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ENGINEERING SCIENCE TO ENGINEERING DESIGN

Zeeshan Ali Khan and Ken Wallace

Abstract

The paper reports findings from a short research project to investigate how scientific knowledge is transferred into the engineering design process. The project explored how research results useful for designers were communicated to them. One of the aims of this research was to establish a model of this knowledge transfer process.

The research was based on three sets of case studies. The first set provided preliminary insights into the knowledge transfer process. Results from the second set suggested the important elements for knowledge transfer. The last set, carried out primarily for the purpose of verifying the findings from previous two, revealed a pattern in which these elements may be arranged to form a model.

Keywords: Knowledge management, aerospace engineering, industrial case study

1 Introduction

The Fan on the Rolls-Royce RB211-22B engine designed in the 1960s incorporated narrow-chord titanium blades machined from solid forgings. A lightweight fan blade was necessary because the front structure had to be able to withstand the large out-of-balance forces that would result from blade failure. To achieve a sufficiently light solid fan blade, even with titanium, required a short chord. However, with this design, the special feature of a mid-span support (snubber) was required to prevent aerodynamic instability. This design had the disadvantage of the snubber being situated in the supersonic flow, where the pressure losses were the greatest, resulting in inefficiency and reduction in airflow.

This disadvantage was overcome with the introduction of the wide-chord fan blade in the 1980s. The increased chord of the blade provided stability avoiding the need for snubbers. The weight was maintained at a low level by fabricating the blade from skins of titanium incorporating a honeycomb core. The design is a feature of the Rolls-Royce RB211-535E4 engine, introduced into service in 1984. Key advances since then include hollow blade technology and a second generation of diffusion bonded/superplastically formed fan blades [1]. These changes were a result of better scientific understanding, improved manufacturing processes, refined design theories and changing needs.

A detailed study of the above example reveals the incremental transformations in technology made possible by improved understanding obtained from engineering science and provides illuminating insights into the evolutionary nature of technological change.

2 Transfer of Knowledge

The aim of this research was to study the transfer of knowledge from scientific research into engineering design. The extent to which this scientific knowledge is applied effectively depends on the transfer process. For example, consider a piece of scientific information that has the potential to improve some aspect of a design. If the value of that information is not fully appreciated, or some of the information is lost during the transfer, or all the design conditions are not taken fully into account, then the full potential improvement will not be realised. If we could identify the factors that influence the transfer process, we might then be able to evaluate and enhance the knowledge transfer process.

The study identified certain elements upon which effective transfer of knowledge depended. It was observed that the presence of those elements, or characteristics, in the knowledge transfer process facilitated the successful transfer of scientific. In addition to those elements, the study also revealed a mechanism in the knowledge transfer process. A speculative method for measuring the effectiveness of knowledge transfer has been proposed. It is important to note that the proposed method evaluates the effectiveness of the knowledge transfer process rather than the value of the knowledge being transferred. After further development and validation, the method might be used to help to improve the effectiveness of the knowledge transfer process.

3 Method

The research was split into three parts. The first part comprised three preliminary case studies linking science and design from a historical perspective. The second part consisted of two more detailed turbofan case studies with a leading gas turbine manufacturer in the UK. Finally, a number of short review case studies were carried out, mostly with designers and researchers from another large aerospace company in the UK. The case studies in the second and the third parts comprised interviews and meetings with key people from the sponsoring companies and partner research groups.

4 Case studies

4.1 Preliminary Case Studies

Some examples from history were studied illustrating the impact of scientific knowledge on engineering design. The examples of fibre optics, the Fokker D-VII aircraft and Newcomen's engine were selected. These highlighted how research in basic physics, aerodynamics and thermodynamics impacted on communications, aeronautical and mechanical engineering design. The examples not only represented various domains of engineering but also different periods in history, enabling them to be studied from different technological and sociological contexts.

Some general observations for scientific knowledge transfer were established from these studies, including:

- Science evolves into technology as it is applied to various fields and applications.

- As a technology reaches maturity, its development becomes less and less dependent on the scientific knowledge underpinning it.
- Developments in society and developments in technology are closely linked. The social, political and economic conditions of a society influence the rate of knowledge transfer from research to design.
- New technology frequently emerges from basic scientific research.
- Technology is not always the offspring of science. Quite often, technology precedes science.

4.2 Turbofan Case Studies

The turbofan case studies were undertaken specifically to understand more fully the process of scientific knowledge transfer from research to engineering design in the aerospace sector.

The research started by selecting several design features on two turbofan engine components, the low-pressure turbine [2] and the fan, and attempting to trace these features back to the first time they appeared. The scientific knowledge that made it possible for these features to be incorporated was also traced. The scientific knowledge was divided into sub-disciplines to filter out domain specific knowledge. Each sub-discipline was then studied to analyse the amount of knowledge used in design compared to the amount of potentially useful knowledge available.

