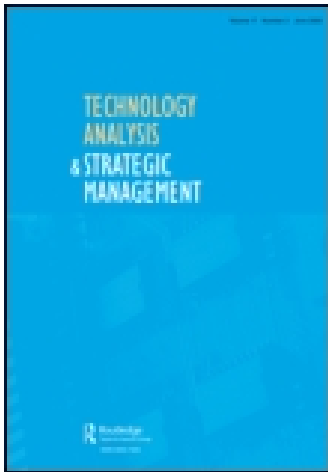


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Power-by-the-hour: the role of technology in reshaping business strategy at Rolls-Royce

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There is a recognised trend of manufacturing companies offering not only products, but also services and even complete solutions to business problems. Research has highlighted economic, market demand and competitiveness factors as responsible for the reshaping of business strategies that this has involved. This study analyses the extent to which another factor, technology, has been a significant factor in the switch from product oriented to service-oriented strategies. A case study of the aero engine manufacturer Rolls-Royce is used to analyse the impact of technology, which is found to have led manufacturers to reshape their business strategies. The study finds that developments in one technology in particular, namely digital electronics, have been a powerful enabling factor facilitating the implementation of service strategies. This provided original equipment manufacturers like Rolls-Royce with a competitive advantage relative to conventional service providers, by enabling them to acquire new knowledge management capabilities.

Keywords: technology and innovation studies; case study; aerospace industry; knowledge management; business and corporate strategy; R&D management

1. Introduction

The management literature urging manufacturers to make the transition from supplying products to supplying products and services on an integrated basis is very extensive (Oliva and Kallenberg 2003). In terms of industry sectors, the literature that has highlighted and analysed this trend extends mainly to capital goods, including computing, cranes, trains and aerospace (Howells 2004).

The logic behind manufacturers moving forward along the value chain to include the provision of services as well as manufacturing is normally attributed to three main determinants: economic factors, demand conditions and competitive advantage (Oliva and Kallenberg 2003). The economic argument is that through the provision of services additional revenue can be generated from an installed base of products especially if the product life cycle is a long one with products remaining in service for many years. To reinforce this, it is also pointed out that services typically yield significantly higher margins than products. The case for demand conditions is that as customers become more sophisticated their expectations rise and they demand solutions rather than mere

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products. Often this is set in terms of the trend towards greater specialisation and a move on the part of many companies to outsource services as they focus on core competences (Prahalad and Hamel 1990). Finally, the case for competitiveness rests on the notion that services are often more difficult to imitate and therefore are a source of potential competitive advantage.

However, very few studies have looked at alternative perspectives. For instance, there has been little consideration of what one would intuitively expect to be an important driver behind this trend towards the provision of services, namely technology. One might well argue that such has been the attention given by strategy researchers to concepts like core competences (Prahalad and Hamel 1990), that technology, particularly long-term technological change has taken something of an analytical back seat, when it comes to analysing the forces that shape business strategy. This study attempts a reassessment. The study looks specifically at the part that technology plays as a factor in the transition from products to services, especially the move towards offering integrated solutions using new business models. The aim is to analyse the role of technology in reshaping the business strategy of manufacturers as they extend their product offerings. The study seeks to answer a single research question – what role did technology play in reshaping business strategy in the aero engine sector? Here, the focus is on the industry environment (Grant 2008, 66) and how this has changed as a result of macro-level factors, specifically developments in technology and the resulting response from manufacturers in terms of revising and reshaping their business strategy. To answer this question, the study analyses recent developments in the aero engine sector of the aerospace industry through a case study of a company often cited as an example of a manufacturer leading the way in offering not merely services, but integrated solutions, namely Britain's largest manufacturing company, the aero engine manufacturer, Rolls-Royce.

2. Review of the literature

The trend towards manufacturing companies moving into the provision of services was first highlighted in the 1980s by Vandermerwe and Rada (1988, 315), who coined the term 'servitisation' to describe the phenomenon. The provision of services is now a conscious and explicit strategy for many firms, resulting in a steady flow of research papers analysing this trend with a variety of terms used to describe it. Baines et al. (2009, 547) refer to it as 'integrated product-service offering' and Howells (2004, 25), noting the way services are sometimes bundled as a 'wrapper' complementing products, uses the term 'service encapsulation'. Wise and Baumgartner (1999), Davies (2004) and Windahl et al. (2004) on the other hand note that the move into services sometimes involves very much more than simply bundling the provision of complementary services along with the product. They use the term 'integrated solutions' to describe a business model where services are typically not an add-on to a product, rather products and services are combined to address specific customer needs.

