produced by complex methodologies such as ethnography.

The ethnographic observations conducted in Chapter 2 highlighted some important characteristics relating to the performance of maintenance tasks. Interestingly the data
gathered by the OPA can provide equally detailed and insightful descriptions of performance. The ethnography showed aircraft maintenance to be characterised by unpredictability and variance, where there exists a high degree of interdependency with organisational systems and other occupational groups. Moreover the observations demonstrated the extent to which each and every maintenance task, those completed by teams and those completed by individuals working alone, has a social element which remains constant. In assessing the performance of the work involved in adjusting the spoiler proximity sensors reported earlier in this chapter, the OPA has shown that it can create descriptions of maintenance tasks which are as detailed and rich as those produced by an ethnographic approach. This, it is argued, can be attributed to the performance elements of the competence model upon which the OPA is based and the appropriateness of the model’s conceptualisation of the issue of competence.

Discussion

The results from the OPA pilot implementation highlighted some interesting aspects of the performance of tasks in Company E. But the critical question relates to the OPA’s ability to explain and account for the performance of maintenance tasks. One way of ascertaining the OPA’s ability to capture performance is to compare the data it gathers with the kinds of elements identified in Chapter 2. In answering this question we are able to infer something about the adequacy of the performance elements of the competence model advanced in the thesis. To recap, the critical aspects of maintenance activities identified in Chapter 2 can be summarised as follows:

- Inadequate documentation and procedures
- Lack of appropriate tools, parts and equipment
- Lack of adequately trained personnel
- Use of unsuitable equipment
- Inadequate work standards
- Lack of procedural compliance
- Inadequate organisational planning (e.g. manpower and co-ordination)
- Flexible, adaptive work practices (e.g. ‘robbing’ of equipment)
The data gathered by the OPA (with which we can attempt to explore the utility of the competence model) are relatively limited; both in number and in quality. Only nine tasks were observed and of this number only one task produced a reasonably complete OPA form. As stated earlier the maintenance organisation collaborating on this study was undergoing a period of considerable growth and was not in a position to invest heavily in the research goals. This meant that resources were limited and unlimited access to the operation could not be given to the researcher. This commercial situation compounded an already problematic situation relating to choosing tasks suitable for analysis with the OPA tool and observing tasks from beginning to end. As a consequence of these problems there are a limited amount of data from the OPA pilot implementation. This inability to gather data in sufficient number should not be taken as an indication of some inadequacy of the competence model. This problem is related to some operational issues to be resolved with the OPA methodology and the way it is implemented. Nonetheless, the specifics of the single task covered in the OPA form discussed earlier have proven to be a microcosm of maintenance operations and many of the general characteristics of maintenance tasks specified earlier in the thesis are reflected in the data gathered by the OPA.

The critical question, however, relates to the ability of the tool, and the competence model upon which it is based, to account for the performance aspects of competence. The interrelatedness of competence and performance has been established in chapter 4 and throughout the thesis: most notably in Chapter 3 where we have seen that practical and human factors training have neglected the training of practical skills. The mentalistic aspects of competence (knowledge, skill, ability, understanding of the work, etc.) have traditionally been prioritised in definitions and conceptualisations of competence. It is unsurprising then, that these conceptualisations inform many activities in organisational life such that this mentalistic bias instantiates itself in any competence development or assessment interventions. Training is one such intervention and we have seen in Chapter 3 that training in aircraft maintenance focuses on developing competence through imparting theoretical knowledge and the practical application of these KSAs is ignored. The prioritisation of the performance
aspects of competence in this chapter is, in part, a reaction to this bias and can be considered as an attempt to redress the imbalance.

We have seen in previous chapters that the performance of maintenance tasks is a social activity. An important determinant of this social performance is the context and situation in which the work takes place. The situational context informs workers understandings of what is going on such that there is a bounded rationality to performance – workers behave in accordance with their understanding of their situation. The two tasks (detailed above) featuring routine non-conformity show how it is that workers performance can be influenced by their situation. The OPA, through its focus of analysis, can gather information on the context and situation such that we (as outsiders) can better understand the situational influences as experienced by the workers. The OPA also showed how context can influence the way in which performance is evaluated. In the illuminating OPA task we saw that procedural violations can be perceived in different ways. In this instance the technicians did not follow the procedures ‘step-by-step’ but merely followed the intent of the procedures. In this context the observer felt that this was a signal of good performance. The observer was a member of the community of practice in which this procedural violation took place and his perspective is influenced by his experience and knowledge of the context and situation in which the work was performed. In allowing for the context that produced and allowed such deviations the model of competent performance is inviting elements of social constructivism and making a move away from rationalist perspectives. There is no one fixed interpretation of violating procedures (even if regulatory authorities would tend to disagree); rather, the appropriateness of a behaviour (any behaviour) is a function of the contextual and situational factors as determined by the members of the community of practice in which the behaviour took place. There are multiple realities and that which was appropriate in this organisation may not be the right thing to do in another organisation. The issues of context and performance are clearly very closely linked.
In terms of the OPA, it is clear that the performance elements of the competence model are useful in describing and accounting for the types of maintenance issues highlighted in Chapter 2. Three elements of the competence model are represented in the OPA and each one has proven its utility in this OPA performance assessment tool and methodology. They are the Performance, Context and Evaluation elements. Instantiated in the OPA, these three elements seem to be able to explain and account for maintenance tasks in all the richness of the descriptions produced by the ethnographic approach of Chapter 2. Indeed, the results of the OPA give confidence that the issues highlighted in Chapter 2 can be encountered using a standardised, focused tool which can be used by operational personnel after some initial training.

The OPA succeeds in gathering information in a structured and focused way about the critical human issues associated with aircraft maintenance tasks. The performance elements of the competence model are instrumental in achieving this. Enabling the context and the situation to be systematically linked to the behaviours of workers facilitates the creation of an accurate description of performance. By doing this the internal workings of the production processes can be linked to the observable behaviours and the analysis can reconcile the two to reflect the reality of performing maintenance tasks from the perspective of the workers. The context element of the competence model also explains the ways in which the meaning of the label ‘competent’ is socially constructed by the members of the community of practice in which the performance took place. In this sense the competence model is informing not only the performance assessment tool (OPA), but also the methodology used to implement the tool.

The OPA can account for the nature of maintenance tasks but it doesn’t represent a better way of understanding maintenance operations than that achieved through an ethnographic approach. Ethnographic methods involve an exploration of social phenomena and deal primarily with unstructured data (Atkinson & Hammersley, 1994). Undoubtedly, the resources that are required to undertake this form of analysis would produce a very detailed and rich assessment of performance. The OPA is a
systematic performance assessment and it is structured in a way which reflects the reality of maintenance operations. The development work ensured that the format of the tool reflected the way in which tasks are performed. Most importantly the development of the OPA was informed by the competence model advanced in Chapter 4. The competence model (especially the performance related aspects) served to guide the OPA tool such that it can gather data which reflect the true nature of the performance of maintenance tasks, and which can link this performance to the contextual and situational determinants which shape human action in that context. The strengths of the OPA, as a tool, are in some ways attributable to the deep understanding of aircraft maintenance which was arrived at thanks to the ethnography conducted in Chapter 2.