Detailed information was gathered from interviews with two researchers from a university and two designers from a leading gas turbine manufacturer. The interviewees talked freely around the topic using a pre-prepared list of questions as a guide. In addition, the scientific and technical literature produced by researchers and designers provided a source of structured technical information.

The observations from the in-depth turbofan case studies provided insights into the process of knowledge transfer from research to design and helped identify the elements essential for the successful transfer of knowledge. The 'elements' were tentatively identified from a detailed analysis of the information gathered. The information was analysed in terms of political, social, technological and economic issues [3]. These studies also provided insights into the mechanism of scientific knowledge transfer.

The elements identified on the basis of this analysis were:

- **Collaboration:** Constant interaction and understanding are necessary for knowledge transfer. Researchers and designers obtain the most benefit from the knowledge produced by working as a team.

- **Promotion:** Salesmanship is an important part of successful knowledge transfer. It plays a key role in communicating ideas and making people realise the importance of new knowledge.

- **Integration:** The success of a project depends on the quality of the people and team-integration. Small teams of high quality people tend to perform better than large ones.

- **Communication:** The way in which results from research are communicated to designers is crucial for knowledge transfer.

- **Acquisition:** One of the major problems with technology transfer is acquisition of scientific knowledge by sufficient people. Usually only a few people, the ‘technology champions’, have the required understanding in a new technology area.

- **Research Motivation:** Problems identified during the design process provide motivation for research. Designers rely on researchers to point to interesting things that are useful for design improvement. They often require expert advice in specific problem areas.

- **Design Motivation:** Research tends to be more relevant if embedded in design. The aims of scientific research are to produce interesting results that can be applied to lower cost, reduce the number of design iterations, and improve overall understanding.

- **Innovation:** Designers have to come up with innovative solutions and design rules within the given constraints and time scales. Effective transfer of scientific knowledge to engineering designs can facilitate this.

The elements listed above were those that appeared from the analysis to influence knowledge transfer directly.

4.3 Review Case Studies

Five review case studies were carried out in the final part of the research primarily for the purpose of verifying earlier results and identifying factors on which the knowledge transfer elements depended. The same method was followed for these studies as for the turbofan case studies, but with a fresh set of questions. Observations from these were analysed in the light of the elements suggested in the previous case studies.

One of the reasons for the review case studies was to investigate whether the elements could be used for assessing the effectiveness of knowledge transfer. Following these studies, a preliminary model for effective transfer of scientific knowledge was proposed. Such a model may serve as a means to evaluate scientific knowledge transfer between research and design bases [4], provided a means for evaluating individual elements can be found. It may then be possible for the transfer to be evaluated quantitatively or qualitatively. The model is described in the next section.

5 Knowledge Transfer Model

Analysis of information from the review case studies suggested a mechanism for the knowledge transfer process. It was observed that partnerships in research start with a design or a research *motivation*, which usually complement each other, and result in collaboration between researchers and designers. *Acquisition* of knowledge depends on the effectiveness of the *communication* and *promotion* of that knowledge between people who may benefit from it. *Integration* is essential if the knowledge transfer is to be effective and lead to *innovation*. Figure 1 shows a way in which the elements may be structured to form a model. Two types of elements can be identified in this figure: the core elements namely motivation, acquisition and innovation; and supporting elements namely collaboration, communication, promotion and integration.