A key feature of the integrated solutions business model is that it is about much more than just moving down the value chain to provide services as well as products. With this business model manufacturers typically 'take over the risks and responsibilities of performing activities previously handled in-house by their customers' (Davies 2004, 732), and in exchange for providing much greater value, they get a significantly higher return. Risk in this context refers to the possibility of a product malfunction leading to a potential loss of service, and the responsibility is to fix it ensure there is no loss of service. Assuming a level of risk implies more than providing additional services since services are being provided on a quite different basis, leading to the use of terms such as 'performance-based contract' (Kim, Cohen, and Netessine 2007) and 'outcome-based contract' (Ng, Maul, and Yip 2009) to describe packages where the customer is buying not merely

services along with a product but, 'a predetermined level of availability to meet the customer's objectives' (Kim, Cohen, and Netessine 2007, 1844). What is provided goes well beyond replacing the sale of goods with the sale of goods plus support services. With such contracts, the integrated solution typically extends to the service provider agreeing to carry out all necessary maintenance and guaranteeing a given level of product availability and performance, at a fixed price normally based on usage.

Davies (2004) suggests that the trend towards the provision of outcomes is particularly a feature of capital goods producers. Given that capital goods tend to have a comparatively long life, this has led some researchers to use expressions like 'long-term service agreement' (Kerr and Ivey 2001, 290) and 'through-life management' (Ward and Graves 2007, 457) to describe the provision not merely of products but support services for them over the course of their life.

According to Wise and Baumgartner (1999), the particular attraction of servitisation for capital goods manufacturers is that it allows them to make use of their installed base comprising the total number of their products currently in use. For capital goods manufacturers whose products are durable and have a relatively long lifespan, this is typically many times greater than the value of their annual sales of products. As examples Wise and Baumgartner (1999) cite trains (i.e. locomotives), civil aircraft and tractors, where the installed base is 10 or more times greater than annual sales.

The inclusion of aerospace is no coincidence as several studies have looked at servitisation in the aerospace sector. These range from studies that mainly cite aerospace as an example of this trend to ones that provide a more detailed analysis of the factors at work and the impact on the firms. Among the former are studies by Baines et al. (2009), Davies, Brady, and Hobday (2006), Howells (2004), Neely (2007) and Oliva and Kallenberg (2003), which note how engine manufacturers like General Electric and Rolls-Royce now provide engine maintenance on an hours flown basis, and studies by Ng, Maul, and Yip (2009) and Kim, Cohen, and Netessine (2007), which use airframe maintenance as an example of the provision of performance-based maintenance.

Four studies (Johnstone, Dainty, and Wilkinson 2009; Kerr and Ivey 2001; Lorrell et al. 2000; Ward and Graves 2007) specifically analyse the move to servitisation in the aerospace industry. Johnstone, Dainty, and Wilkinson (2009) provide an in-depth case study that analyses how one engine manufacturer has moved into the provision of services. It broadly confirms Oliva and Kallenberg's (2003) findings from other sectors noted earlier in this paper, i.e. the three factors leading to servitisation are economic factors, customer demands and the pursuit of competitive advantage. The authors (Johnstone, Dainty, and Wilkinson 2009) pinpoint two of these three factors, namely economic factors in the form of cost pressures and the need to provide a stronger customer focus given the trend towards greater use of outsourcing. They also note that implementation creates challenges in terms of gaining employee involvement and the integration of different parts of the organisation. A study by Ward and Graves (2007) surveyed 11 companies operating in different parts of the aerospace supply chain. It identified four factors behind servitisation. Three were those noted by Oliva and Kallenberg (2003). The additional fourth factor identified by Ward and Graves (2007) was risk, specifically a desire to push the risks associated with revenue streams, down the supply chain. The authors noted that this factor was less significant than the other three. Ward and Graves (2007) also highlighted the importance of information systems in implementing this kind of service. Significantly, Ward and Graves (2007) like Johnstone, Dainty, and Wilkinson (2009) said little about the part played by technology, in providing information in the first place. In contrast, an earlier study by Lorrell et al. (2000), while noting the importance of the factors identified by Oliva and Kallenberg (2003), also cited industry specific institutional changes, in the form of market deregulation, as an important driver particularly in the commercial

sector. This they argued had caused manufacturers to rethink the way they do business. The study cited the move into services as a direct consequence of institutional changes, though it said little about the strategies of particular companies.