It is clear that the OPA can highlight many of the intractable human factors issues detailed in Chapter 2, but the OPA cannot assess all aspects of competence. It has prioritised the performance and practical aspects of competence and represents an instantiation of only a portion of the competence model. We have seen throughout this thesis how it is that the practical side of competence has been ignored and how mentalistic explorations and explanations of competence have been dominant. The OPA cannot provide information on the utility of all aspects of the competence model; only on those elements relating to performance. Performance aspects of competence have been marginalised and in taking a performance perspective we have explored the supplementary roles of context and culture in the competence debate. The OPA has shown that maintenance work is done in a context and this context can determine the performance of those operating within it. Through the use of the inputs sections on the form and the TEM worksheets the OPA has developed a mechanism which allows workers' actions to be understood in terms of the context in which the behaviours were actualised. Culture is implicated in terms of the ascription of competence and the negotiation of the meaning of competent action in that community of practice.

The overall conclusion which can be drawn from the experiences of the OPA is that the performance elements of the competence model reflect in a real and meaningful way
the critical aspects of maintenance operations. The explanations of the role of context and the social nature of performance offered by the competence model show, through their instantiation in the OPA tool and methodology, that these concepts are useful in addressing the issue of performance assessment. This evidence suggests that the performance elements of the competence model are a useful and sound representation of the critical issues.

One important question posed at the beginning of the chapter related to how well the performance elements of the competence model can account for the fact that the way in which technicians perform their work in normal everyday circumstances differs significantly from the way in which the work is described in manuals, procedures and job descriptions. Through exploring the specifics of two tasks which featured procedural deviation, an attempt was made to provide an answer to this question. The competence model advanced in this thesis invokes interpretative and social constructivist explanations of competence. In departing from dominant rationalistic approaches the model allows for multiple realities. In contrast to rationalistic approaches to procedural deviation and routine non-compliance (which assume that people operate under a perfect rationality) the model of competence detailed in this thesis works under the assumption that people’s rationality is bounded by their understanding of a situation, their goals and the contextual situation in which they find themselves (Dekker, 2005). Their actions make sense in relation to these local factors. So, in order to properly understand why some workers break rules we need to explore the reality of their world as they experience it. The competence model acknowledges the centrality of context to the performance of maintenance and allows us to understand issues like workarounds by looking at the context in which workers perform these actions and attempting to understand why it is that committed workers would deviate from the procedures. As we have seen in Chapter 2 there are any number of reasons why this might occur but it is only when we look at the context that we can properly understand the other ‘reality’.
Chapter Summary

This chapter explored the utility of certain aspects of the competence model advanced in Chapter 4. A performance assessment tool for aircraft maintenance (the OPA) was developed based on the performance aspects of the competence model. The pilot implementation of this tool provided an opportunity to explore the ways in which the performance aspects of the competence model can account for the characteristics of maintenance operations as detailed earlier in the thesis.

Operational problems with the tool (regarding selection of appropriate tasks) were compounded by limited resources in the maintenance company with the result that the implementation gathered a limited amount of data. Only one task (out of a total of nine) had a reasonably complete OPA form. This task was examined and discussed, together with one of the earlier tasks observed as part of the ethnography in Chapter 2. The OPA was shown to provide a detailed and appropriately focused assessment of performance and it managed to gather rich data which reflect the way in which maintenance tasks are typically performed. This provided evidence that the performance elements of the competence model (Performance, Context, and Evaluation) offer a useful way of describing the relevant processes governing the performance of maintenance tasks. The strength of these aspects of the competence model is in systematically acknowledging the contextual situation and the role it plays in mediating the performance of maintenance tasks.

The OPA tool didn’t allow a full exploration of the utility of all elements of the competence model but it did allow us to explore the most under-explored aspect of competence: performance. Future research should focus on exploring the utility and validity of the other elements of the competence model such that the overall effectiveness of the approach can be established.
CHAPTER 6
OVERALL DISCUSSION AND CONCLUSIONS

Introduction

This thesis has explored the nature of human factors competence in aircraft maintenance from a number of different perspectives: an ethnographic study of normal maintenance operations, observations of practical training, reviews of human factors training, and the development of a performance assessment tool. The issue of human factors competence emerged as an important issue early in the research process and quickly became the focus of this thesis. In following the chronology of the research process the reader has explored the research in the order in which it was conducted.

The issue of human factors competence, it seems, has many applications and seems to underpin many facets of aircraft maintenance activities. The next section reviews the work of the thesis and summarises the main findings before moving on to explore the implications of the research. Some methodological and epistemological issues are also considered before the discussion concludes by discussing possible directions for future research.

The thesis

A description of some of the main human factors characteristics of aircraft maintenance emerged from the observations of tasks which were conducted in Chapter 1. This served to situate the work of the thesis in the context of the aircraft maintenance industry and provided a basis from which to explore the issues of competence and human factors.

Chapter 2 presented an ethnographic analysis of normal maintenance operations and highlighted some important issues. The ‘thick description’ of normal aircraft maintenance operations identified some of the critical deficiencies of maintenance
systems and highlighted the ways in which these problems manifest themselves in the operational setting. Human and technical problems are inherently interrelated and they manifest themselves in human factors problems such as routine non-compliance, workarounds, procedural deviance, etc. Despite these intractable problems most maintenance tasks are performed in a safe and efficient manner.

The observations of normal operations showed that the maintenance environment is unpredictable and variable. The analysis suggested that the task of maintaining aircraft is considerably reliant on social interaction. The outputs of any maintenance task (whether performed by an individual or a team), it was found, are achieved through a complex social process. Technicians work in a multifarious collective environment and rely on the input of others to complete their work. Social interaction can be direct or indirect. Indirect social interaction, and the role it plays in influencing maintenance operations, is often overlooked. In achieving a positive performance outcome a technician is indirectly interacting with, and relying upon, the performance of workers such as planners, task designers, documentation writers, parts suppliers and managers.

This finding was particularly relevant to the issue of competence. Explanations of the way in which deficient maintenance systems can result in safe, efficient, and reliable outputs typically invoke notions of competence. The competence of the individual is seen as the system component which has the ability to compensate for the inadequacies of the operational systems, but the observations from Chapter 2 showed that maintenance tasks are never performed by just one person – it involves groups of individuals working together (sometimes indirectly) to achieve a successful outcome. The competence of an individual is important, but perhaps this is not the correct level of explanation.

Training is a typical competence intervention so Chapter 3 sought to explore the training of maintenance technicians in order to understand the extent to which training equips technicians to deal with the operational realities of maintenance activities as highlighted in Chapter 2 and to explore the conceptual model of human factors.
competence which underpins the training. Maintenance training does not integrate human and technical training so separate analyses were undertaken. Observations of practical (technical) training and a comprehensive review of human factors training provided interesting analyses. In particular the reviews of training highlighted a number of problems with the systems governing maintenance training: there are operational problems relating to access to training resources and a limited timeframe in which to conduct the training, and there are conceptual problems which relate to the models of competence informing practical and human factors training.

The observations showed that there is an industry-wide failure to provide adequate practical experience during practical training. Trainers operate in a pressurised commercial environment and do not have the time or the resources to allow all trainees to practice performing a task during their practical training sessions. Instead trainers have developed a system where small groups of technicians are trained as a unit (2-3 trainees): the “one does, one reads and one watches” procedure. Trainees are disappointed by the inability to ‘prove competence’ to themselves by practicing each particular task. The assessment of training is similarly affected by the lack of resources such that trainers have developed informal ways of operating within the system constraints. Rather than assess each trainee the trainer uses a more global training approach such that his assessments reflect group performance rather than that of any one individual.