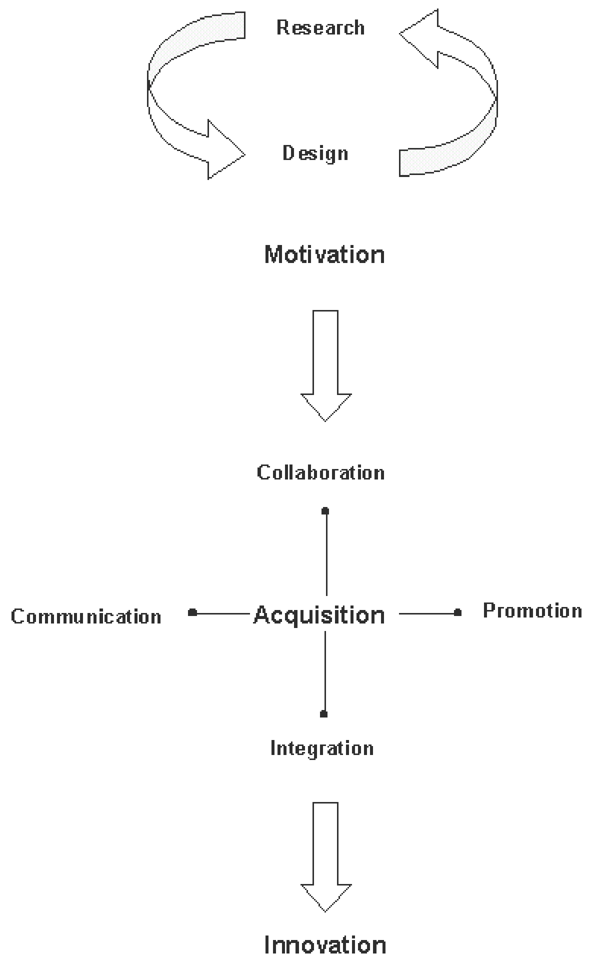

Figure 1. Model of Knowledge Transfer

The next step was to find a way of evaluating the knowledge transfer process using the model. It was clear that the *elements* could not be measured directly. One way to measure them is to determine the factors upon which they depend. If a factor cannot be measured, further dependencies must be sought until measurable ones are found. This is described in the following Section.

6 Speculation: A Method for Evaluating Knowledge Transfer

Figure 2, which was derived from the Turbofan and Review Case Studies, proposes factors which influence the single element communication. First all the factors that influence an element are placed at level 1. If the factors at level 1 are not measurable, then further factors are sought and listed at level 2. This process may be repeated until all influencing factors are identified. For instance, it was observed from the case studies that effective communication between the research and design interface depended on the content of the knowledge, the source, the channel through which it gets transferred, the timing of its arrival, the purpose, and the location (see Figure 2). Although these factors may be helpful in describing communication, some of them do not appear to be appropriate for the purpose of evaluating it. Levels 2 and 3 therefore list further factors that may be measured more directly. For instance, the content may be evaluated on the basis of publications, presentations and design methods. The publications may in turn be evaluated in terms of quantity and quality. Factors for all other core and supporting elements may be identified similarly.

Figure 3 suggests a way of showing how scientific knowledge accumulated over time for the high-lift blade research. The graph is based on the published scientific literature that contributed to the development of such blades. The relation between the accumulation of knowledge, milestones and innovation (in the form of patents) can be seen from the graph. An 'index' for evaluating published work is introduced here based on the cumulative number of key research papers published each year over a period of 60 years. The 'index' may be based on the quantity as well as the quality of published work. Other elements or factors may be evaluated in a similar way.