The most comprehensive analysis of servitisation in the aerospace sector is that by Kerr and Ivey (2001). It focuses specifically on the aero engine sector and provides extensive contextualisation covering not only institutional changes, but also other changes affecting the sector in general and maintenance services in particular. A feature of the study is the attention it gives to economic factors especially the economics of engine maintenance. It also highlights the crucial importance of knowledge of engine performance characteristics in the provision of maintenance services, particularly the scope such knowledge provides for accurately predicting maintenance requirements and optimising engine performance. To this end, the study notes that engine data is increasingly becoming available on a real time basis through the development of engine monitoring systems, and the authors highlight the implications of this for the engine manufacturers. However, relatively little is made of the part played by technology in facilitating this, nor does the study consider the wider implications of this for the strategies employed by the engine manufacturers.

Overall, the studies of the aerospace industry support and reinforce Oliva and Kallenberg's (2003) general perspective on servitisation that there are three main factors acting as drivers for servitisation, namely economic factors, customer demands and the pursuit of competitive advantage. The studies identify a small number of additional factors contributing to servitisation, namely risk (Ward and Graves 2007), institutional changes (Lorrell et al. 2000) and the increased availability of information (Kerr and Ivey 2001), but none of the studies identifies any of these factors as being particularly important.

Significantly none of the studies specifically cites technology, especially advances in technology, as a driver for servitisation. One might argue that the study by Kerr and Ivey (2001) comes close because it did note how increased knowledge of product performance is becoming available through the development of engine health monitoring systems. However, the study said nothing about the technologies that are helping to make this possible. In the light of this, and the way in which studies of servitisation in aerospace like studies of other sectors have ignored advances in technology, as a possible factor behind servitisation, this study seeks to rectify this omission.

3. Methodology

A case study methodology was selected for two reasons. First, because Eisenhardt (1989) argues that case study research focuses on the dynamics present in a given setting or context and the focus of the study was factors influencing the reshaping of strategy in a specific industry context. Second, because Voss, Tsikriktsis, and Frohlik (2002) maintain that case study research is particularly appropriate for analysing changes in technology and the impact of technology was a theme running throughout the study.

Following Leonard-Barton (1990), a 'dual' methodology was used for data collection, involving both archival materials and interviews and both public and private in nature. The former were largely publicly available archival materials and reliance on them was justified on the grounds that Lazonick and Prencipe (2005), who have researched aerospace extensively, maintain that with company-level research on strategy, much can be achieved with such materials.

The archival materials included a range of documentary sources. They consisted of documents published by the case company together with a range of specialist published materials covering aviation in general and the aerospace industry in particular. Among the case company documents consulted were annual reports from 1970 to the present, the in-house quarterly magazine published

by the case company from 1979 to the present, together with a range of reports that included technical summaries and market reports. The specialist published materials included both printed and online resources. Of these, the most used item was the searchable online digital archive of the specialist aviation periodical *Flight International*, which is available from 1909 to 2009. This provided a number of contemporary reports (Lewis 1999; Paddon 1988) on developments in engine technology. Other specialist aviation periodicals consulted included *Aviation Week and Space Technology* (Terino 2005), *Aerospace* (Baldwin 1993; Robins 1994; Ruffles 1986), *Air International* (Walters 1999) and *Airways* (Davis 2010). This was supplemented by further data, much of it technical in nature from specialist technical publications. These included material from the trade press such as *Military and Aerospace Electronics* (Wilson 2003) which had been identified from online databases including *Business Source Complete* and *Science Direct* and reports, lectures and other materials published by the principal professional body in the UK dealing with aviation, the Royal Aeronautical Society (Howse 2004; Robins 2004).