The interesting thing about these informal actions is the way in which they reinforce the notion of aircraft maintenance as a profoundly social activity. Training is generally acknowledged to be an intervention aimed at changing aspects of the ‘individual’ (Boreham, 2004; Eraut, 1998) and this is definitely true of aircraft maintenance. But it seems that the informal training system de-emphasises the individual in favour of the group. The unofficial ways in which trainers reconciled the competing demands of their job represent an element of social formation in an attempt to improve the system. This suggests that the social relations of the workplace are being recreated in the informal aspects of the training system developed as a response to system deficiencies.
The argument is that the social and organisational aspects of maintenance activity are misaligned and imperfectly represented in training and the compensatory actions of well-intentioned trainers serve to correctly align the training with the way the job is done in practice.

The review of human factors training focussed attention on some conceptual problems in relation to competence. In Europe human factors training is mandated by EASA who have an important role in determining the nature of this training. The regulator has set out a HF training curriculum which specifies a pre-defined list of knowledge areas which, it is assumed, will see them through the types of problematic situations which were detailed in Chapter 2. The focus on pre-defined categories of knowledge inherent in this approach to human factors betrays a rationalist and individually-oriented conception of competence.

The limitations of the STAMINA human factors training course are related to a similar problem. The training course defines, in advance, all the pieces of information which a technician must know in order to be human factors competent. Using reason to understand the role of a technician, this approach prioritises a priori knowledge and has no grounding in the real world of maintenance operations. The AITRAM approach to human factors training was similarly limited by a rationalistic conception of competence. The limitations of these training interventions present clear conclusions regarding the suitability of the models of human factors competence which are informing them. Rationalistic approaches to competence and human factors (prioritising theoretical knowledge) have failed to represent the richness and complexity of the social life of maintaining aircraft as depicted in Chapter 2.

As such, a new approach to human factors competence was called for – one grounded in an empirical understanding of the activity of maintaining aircraft where the emphasis is on ‘doing’ human factors rather than ‘knowing about’ human factors. The only way in which a model of human factors competence can explain the realities of maintenance operations as reflected in Chapter 2, is by accounting for the social nature
of maintenance activities. The regulations have conspired to instantiate their individualistic perspective in the human factors training requirements but it is clear that human factor training needs to move beyond knowledge to encompass more practical skills training. These skills should, in turn, reflect the social aspects of maintenance activities. These twin issues relating to practical competence and the profoundly social nature of maintenance tasks are neglected elements of the competence debate.

The problems with training, by and large, arise from the lack of an adequate definition of competence. Chapter 4 reviewed dominant rationalistic approaches to competence, explored two alternative perspectives and proposed a new model of competence for human factors in aircraft maintenance. Rationalistic conceptions of competence conceive of it in terms of an individual's knowledge, skills, abilities and attitudes, and the activities (such as planning, managing and communicating) which are used to accomplish the work. This approach is typified in Boyatzis' definition of competence as "an underlying characteristic of a person causally connected to effective or excellent performance in a job" (1982, p.21, emphasis in original). This characteristic or attribute refers to a KSA which a worker possesses and which is released in a work situation. Rationalistic approaches to competence assume that KSAs 'come with a person' and help them to perform maintenance tasks. It is this element of the rationalistic approach that has attracted most criticism and which, ultimately, illustrates the inadequacies of the approach. The problem with locating KSAs within an individual is the assumption that, once acquired, these KSAs will assure the competence of the individual.

The problem with this is that knowledge, skills and abilities are only part of the competence equation. Rationalistic approaches to competence prioritise the mentalistic aspects of competence at the expense of the performance aspects and in so doing they invite criticism on the grounds that they neglect to acknowledge the role of social and environmental explanations. As Bramming and Larsen (2000) assert: "work is not done in a vacuum" (p.78). Rationalistic approaches focus on theoretical knowledge and in neglecting to include practical knowledge or any notion of performance the culture,
procedures, norms, technology, systems and social make-up of organisational life are ignored. Some theorists are particularly vociferous in their claims that practical knowledge and context should be included in expanded notions of competence (e.g. Bramming & Larsen, 2000; Hutchins, 1995). Attewell (1990) and Norris (1991) similarly argue that rationalistic approaches result in abstract descriptions of competence which are simplified and narrow in focus. In pre-defining what competence actually is it is not possible to account for the role of contextual and organisational factors.

Rationalist approaches to human factors competence use reason to understand the role of a technician. These approaches therefore prioritise a priori knowledge and are based on conceptions of competence which prioritise theoretical knowledge. Ultimately, because rationalist approaches to competence focus on de-contextualised theoretical knowledge the explanations they offer are limited by the inability to acknowledge the complexity of the environment in which technicians perform their work. The rationalistic focus on knowledge inherent in the STAMINA approach, for example, meant that other critical aspects of competence and performance were sidelined: in particular, the social aspects of maintenance activities. Without acknowledging the social and environmental contexts in which work is performed it is impossible to come up with an adequate description or explanation of competence. Chapter 2 showed that maintenance tasks take place in a social space and the actions of the members of that social space have a direct, or indirect, impact upon the performance of any given task. The observations of training in Chapter 3 provided further evidence of the profoundly social nature of maintenance operations. In compensating for the deficiencies of the formal training process trainers and technicians developed informal ways of operating within the system. Interestingly, most of these informal practices served to re-create the social relations of the work environment in the training context. These findings, obviously, had some important implications for the development and specification of any model of competence which attempted to describe maintenance operations.
In order to overcome these problems a new approach to competence was developed in the thesis. This hybrid model was based upon the interpretative studies of competence by Sandberg (1994, 2000), and also drawn on Bramming and Larsen’s social and relational explanations of competence (2000). The approaches to competence advanced in their papers were a response to the epistemological inadequacies of the rationalist approaches. The new competence model has a dual focus: the ‘doing of the job’ and workers conceptions of their job. The model reflects the ways in which maintenance is performed and incorporates KSAs as an integral part of the competence equation. Competence is conceptualised as the behaviour which is able to compromise between the various coalitions and interests in an organisation and competence relates to being able to cope as deemed appropriate by the opinion makers, because of, or despite, the formal qualifications deemed necessary. At the same time competence, at a more mentalistic level, is first and foremost related to workers understandings of their work (as informed by their lived experience of it) and this understanding of work delimits certain attributes which are necessary to perform the work. Thus, workers KSAs are preceded by and based upon their understanding of their work.

This model of human factors competence accounts for the social and collective nature of maintenance tasks and is grounded in the social reality of operations. Competence in aircraft maintenance is not just about an individual. To reflect the social processes of maintenance activities it was necessary to move beyond individualistic conceptions of competence. From Chapter 2 it was clear that maintenance activities are not just about the actions of an individual; they are about the collective actions of individuals working together. These individuals may be working in different areas of the organisational system, and may interact only in indirect ways, but the performance output for these types of tasks is collaborative: it reflects the actions of all those who had an input.

The new model of competence has six key elements: Understanding of the Work, Attributes, Action, Performance, Context and Evaluation. A brief description is given over:
Understanding of the work

This is the basis of competence. Understanding is gained through the lived experience of work. This prescribes the KSAs necessary to perform the work.

Attributes (KSAs)

This element refers to the knowledge, skills, abilities and attitudes which a worker uses to perform his work.

Action

This refers to the enactment or actualisation of the KSAs. This is when knowledge and skill are externalised and expressed in behaviour.