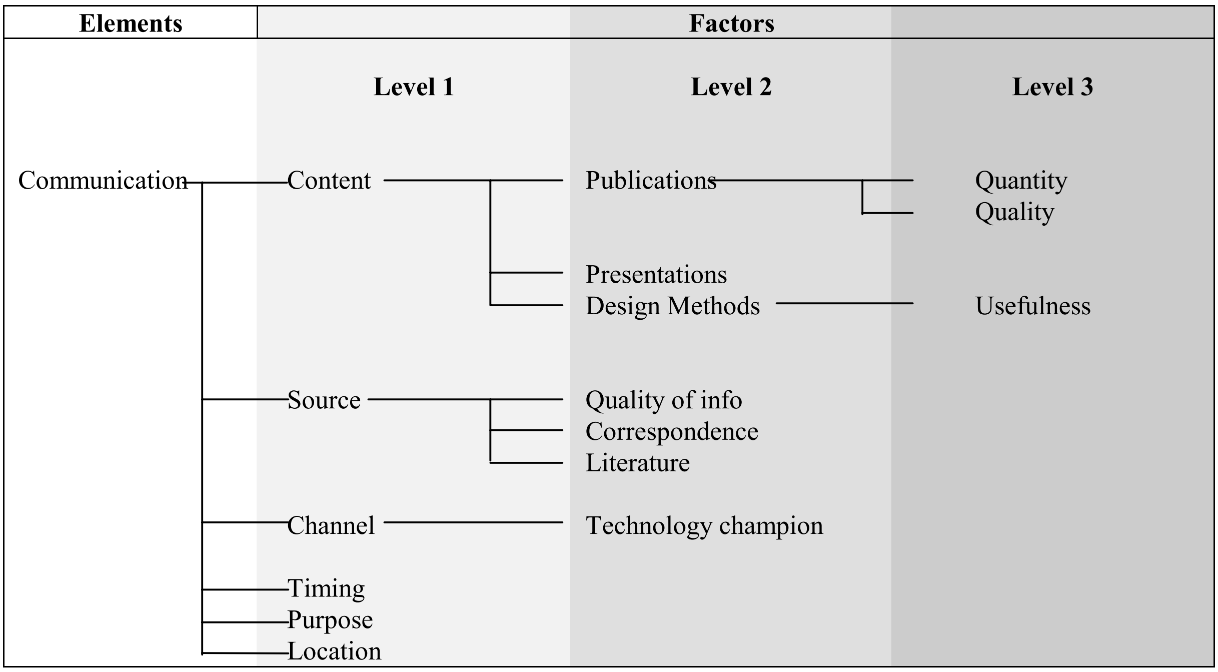

Figure 2. Factors that influence communication

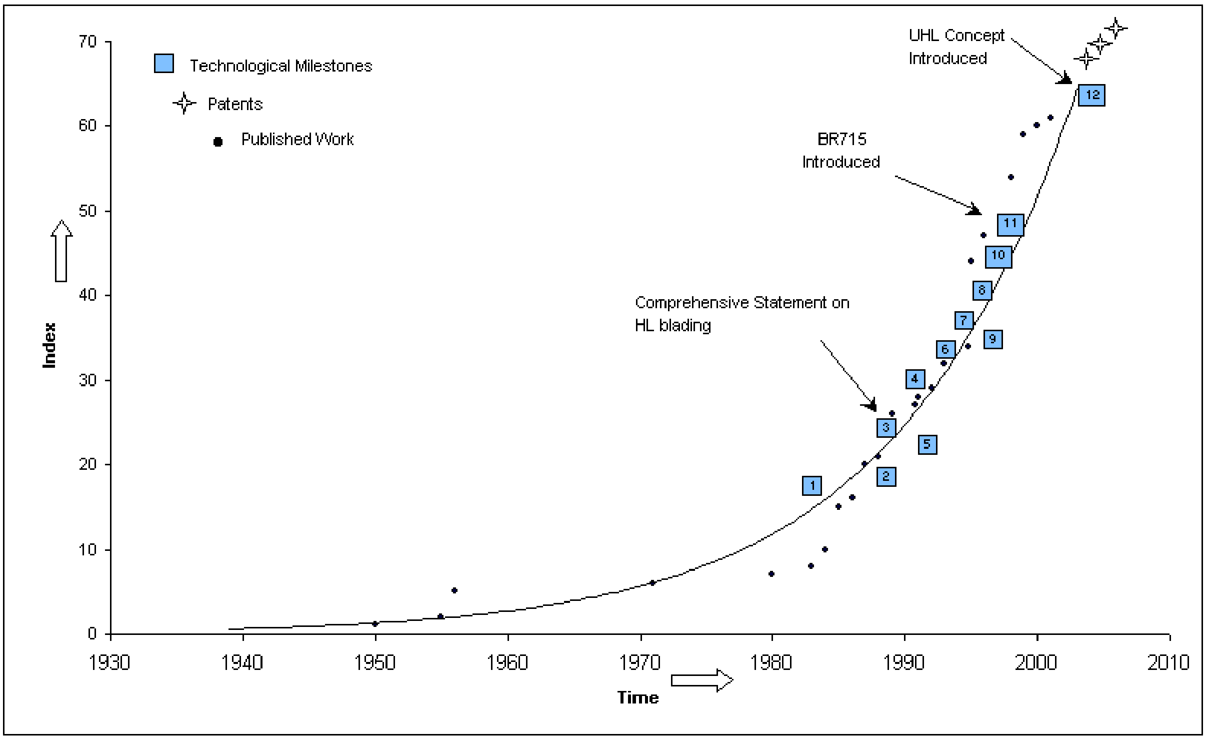

Figure 3. Accumulation of Scientific Knowledge for High-Lift Blade Research

7 Conclusions

The case studies provide insights into the knowledge transfer process and suggest a model of scientific knowledge transfer from research to engineering design.

Findings from the preliminary case studies suggest that science and technology complement each other and science evolves into technology as knowledge is applied. The rate at which knowledge is applied is influenced by the social, political and economic conditions of a society. It was also discovered that it is not only new science that gives rise to technology, but the reverse is also true.

The turbofan case studies show that collaboration, promotion, integration, communication, acquisition, research motivation, design motivation and innovation are essential elements for the transfer of scientific knowledge from research into engineering design. It was also discovered that the transfer of scientific knowledge almost always depends on a technology champion or translator.

From the insights gained from the review case studies, it is inferred that the knowledge transfer process has a mechanism and the suggested elements may be arranged in the form of a model. The effectiveness of knowledge transfer might be appraised using this model, provided the underlying elements can be measured. One of the methods for evaluating the elements or the underlying factors is to use an ‘index’ which may allow results from the evaluation to be represented graphically and thus be used to assess the effectiveness of knowledge transfer.

Finally it is concluded that the study of social, political and economic aspects in addition to technological aspects is essential to fully understand the process of scientific knowledge transfer. The process is very complex to describe since it involves so many factors and clearly varies from case to case. However, it is believed that the main factors and some of their links have been identified.

8 Acknowledgements

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Corresponding author:
Zeeshan Ali Khan
Cambridge University Department of Engineering
Engineering Design Centre
Trumpington Street
Cambridge
CB2 1PZ
United Kingdom
Tel: Int +44 1223 330271
Fax: Int +44 1223 332662
E-mail: zak22@eng.cam.ac.uk
URL: http://www-edc.eng.cam.ac.uk/people/zak22.html