Alongside these documentary sources a number of specialist texts were used covering various aspects of aviation. These fell into two broad categories, those that were essentially of a technical nature and those that were largely historical. The former included several works covering a variety of aspects of engine technology (Gunston 1995; Kay 2007; Miller and Sawers 1968; Rolls-Royce 1966), while the latter included biographies (Hooker 1984; Rowe 2005); corporate histories (Donne 1981; Pugh 2002); and studies of the aviation industry (Bluestone, Jordan, and Sullivan 1981; Langewiesche 2010; Whitford 2007).

The use of a number of different types of document served to ensure the quality of the evidence used. The various types of document used were written either by specialist technical authors and journalists with many years' experience, including a number who had previously worked in the industry often in a technical role, or by senior technical figures working for the case company, with extensive personal knowledge of the technologies and technological advances detailed in the case study.

The data gathered in this way were corroborated and verified through a small number of interviews conducted using the key informant approach, a technique widely used in ethnographic studies (John and Reve 1982; Phillips 1981). Five key informants were interviewed, having been selected not on a random basis but specifically because they occupied, or had until recently occupied, senior roles within the aerospace industry. This meant that they had specialised knowledge of the issues being researched (Kumar, Stern, and Anderson 1993). They included a commercial director, a business development manager, a new product development manager, a finance director and an aerospace industry consultant. Four had been employed by companies that were partners of the case company on joint ventures or partnerships for major engine programmes at some point during the period covered by the case study. One had had worked as a contractor to the case company for many years. The interviews were in Marshall and Rossman's (1989, 94) terminology, 'elite interviews' with respondents well qualified to comment on the case company's strategies, as well as industry trends and practices. Identification of the sample of key informants followed a snowballing strategy similar to that outlined by Healey and Rawlinson (1991, 346), whereby having interviewed 'one good senior contact' that individual's personal network proved very effective in identifying further suitable key informants. The interviews, which were semi-structured, lasted between 40 and 90 minutes and were recorded and transcribed. Four were conducted face-to-face interview, while one was a telephone interview.

Having amassed a substantial body of data in this way, it was then subjected to content analysis (Bryman and Bell 2007) using a simple manual coding system based on critical incidents in relation to the development of aero engine technology. From this, a timeline tracing the historical

path of advances in engine technology was produced, which in turn formed the basis of the narrative for the detailed in-depth case study. In terms of analysis, the archival materials provided the initial basis for the development of the case study. The key informant interviews were then used to triangulate the emerging picture of developments within the case company and to evaluate the extent to which new technologies had contributed to the reshaping of business strategy within it.

4. Case study: Rolls-Royce plc

4.1. Jet engine technology

The jet engine that forms the powerplant of today's modern jet airliner is a gas turbine made up of three main elements, namely a compressor, a combustor and a turbine (Figure 1). While the first jet engines were turbojets, since the 1960s more efficient turbofan designs have been used. These have an inlet fan at the front which both draws air into the compressor and sends some into a bypass duct around the engine in order to cool it, reduce noise and generate a significant proportion of engine power. The function of the compressor, which comprises rows of ever smaller rotating blades on a central shaft (Scranton 2011), is to compress the incoming air. The high pressure air is then mixed with atomised fuel and burnt in the combustor. This produces very hot gases which expand rapidly and are forced out of the back of the engine under intense pressure to provide the thrust which propels the aircraft forward (Rolls-Royce 1966). On the way, the exhaust gases drive a multi-stage turbine rotating at high speed which powers the compressor. The power generated is measured in pounds of thrust and early jet engines produced only limited thrust, typically less than 10,000 lbs.

Although the jet engine was readily taken up by the military in the years immediately after Second World War for applications such as interceptor fighters (Geels 2006), largely because of its performance in terms of power to weight, it was more than a decade before jet airliners became anything like a serious proposition for the world's airlines. The cause of the delay was that although jet travel offered passengers the twin potential benefits of speed and comfort, the development of the jet airliner in the early years was held back by two key factors, namely poor fuel economy and poor durability (Geels 2006). Early jet engines used a lot of fuel. Specific fuel consumption (SFC) on the first generation of turbojet engines was about 0.9 lb/hr/lb, making them significantly less fuel efficient than the piston engines they replaced (Figure 2). Although