Performance

This refers to the actualisation of KSAs. This is where the work activities (or actualised KSAs) of one worker interfaces with the work activities of another (directly and indirectly).

Context

This element refers to the community of practice in which performance occurs.

Evaluation

The use of the label ‘competent’ is negotiated by the members of the community of practice.

The model, in reconciling Sandberg’s interpretative perspective on competence with Bramming and Larsen’s social and relational model of competence, provides the basis for a new approach to competence in aircraft maintenance which attempts to account for the variety and complexity of issues and problems which were detailed in Chapter 2. The next chapter in the thesis, Chapter 5, explored an instantiation of this new model of human factors competence in an attempt to establish the ability of the model to achieve these aims. Chapter 5 set about establishing the extent to which the competence model advanced in the thesis, instantiated in the OPA tool, provided an accurate account of the nature of the hitherto neglected performance aspects of competence as they relate to aircraft maintenance tasks. Chapters 2 and 3 have pointed out the important social aspects associated with the performance of maintenance tasks and the ways in which dominant rationalistic approaches to competence have deflected
attention away from the practical aspects of competence. The OPA was developed as a performance assessment tool to be used by maintenance organisations to assist them in managing the human aspects of their operation. The development of the tool was informed by the competence model proposed in this thesis and as such represents an instantiation of the performance-related elements of the competence model. In privileging the performance aspects of the model the OPA could not facilitate an exploration of all elements of the competence model. Instead, the OPA was used to discover the utility of the competence model in explaining important aspects of performance – undeniably, one of the most important elements of competence.

Limited data from the OPA implementation was supplemented by a re-examination of a task originally detailed in Chapter 2 and showed that the performance elements of the competence model (‘Context’, ‘Performance’, and ‘Evaluation’) are very useful in explaining patterns of behaviour which characterise real-life maintenance operations like those in Chapter 2. A particular strength of these aspects of the competence model is in systematically acknowledging the contextual situation and facilitating an examination of the role it plays in mediating the performance of maintenance tasks. It was not possible to evaluate the more mentalistic aspects of the competence model (elements such as ‘Understanding of the Work’ and ‘KSAs’ and ‘Action’ (in terms of the internal processes governing the actualisation of KSAs)) in this thesis. Future research should explore these aspects of the model to establish their utility and begin to establish the overall effectiveness of the model.

**Implications of the Research**

**Contribution to Knowledge**

This thesis makes two main contributions to knowledge. The first contribution relates to the findings of the ethnographic study of maintenance tasks and the training case study.
These studies highlighted some important aspects of maintenance activity which had been overlooked hitherto. Specifically, the thesis brought to prominence the social and collaborative nature of maintenance activities. This was an important finding which has implications for regulations (discussed below), for training and for any intervention aimed at improving the maintenance system. The second main contribution to knowledge made by the thesis is the model of competence. The advancement of a competence model which can account for the collaborative nature of maintenance activities and which acknowledges the social context of performance represents a new way forward for the aircraft maintenance industry.

**Theoretical Implications**

This thesis grappled with some theoretical and epistemological issues which seem to be reflective of a wider theoretical reformation which is occurring in human factors. Dekker (2005) recently started a debate regarding the nature of the discipline of human factors by making a case for a shift in the theoretical underpinnings of the human factors discipline. He argues that human factors is currently undergoing something of a transformation based on the identification of deep-rooted problems with current approaches to safety and human factors. He asserts that the discipline of human factors grew out of a Cartesian-Newtonian view of science which emphasised the certainty of scientific knowledge and which aims to derive general laws of nature. The influence of this thinking can be seen to this day – what with the emphasis on experimentation and reductive attempts to explain complexity. But he says that the limitations of these approaches are making their presence felt and it is time for some new perspectives.

Interestingly, the methods used in the thesis, the findings of the research, and the arguments proposed in the course of developing a new competence model seemed to be suggesting that the theoretical approaches to human factors research and practice need reconsideration in light of new technology and new ways of working.
Throughout the thesis there was evidence of a tension between different world views. In Chapter 2 there was an underlying tension between the methods used in the study and the data it was attempting to gather. Atkinson and Hammersley (1994) have defined ethnography as "the production of knowledge" and state that its strength is in exploring the nature of social phenomena. The methodology's grounding in an interpretative paradigm allows naturalistic data to be gathered and assimilated. But this doesn't sit well with ethnographic research which uses a priori categories and a 'cooked' conceptual structure to inform and guide the research. The observations of maintenance tasks which were conducted in Chapter 2 adopted an ethnographic approach but the data collection was guided by a protocol which featured a priori categories. In doing so the research introduces an element of tension.

Those who review the history of ethnography can easily view it as a story of two opposing forces: the positivist paradigm on one side and the interpretive paradigm on the other. Ethnography is assumed, of course, to belong to the latter (Filstead, 1970; Smith, 1989; Smith & Heshusius, 1986). In general terms social scientists have pondered the possibility of a science of social life for over a century. Unsurprisingly ethnography has not escaped this debate. Tension between science and humanities has dogged ethnography since its inception and continues to this day (see Atkinson and Hammersley, 1994; and Redfield, 1962; for more).

While some researchers wish to distance ethnography from the scientific model (positivism) others adopt a more radical view where both positivism and quantification are rejected together (Lincoln & Guba, 1985; Smith, 1989). Positivism adopts the view that the scientific model (positing that we can only learn through hypothesis-testing of data based upon quantitative measurements) should inform social research. All ethnographers argue that positivism cannot always facilitate an adequate insight into human social behaviour. Its reliance on studies conducted in artificial settings (experiments) and on accounts of what people say rather than what they do (surveys) results in an understanding of social phenomena that is overly simplistic; reducing
them to "mechanical products of social and psychological factors" (Atkinson & Hammersley, 1994; p.251).

Agar (1986) detailed what he called a ‘received view’ of science: one which emphasised hypotheses, measurement, sampling and instruments. While he acknowledges the utility of these concepts in science he argues that there are certain styles of research for which these questions are irrelevant and inappropriate. When researchers wish to understand what is going on in a situation – or what people are doing – hypotheses, measurement, sampling and instruments are the wrong guidelines. Furthermore, he asserts that what is important is to encounter firsthand the situation about which you want to learn. What Agar was actually rejecting was positivism. He was suggesting that it simply did not facilitate certain types of important research.

Ethnography is held, by many, to represent a unique humanistic, interpretive approach to the study of social life, as opposed to the “scientific” and “positivist” traditions. While the ethnographic tradition is neither united nor coherent it does represent a powerful alternative to the positivist tradition. The pursuit of a positivist agenda in attempting to explore and better understand human factors in aircraft maintenance would have contributed nothing to furthering and re-examining our knowledge of the issue. In order to properly understand the nature of complex contextual aspects of performance that interact with aspects of the task itself we need to observe the task as it is normally performed and look at it afresh: from a different perspective.

It is in defining the research problem that the tension makes its presence felt. For a long time there has been a common belief amongst qualitative researchers that the early stages of the research process should not be hindered by the specification of variables, hypotheses, and definitions of concepts. Bryman (1988), for instance, champions flexible research designs and dismisses the early use of theories or concepts to guide ethnographic research. Thinking has much progressed on this issue recently. Researchers such as Silverman (2001) now warn against beginning field research without any guidance. Silverman goes on to discredit the view of some empiricists: that
‘the facts speak for themselves’. He advises that without some guiding principles or a set of animating questions there is nothing to report. He is not alone in thinking this: Mason (1996) concurs, as do Miles and Huberman who, as early as 1984, asserted that:

> “the looser the initial design, the less selective the collection of data; everything looks important at the outset to someone waiting for the key constructs or regularities to emerge from the site, and that wait can be a long one” (p.17).

Wolcott (1980) argues that it “is impossible to embark upon research without some idea of what one is looking for and foolish not to make that quest explicit” (p.157). Later he similarly argues that researchers have to define the research problem, use concepts drawn from a particular model and limit the amount of data that you can analyse: to “do less, more thoroughly” (1990, p.62). ‘Doing less, more thoroughly’, Silverman (2001) argues, is not burdened by a partial analysis of data: this is only a problem if claims are made that the data gives the whole picture. Of course qualitative analysis can never make this claim and we are urged by an excited Silverman to “celebrate the partiality of [our] data and delight in the particular phenomena that they allow [us] to inspect” (p.61).

In the end, this tension was not resolved in Chapter 2. A pragmatic decision was made to use a pre-defined conceptual structure drawing on the rationalist tradition but using an ethnographic approach to gather naturalistic data. This was the simplest way of overcoming a deep philosophical tension but there is still a sense in which social constructivist/interpretative approaches and rationalism are vying with each other: each offering different explanations of life and lived experience.

Tension appeared again in the training and competence chapters (Chapters 3 and 4, respectively). Again, the tension was between rationalism and interpretative and social constructivist approaches. These chapters dealt with the differences between these world views in a more explicit way. Training courses and the regulations governing
them were shown to be operating under rationalistic models of human factors competence – where competence is seen to relate to the KSAs held by an individual and the way in which these compare with a purely rational notion of the KSAs required to perform work.

The thesis established the pervasiveness and inadequacy of rationalistic perspectives in human factors. They inform the training courses, they inform research (much as we try to avoid it) and they also inform regulations. The fundamental problem with rationalistic approaches relates to their inability to properly engage with and account for the nature of aircraft maintenance because of their individualist focus and the generalised, abstracted explanations they offer. The observations of normal operations reported in Chapter 2 showed us that maintenance tasks are performed in a complex social milieu, where task performance is a collaborative effort involving direct and indirect interaction with various other workers. Rationalistic approaches cannot account for these realities and a new perspective is needed.

The thesis attempted to illustrate the benefits of adopting a new approach by developing a model of competence based on social constructivist and interpretative approaches. The model has been shown to offer a better explanation of competence than any of the theories advanced hitherto. In this sense, the thesis seems to be suggesting a move away from rationalism towards more social constructivist methods which may represent an alternative approach for human factors.

**Practical Implications**

The model of competence developed in the thesis has some important implications for human factors training regulations. The regulator has been making successive approximations to adequately regulate for the role of the human factor in reducing accident and incidents. What began as a simple requirement for licensed technicians to be trained in human factors (JAR 66) eventually led to a current requirement for organisations to ‘establish and control the competence of personnel’ where
'competence must include an understanding of the application of human factors and human performance issues appropriate to that person’s function in the organisation'. (EASA Part-145.A.30(e)).

This requirement skirts around the issue of assessing human factors competence and does not expressly mandate it but the imprecise wording of the requirement leaves open the possibility that future amendments to the requirement may explicitly address the assessment of human factors competence. Given this, the model of human factors competence developed in this thesis can be used to provide guidance to the regulator in drafting the requirement and the maintenance organisation in satisfying the requirement.

The regulator has, in the past however, conceived of competence in terms of abstracted theoretical knowledge held by an individual and this seems to be informing the new requirement also – competence is defined as knowledge. The thesis has established the unsuitability and ineffectiveness of this approach to human factors competence. The regulator operates a very individualist training policy as informed by one of its primary roles in issuing licences to technicians (Boreham, 2004). But the research contained in this thesis has shown that a training program or an assessment methodology which has the individual as the unit of analysis cannot account for the social nature of aircraft maintenance activities. The observations of practical training have highlighted the ways in which informal training practices designed to compensate for the system deficiencies de-emphasise the individual in favour of the group. These practices serve to increase the psychological and organisational fidelity of the training sessions by imposing a social emphasis on the training, which, in turn increases the likelihood that skills taught in training will transfer back to the workplace.

The regulator needs to take account of the social nature of maintenance operations and should look to the competence model advanced in this thesis as a way of reconceptualising training and assessment, particularly as they relate to human factors. In reality this is highly unlikely to happen but until the regulator begins to appreciate
the inadequacies of the models of competence informing their regulations there will continue to be two parallel worlds: one official, the other unofficial.

**Strengths and limitations of the research**

One strength of this thesis relates to the range of diverse research activities which provided contrasting perspectives on critical issues. Because the research was conducted in two different projects the studies which comprise this thesis had different foci but the findings had important implications for human factors and competence. Thus each study and piece of analysis included in the thesis is not included to sustain a particular argument decided a priori. By following a logic dictated by other research projects the issues emerged themselves. This placed a requirement for more reflection to be conducted, for deeper analyses to be considered and ultimately, this provides added value to the end result.

The thesis is limited because a full exploration of the utility of the competence model was not possible. Only the performance elements of the model were evaluated. This is because the task of exploring the more mentalistic elements of the model was too onerous a task and was beyond the remit of the thesis.

In general terms the thesis has been further limited by the inability of the maintenance organisations involved in the research to fully commit to all aspects of the research agenda. In the current turbulent market conditions resources are limited and human factors is not seen as a priority.

**Future research**

Future research can attempt to alleviate the performance bias of the evaluation of the competence model by looking at some of the mentalistic aspects of the model in more detail. The two elements ‘Understanding of the Work’ and ‘Knowledge, Skills, and Abilities’ in particular need to be explored.
A new EU-funded research project entitled TATEM (Technologies and Techniques for New Maintenance Concepts) is building upon the work of the competence model by attempting to specify the KSAs requirements of a series of representative maintenance tasks. The project is attempting to develop a method of extracting contextually relevant KSAs that account for the processes governing maintenance tasks such that it is possible to specify a set of contextual KSAs which are grounded in the social reality in which a task is typically performed. The project is ongoing, and if it is successful in achieving its aims it will be possible to explore the utility of the competence model in relation to this element. The project could also contribute something to the specification of behavioural markers for the OPA.

Future research might also wish to explore the extent to which the competence model advanced for aircraft maintenance is relevant to other safety critical industries. While it may not easily transfer to flight operations or the surgery room, it might be applicable for the rail maintenance, shipping and process industries.
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APPENDICIES

Appendix A:
Observation Protocol for Maintenance Tasks

Appendix B:
Protocol for Observation of OJT and Practical Training

Appendix C:
Interview Schedule for OJT and Practical Training

Appendix D:
Operation Performance Audit (OPA) Forms

Appendix E:
OPA Evaluation Report
Appendix A:

Observation Protocol for Maintenance Tasks
Observation Protocol for Maintenance Tasks

Task:

Company:

1. THE INDIVIDUAL

**Individual Capabilities**

**Strength/agility/body size required**
To what extent does the task require these abilities?

**Skill**
What technical skills (if any) are required?

**Understanding of the system**
What level of understanding of the system is required?

**Knowledge**
What additional knowledge is necessary to complete the task?

**Physical effort**
To what extent is physical effort required? (Rate the level of effort).

**Experience**
How much technical experience is required? What type of experience?

**Assertiveness**
To what extent does the task depend upon the assertiveness of the technician?

**Task Management**

**Multi-tasking**
How often does this task have to be completed at the same time as doing something else?
Time organisation and planning
How much planning and time management goes into the task? How does this affect its execution?