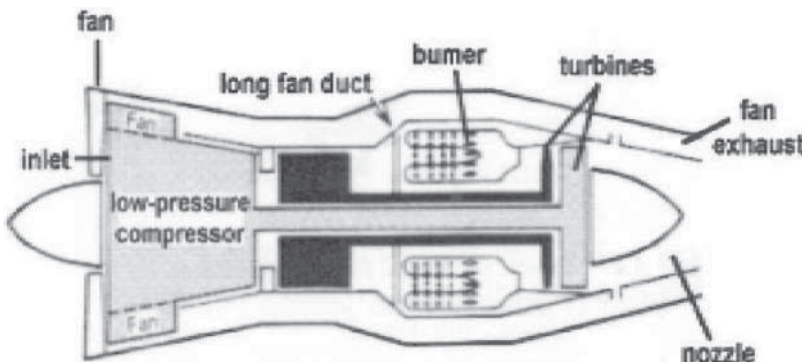


Figure 1. Schema of a modern jet engine.

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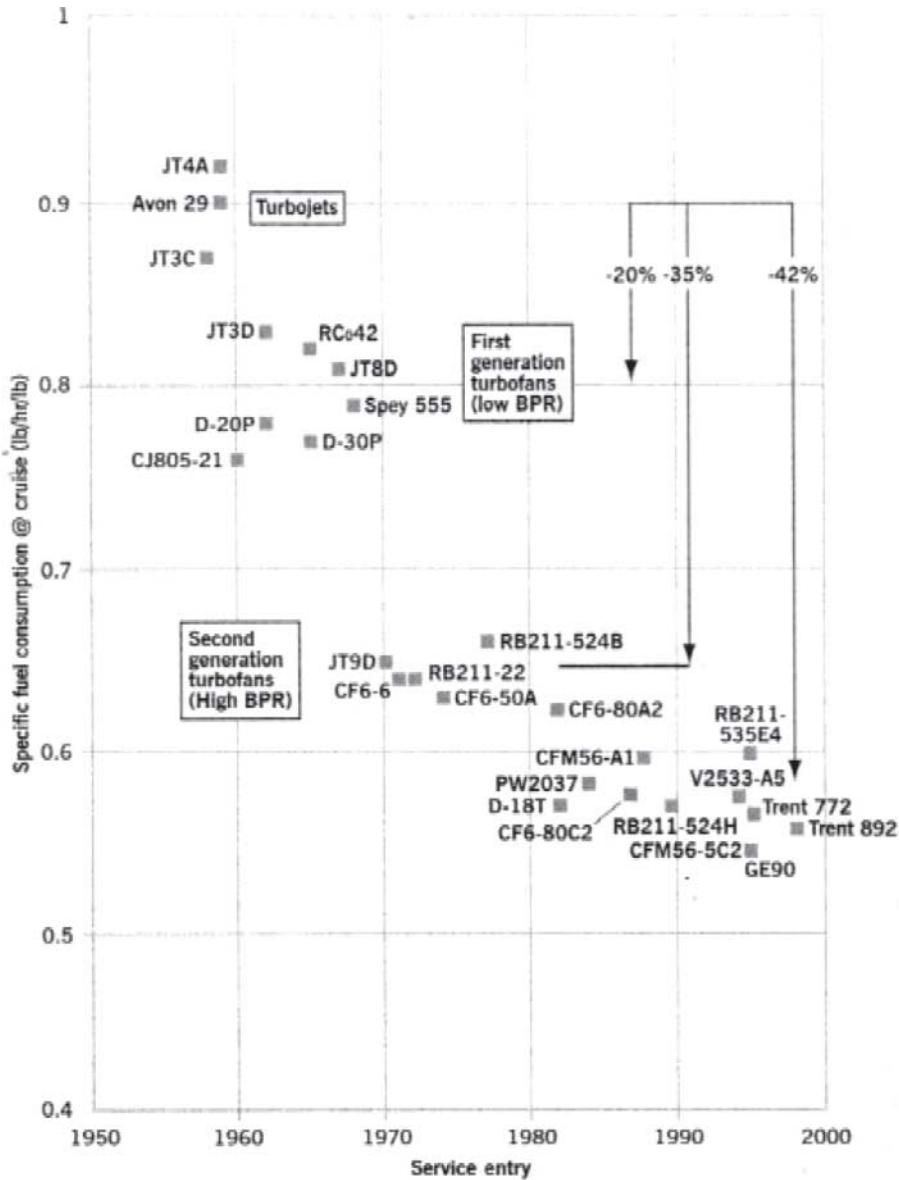


Figure 2. Improvements in SFC of civil jet engines 1950–2000. Source: Whitford (2007, 116).

simpler than piston engines by virtue of replacing a reciprocating motion with a rotating motion, jet engines also required more maintenance than equivalent piston engines, by virtue of their novelty and their high operating temperatures (Miller and Sawers 1968, 178), which demanded new and unproven materials. General Electric’s J-47 engine for example, admittedly a military rather than a commercial engine, went for only 500 hours between overhauls even in the mid-1950s (Miller and Sawers 1968, 186). Poor durability meant that mechanical parts like turbine

Table 1. Comparative performance of Rolls-Royce engines.

	Conway RCo. 12 (1960)	Trent 892 (1998)
Application	Boeing 707	Boeing 777
Max. thrust (lbs.)	17,500	91,500
Engine weight (lbs.)	5147	16,000
Bypass ratio	0.3:1	6.5:1
TET (°C)	1050	1750
SFC (lb/hr/lb)	0.87	0.575
Pressure ratio	15:1	40.8:1
Thrust; weight ratio	3.4:1	5.7:1

Sources: Davis (2010); Gunston (1995); Kay (2007); Owen (2001).

blades had to be replaced after a short time, a serious problem for commercial airlines in view of the high levels of usage demanded of their aircraft.

Key factors in improving engine performance in terms of fuel economy were the bypass ratio, the pressure ratio and turbine inlet temperature (TET). As a base line Rolls-Royce’s first generation turbofan engine the RCo12 Conway which powered both British and American airliners in the 1960s had a bypass ratio of 0.3:1, a pressure ratio of 15:1 and an operating temperature of 1050°C (Table 1). To improve the fuel efficiency, engines needed to operate at higher temperatures and higher pressures so as to ensure fuel was turned into energy as efficiently as possible. Improving durability required a combination of factors including the development of stronger heat resistant materials, more effective design and improved manufacturing processes.

4.2. *Advances in engine technology*

Over the last 40 years, successive generations of new engine have introduced advances in engine technology that have progressively improved not only engine performance but also engine durability. Rolls-Royce’s RCo42 Conway engine which entered service in the 1960s included one significant innovation designed to boost durability, over first-generation turbojets. Although the compressor utilised what were then conventional extruded aluminium blades (Howse 2004), the Conway pioneered the use of forged nickel alloy turbine blades incorporating internal air cooling (Gunston 1989; Hooker 1984; Whitford 2007), which significantly extended the life of turbine blades.

The successor to the Conway (Donne 1981) was the Rolls-Royce RB211, a very much larger and more powerful high-bypass turbofan engine that powered the first wide-bodied airliners like the Lockheed L-1011 Tristar and Boeing 747. Entering service in the early 1970s, it was designed to operate under more demanding conditions, including a much higher 5:1 bypass ratio, twice the pressure ratio and an operating temperature of 1250°C. It was more than twice as powerful as the earlier Conway and significantly more fuel-efficient (Figure 2). It also incorporated a number of technological advances designed to improve durability. Following the lead given by its American rivals General Electric and Pratt and Whitney, Rolls-Royce switched from forged to cast turbine blades, manufactured using the ‘lost wax’ process (Hooker 1984). Substituting investment casting for forging not only allowed harder alloys to be used but it also facilitated more effective and reliable internal cooling of turbine blades, resulting in them being significantly more durable. The 524 variant, a later and more powerful version of the RB211 engine also incorporated film-cooled