Distraction
To what extent is this task subject to distraction? From where does the distraction come?

Interruption
To what extent is this task subject to interruption? From where does the interruption come?

Routine?
Is the task routine or non-routine?

Scheduled?
Is the task scheduled or not?

Task focus
Does the technician complete the whole task or part of the task?

2. THE SOCIAL

The Team

Team co-ordination
To what extent does this task depend upon team co-ordination?

Team-Task relationship
How many individuals are involved? To what extent is previous experience to work in team is necessary?

Allocation of functions to team members
Is each team member allocated a specific/precise sub-task? To what extent are team members free to organise their collective activity?

Shift hand-over
Do shift hand-overs occur during the task? How often and how are they managed?
Leadership
Is there a clear leadership structure? How often does this affect the task?

**Communication**

**Communication during task**
How much communication is necessary during the task execution? What type(s) of communication?

**Location/dispersal of team**
Are team members physically distributed when working on the task? Are they located in the same area? Where are they located?

**Team pressure**
To what extent is this task subject to team pressure? What is the nature of this pressure?

**Team dynamics**
What are the dynamics of the team? How do they work together? How does this affect the task?

3. *THE WORKPLACE*

**Task Support**

**Tools**
How do tools affect the task?

**Parts**
How do parts affect the task?

**Manuals/documentation**
In what way do manuals and documentation affect the task?

**Job cards**
How do job cards affect the task?
Signing for/records
In what way does signing for affect the task?

Degree of interaction with IT systems
To what extent does the task involve the use of IT systems?

Performance Shaping Factors

Fatigue
To what extent does this influence the task?

Noise
To what extent does this influence the task?

Lighting
To what extent does this influence the task?

Access – physical & visual
To what extent does this influence the task?

Dexterity
To what extent does this influence the task?

Weather
To what extent does this influence the task?

Surface
To what extent do the surface conditions influence the task?

Fumes etc.
To what extent does this influence the task?

Stress
To what extent does stress manifest itself during the task?

Comfort
To what extent is comfort an issue in this task?
The Operation and Organisation

**Time pressure**
To what extent is the task subject to time pressure?

**Commercial pressure**
To what extent is the task subject to this?

**Safety critical**
To what extent is the task safety critical?

**Efficiency critical**
To what extent is the task efficiency critical?

**Shift-work**
To what extent does this influence the task?

**Legal framework**
How is the task affected by legal/regulatory issues (certification levels, signing off etc.).
Appendix B:

Protocol for Observation of OJT and Practical Training
Protocol for Observation of OJT

Trainee Participation

Motivation

Participation/Interest

Training Methods

<table>
<thead>
<tr>
<th>Delivery methods</th>
<th>Tick methods employed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demonstration</td>
<td></td>
</tr>
<tr>
<td>Guidance</td>
<td></td>
</tr>
<tr>
<td>Practice</td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>Observation</td>
<td></td>
</tr>
<tr>
<td>Free play</td>
<td></td>
</tr>
<tr>
<td>Use of scenarios</td>
<td></td>
</tr>
</tbody>
</table>
### Training Message

<table>
<thead>
<tr>
<th>Training Message</th>
<th>Explicit</th>
<th>Implicit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role of procedures?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Role of technician?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dealing w/ bottlenecks?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF knowledge/practice?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skills required to do job?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focus? (system, procedures or task)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Organisational Issues

- Duration
- Class Size
- Access to Aircraft
- Assessment
Appendix C:

Interview Schedule for OJT and Practical Training
Interview Schedule: OJT and Practical Training

Trainers

1. What are the stated objectives of OJT?
2. How do you achieve these objectives?
3. Do the ‘stated’ objectives differ from what is actually learned in OJT?
4. How do you view the training objectives (both ‘stated’ and actual)?
5. How do you measure the effects of training?
6. What, if any, difficulties do you encounter in OJT?
7. What, if any, difficulties do trainees encounter in OJT?

Trainees

1. What, to your mind, is OJT trying to achieve?
2. How do you view these training objectives?
3. In what way could the likelihood of realising these training goals be increased?
4. What, if any, difficulties do you encounter in OJT?
5. What, if any, difficulties do trainers encounter in OJT?
Appendix D:

OPA Forms
OPA Observation Form

**Input conditions**

**Information**
- **PFR**
  - Available? Y / N
  - Adequate? Y / N
- **Service Bulletin**
  - Available? Y / N
  - Adequate? Y / N
- **AMM/IPC**
  - Available? Y / N
  - Adequate? Y / N
- **Troubleshooting Manuals**
  - Available? Y / N
  - Adequate? Y / N
- **Wiring Diagram Manuals**
  - Available? Y / N
  - Adequate? Y / N

**Expertise**
- **Job allocated by? (Supervisor? Check manager?)**
- **When (if ever) task was last performed by personnel?**
  - Adequate number of personnel? Y / N
- **Skill set of personnel appropriate?** Y / N
- **Have personnel received OJT on task?** Y / N
- **Additional personnel were drafted?** Y / N

**Resources**
- **Tools**
  - Available? Y / N
  - Adequate? Y / N
- **Parts**
  - Available? Y / N
  - Adequate? Y / N
- **Equipment**
  - Available? Y / N
  - Adequate? Y / N
- **Materials**
  - Available? Y / N
  - Adequate? Y / N

**Task Type**
- Routine
- Non-routine
- Scheduled
- Unscheduled
- Corrective
- Preventative

**Reason for the Job / Job Introduction**

**Narrative:** Please provide a brief description of the reason for the job... why is it being done?
Behaviours

Job Set-up

<table>
<thead>
<tr>
<th>Narrative</th>
<th>Please justify behavioural ratings. Tell exactly what happened in general terms. What was done well? What was done badly? How were threats, errors and significant events handled?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Poor Observed performance had safety implications</td>
</tr>
<tr>
<td>2</td>
<td>Marginal Observed performance was barely adequate</td>
</tr>
<tr>
<td>3</td>
<td>Good Observed performance was effective</td>
</tr>
<tr>
<td>4</td>
<td>Outstanding Observed performance was truly noteworthy</td>
</tr>
<tr>
<td>5</td>
<td>Not observed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Planning Behaviours</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plans Stated</td>
<td>Operational plans and decisions were defined. Plans were communicated and acknowledged - everybody understands operational plans and what will be happening</td>
</tr>
<tr>
<td>Task Priority</td>
<td>Importance of task re: efficiency/safety criticality is communicated and acknowledged - Everybody knows importance of the task (e.g. task is the lead item on the check)</td>
</tr>
<tr>
<td>Task allocation</td>
<td>Tasks and activities are communicated and acknowledged - Everybody aware of their role and responsibilities and &quot;knows what to do&quot;</td>
</tr>
<tr>
<td>Anticipation</td>
<td>Strategies for anticipation of problem situations are prepared - Possible delays/problems are identified and contingencies are in place</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Execution Behaviours</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tools/doc/parts/materials procurement</td>
<td>Tools etc. have been sourced in a timely way… - Tools etc. are available and ready to be used</td>
</tr>
<tr>
<td>Supervision</td>
<td>Management personnel actively supervised subordinates - Managers asked about progress and offered advice</td>
</tr>
<tr>
<td>Document usage</td>
<td>Relevant documents were used to support task performance - Operatives/management actively consulted documents during task</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Operative personnel actively monitored their own performance and that of workgroup members (if any) - Keeps track of task supports (docs, tools, parts) and checks progress to see what is done and what is yet to do</td>
</tr>
</tbody>
</table>

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**Job Procedure**

| Narrative | Please justify behavioural ratings. Tell exactly what happened in general terms. What was done well? What was done badly? How were threats, errors and significant events handled? |

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>Marginal</td>
<td>Good</td>
<td>Outstanding</td>
<td>Not observed</td>
</tr>
<tr>
<td>Observed performance had safety implications</td>
<td>Observed performance was barely adequate</td>
<td>Observed performance was effective</td>
<td>Observed performance was truly noteworthy</td>
<td>Not observed</td>
</tr>
</tbody>
</table>

### Execution Behaviours

<table>
<thead>
<tr>
<th>Document usage</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant documents were used to support task performance</td>
<td>– Operatives/management actively consulted documents during task</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Procedures</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant procedures were followed to support task performance</td>
<td>– Operatives/management actively complied with procedures during task</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supervision</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management personnel actively supervised subordinates</td>
<td>– Managers asked about progress and offered advice</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Monitoring</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operative personnel actively monitored their own performance and that of workgroup members (if any)</td>
<td>– Keeps track of task supports (docs, tools, parts) and checks progress to see what is done &amp; what is yet to do</td>
</tr>
</tbody>
</table>

### Review/Modify Behaviours

<table>
<thead>
<tr>
<th>Inquiry</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questions were asked to investigate and/or clarify plans</td>
<td>– Workers not afraid to display a lack of knowledge and lose face</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assertiveness</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical information and/or solutions were offered confidently</td>
<td>– Workers spoke up without hesitation when necessary</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Evaluation of plans</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing plans were reviewed and modified when necessary</td>
<td>– Decisions and actions were openly analysed and considered to assess suitability in light of changes</td>
</tr>
</tbody>
</table>

315
**Job Close-up**

<table>
<thead>
<tr>
<th>Narrative</th>
<th>Please justify behavioural ratings. Tell exactly what happened in general terms. What was done well? What was done badly? How were threats, errors and significant events handled?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>Observed performance had safety implications</td>
<td>Marginal</td>
<td>Observed performance was barely adequate</td>
<td>Good</td>
</tr>
</tbody>
</table>

**Execution Behaviours**

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Description</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring</td>
<td>Operative personnel actively monitored their own performance and that of workgroup members (if any) – Keeps track of task supports (docs, tools, parts) and checks progress to see what is done &amp; what is yet to do</td>
<td></td>
</tr>
<tr>
<td>Checking</td>
<td>Operatives ensure work is done in accordance with procedures and best practice guidelines – Operatives check their own work to ensure it is complete and correct</td>
<td></td>
</tr>
<tr>
<td>Inspecting</td>
<td>Managers inspect work done to ensure it is complete and was performed correctly – Managers visually inspect work done &amp; verify verbally that it was done according to procedures</td>
<td></td>
</tr>
</tbody>
</table>

**Review/Modify Behaviours**

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Description</th>
<th>Rate 1..2..3..4..5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inquiry</td>
<td>Questions were asked to investigate and/or clarify plans</td>
<td>Workers not afraid to display a lack of knowledge and lose face</td>
</tr>
<tr>
<td>Assertiveness</td>
<td>Critical information and/or solutions were offered confidently</td>
<td>Workers spoke up without hesitation when necessary</td>
</tr>
<tr>
<td>Evaluation of Plans</td>
<td>Existing plans were reviewed and modified when necessary</td>
<td>Decisions and actions were openly analysed and considered to assess suitability in light of changes</td>
</tr>
<tr>
<td>Outputs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Task was completed on time?</strong> &lt;br&gt;Y / N  &lt;br&gt;(IF NO please give details of delay)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Was there any re-do?</strong>  &lt;br&gt;Y / N  &lt;br&gt;(If YES please give details)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Were there any quality issues noticed once task was completed?</strong>  &lt;br&gt;Y / N  &lt;br&gt;(If YES please give details)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Once task was completed and aircraft released to service were there any quality and/or safety issues of which you are aware?</strong>  &lt;br&gt;Y / N  &lt;br&gt;(If YES please give details)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Threat Management Worksheet

<table>
<thead>
<tr>
<th>Threat Description</th>
<th>Threat Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Describe the threat</td>
<td>Task Phase</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Error Management Worksheet

<table>
<thead>
<tr>
<th>Error Description</th>
<th>Task Phase</th>
<th>Who committed the error?</th>
<th>Who detected the error?</th>
<th>Workgroup Error Response</th>
<th>Error Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Describe the error</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Error #</th>
<th>Associated with a threat? (If Yes, enter Threat ID)</th>
<th>How did the crew manage or mismanage the error?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
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</tbody>
</table>
Appendix E:

OPA Evaluation Report
This report, as noted earlier in Chapter 5, details the evaluation of the OPA tool. The OPA tool was evaluated by two main sources. Firstly, the quality inspectors from Company E who were involved in the pilot implementation of the OPA were asked to complete an evaluation protocol. This evaluation is considered an end-user evaluation. In addition, a number of aviation safety experts evaluated the tools as part of the ADMAS2 Dissemination Day. At this meeting experts from national regulatory authorities, universities, research institutes and industry were informed of the outputs of the ADMAS2 project and had the chance to use the tools in workshops. The attendees then completed evaluation forms designed to elicit their responses to questions of evaluation based on their (admittedly limited) experience of the tools.

**End-User Evaluation**

**Evaluation Tools**

In order to produce a coherent evaluation of the tools and their implementation a set of evaluation protocols for end-users were developed. These protocols consisted of a general structure for gathering data relating to evaluation both in terms of the items to be evaluated and, more importantly, the method of evaluation itself. The main evaluation criteria were as follows:

**Table A: General Evaluation Criteria for OPA**

<table>
<thead>
<tr>
<th>Usability</th>
<th>Validity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Satisfaction/Confidence</td>
<td>1. Consistency</td>
</tr>
<tr>
<td>2. Difficulty of Ideas</td>
<td>2. Observability</td>
</tr>
<tr>
<td>3. Command retention</td>
<td>3. Completeness/Clarity</td>
</tr>
</tbody>
</table>
Two evaluation forms were developed for the Quality Auditing Tools— one focusing on evaluating the use of the tool (see ‘Usability’ column in Table A above) and the other focusing on evaluating the content of the tool (see the ‘Validity’ column in Table A). The forms were administered to each of the quality inspectors who were involved in implementing the OPA. The quality inspectors were familiar with the OPA tool and had used the tools by themselves. They filled in the evaluation protocol based on their personal experience of the tools and as such this constitutes an end-user evaluation of the OPA. Each of the two forms gathered generic information regarding the participant background, their experience in quality auditing and their human factors training history. Each protocol had specific content areas as outlined above: the results are outlined in the next section.

**Respondents:**
Two quality personnel (both former maintenance technicians) were trained in the use of the OPA and embarked upon a pilot implementation. Both had previously received basic human factors training, had on average 11.5 years of experience in aircraft maintenance and together had nearly four years of experience working in the quality department.

**Process:**
The standardised evaluation protocols (briefly outlined earlier) were used to evaluate the OPA. Both quality inspectors in Company E completed each of the forms. The results documented below reflect the responses of these personnel.

**Results:**
It should be stated that the sample size is inadequate to draw any statistical inference from the data elicited by the questionnaires. Given that the OPA was implemented in only one end-user organisation, and only two people were involved in the implementation of the tool there was a limited number of respondents available for the evaluation work. This should be borne in mind when reviewing the results below. That said, the results do represent valid opinions of end-users who are uniquely positioned
to comment, given that they are experienced maintenance technicians and quality inspectors. In this sense their responses can be seen to represent two viewpoints which are often in opposition.

**Usability Results**

![Usability Criteria](image)

Figure A: Mean scores for End-User Usability Evaluations

1. **Difficulty of Ideas** measures relate to the difficulty of concepts and logic of tool, the overall difficulty of materials and operations to apply the tool and the novelty of the approach. Scores range from 1-4: (1) very low (2) low (3) high (4) very high.

2. **Satisfaction/Confidence** measures, on the other hand, pertain to levels of satisfaction after using this tool and levels of confidence in using the tool. Scores range from 1-4: (1) very low (2) low (3) high (4) very high.
3. **Command Retention** concerns perceptions of post-training retention of tool commands and activities. Scores range from 1-4: (1) very low (2) low (3) high (4) very high.

The 'Command Retention' measure was rated on the positive side of the scale (with a score of 2.5) as shown in Figure A above. Clearly the respondents are moderately confident in the extent to which the commands and instructions of the OPA can be remembered over time – there is room for improvement, however.

'Difficulty of Ideas' and 'Satisfaction/Confidence' were rated slightly higher; at 2.6 and 2.7 respectively. Both these scores are above the mid-point and are verging towards a high score. Respondents found the materials and techniques involved in the OPA to be slightly difficult but not outside of their capabilities. Clearly the respondents were satisfied with the OPA, and perceive the future use of the tool with confidence.

*Validity Results*

![Figure B: Mean scores for End-User Validity Evaluations](image-url)
Consistency measures how well the tool can define operational problems and causal factors, which are consistent with the reality of the organisation. Terminology, charts, figures etc. used in the tool is coherent and consistent. Scores range from 1-5: (1) disagree (2) slightly disagree (3) neutral (4) slightly agree (5) agree.

Observability measures relate to the extent to which the items/situations investigated by the tool can be observed in the work environment and quantified and measured appropriately. Scores range from 1-5: (1) disagree (2) slightly disagree (3) neutral (4) slightly agree (5) agree.

Completeness/Clarity relates to the extent to which the items/situations investigated by the tool are complete and comprehensive descriptions of the issue being analysed along with how clearly the tool measures what it is supposed to measure. Scores range from 1-5: (1) disagree (2) slightly disagree (3) neutral (4) slightly agree (5) agree.

None of the factors depicted in Figure B (above) scored below a 3, indicating some level of agreement with the statements contained in the questionnaire. From analysing these statements in relation to the answers it is clear that favourable ratings were given by the respondents to all the categories outlined above.

Observability was the factor that was ranked highest – the average score for this was 4.2 – thereby indicating that respondents believed that the items and situations investigated by the OPA could be observed in the work environment and that they can be quantified and measured appropriately. This factor pertained to the validity of the tool and speaks to its ecological validity.

The results also highlight that the tool uses items which offer complete and comprehensive descriptions of the issues being measured.
Open-ended Survey Questions:

The evaluation forms also elicited opinions on the strengths and weaknesses of the tool as well as providing an opportunity for any additional comments which respondents wished to make.

Strengths of the tool:
1. "The tool will help improve observation of communication/interactions, within/between teams"
2. "When you have many tasks observed you might get useful conclusions about the behaviour of personnel"

Weakness of the tool:
1. "Long lasting [time consuming] method"

Additional Comments:

- "From the technical point of view OPA Pilot test is equal to our Product Audit"
- "From communication point of view an ‘A’ check is too routine and people know what to do, thus they don't talk much. The OPA would be more helpful when you observe non-routine tasks and more challenging checks".

End-User Evaluation Results Conclusion

Generally, the evaluation results for the OPA are consistently, if not overwhelmingly, positive. The results indicate that the OPA is a tool which has a high level of face validity, as evidenced by the high score on the ‘Observability’ factor. This score also speaks to a high degree of ecological validity in that the tool is structured in such a way that it reflects the reality of aircraft maintenance operations and also that it facilitates the quantification and measurement of pertinent variables.

In terms of learning from the end-users it seems that some additional work may need to be done to render the tool (distinct from the methodology) a little more useful in terms of the overall concept and its novelty. The fact that human factors audits of normal operational practice have never been conducted in aircraft maintenance means that it is

* These comments have been edited and corrected.
a new concept and one that is not readily grasped. More information on the logic of the tool in a more accessible format could benefit the tool greatly.

While there were only two respondents in this evaluation of the OPA we must pay attention to the trends inherent in this data while, at the same time, attempting to broaden our range of evaluation sources in the future. Nonetheless, the results provide some interesting issues to be considered. It is clear that the respondents believe that the OPA tool can contribute to the improvement of teamwork and that monitoring performance of key personnel serves a key function in securing the safety and efficiency of an operation.

**Expert Evaluation**

In addition to the end-user evaluation the OPA was evaluated by a number of international experts in aviation maintenance safety. The OPA was demonstrated at the ADMAS 2 Dissemination Workshop and this provided an opportunity to elicit expert opinion on the efficacy of the OPA tool.

**Process:**

In the workshop experts from national regulatory authorities, universities, research institutes and industry were informed of the OPA and had the chance to use the tool in a simulated exercise. The attendees then completed evaluation forms designed to elicit their responses to questions of evaluation based on their (somewhat limited) experience of the tools.

**Evaluation Tool:**

For this external evaluation a short questionnaire was prepared and participants were requested to complete the form given their experience of the tool in the simulated observation exercise. The evaluation items covered issues of usability and utility in terms of the OPA’s ability to satisfy an industrial need.
Results:

The OPA was considered a usable tool by 37% of the respondents in the workshop. Overall, some 87% of the respondents considered the method a positive one (their opinions ranged from "relatively usable" to "very usable"). Eight participants gave their opinion to this question.

Some of the respondents further commented on the usability of the tool by saying; "Practical process observation (this is in addition to the theoretical part of the Audit)," and "(It) seems to be of (some) use."

The OPA met industrial needs for some 58% of the respondents to the workshop. Overall, 72% of them considered that the method met industrial needs, be this in a weak or stronger manner. Seven participants gave their opinion to this question.

Some of the respondents further commented on the negative side, saying; "(It is) difficulty to judge (its) usability" and "(It is) already required with Part 145 (145.A.65)."

To the question whether they would implement OPA in their organisations, three participants answered positively, while one answered negatively. The former group saw a utility in the tool for "tasks performed by groups." The latter respondent would
not implement OPA in his organisation namely because "(the) difficulty to judge usability."

The implementation of OPA was perceived as providing the following benefits:

- "Practical process surveillance"
- "Independent observation findings"

The implementation of OPA was perceived as providing the following costs or disadvantages:

- "Quality in cost saving"
- "Training"
- "Time for (the) auditor"

**Evaluation - Overall Conclusions**

The organisation involved in the end-user evaluation determined that no real conclusions could be drawn from the results of the pilot implementation of the OPA, given the small sample size. Similarly, the expert evaluation data from the ADAMS 2 workshop are limited in number and no firm conclusions can be made. General indications are that the OPA has some face validity but obviously a more intensive evaluation must be made following a more sustained implementation of the tool and the processes surrounding the tool.