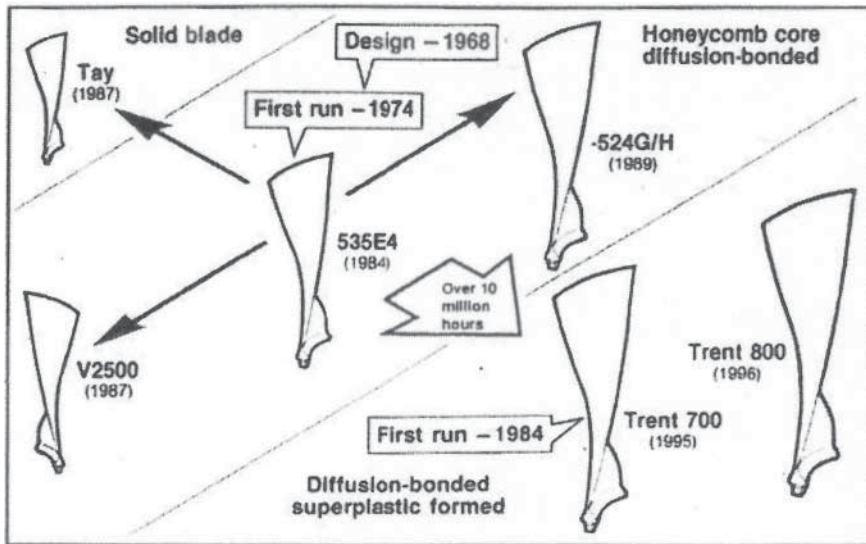


Figure 3. Applications of wide-chord titanium fan blade technology.
Source: Baldwin (1993).

turbine blades enabling them to operate at even higher temperatures, while the 535 variant used a new 'directionally solidified' blade (Howse 2004, 12) that was both stronger and more durable.

Later versions of Rolls-Royce's 535 engine, designated the 535E4 that entered service in the late 1980s (Walters 1999), saw the introduction of one of the most significant advances in engine technology (Robins 1994), the hollow titanium wide chord blade fitted to the large fan at the front of the engine. Hitherto engine manufacturers had used narrow solid titanium blades. These suffered a number of disadvantages. They were heavy, a large number of them were needed and they required a mid-span support or snubber to prevent vibration. This significantly reduced aerodynamic efficiency. Rolls-Royce's introduction of the much lighter and stronger hollow titanium wide chord fan (Prencipe 2001) on the E4 version of its 535 engine, produced by an entirely new process of diffusion bonding (Howse 2004, 18), resulted in a fan that was much lighter and much stronger (Figure 3). Many fewer blades were required, 22 as opposed to 33 on earlier versions (Baldwin 1993), and it dispensed with a mid-span support, resulting in a significant (4%) improvement in fuel efficiency (Figure 2). Being wider and stronger, the blades were also more robust and durable resulting in less susceptibility to bird strikes and foreign object damage.

Rolls-Royce's latest generation of engine, the Trent and its associated variants that entered service in the late 1990s and 2000s on the new generation of large twin jet airliners like the Airbus A330 and Boeing 777, introduced further advances in technology associated with design, materials and manufacturing processes, which again resulted in improvements not only in fuel efficiency (Figure 2) but also particularly in engine durability. These included turbine blades made from advanced single-crystal titanium alloys which eliminate the grain boundaries which reduce the life of conventionally cast blades (Owen 2001, 132) and the introduction of thermal barrier coatings (Howse 2004, 12). These advances in technology combined with improvements in internal cooling mean that turbine blades can now operate at 1800°C, while the base material only has a temperature capability of 1350°C. Another development with later versions of the Trent was the introduction of

swept fan blades. Introduced on the Trent 900 engine that powers the Airbus A380, the swept fan requires fewer blades and significantly increases damage resistance and durability by centrifuging debris away from the engine core and down the bypass duct (Howse 2004, 18). These changes mirrored similar developments at its rivals General Electric and Pratt and Whitney.

With the development of ultra high-thrust engines like the Rolls-Royce Trent in the 1990s, manufacturers were forced to develop engine control systems capable of handling a much greater number of engine parameters (Brusoni and Prencipe 2001), as the hydro-mechanical engine control systems used up until this point, as one commentator (Paddon 1988, 33) put it at the time, ‘just could not cope . . . they were becoming mechanical monsters’. As a result, Rolls-Royce and the other leading engine makers who developed similar ultra high-thrust engines introduced full authority digital electronic control (FADEC) systems, which were fundamentally different from earlier engine control systems. Data on engine parameters, such as turbine temperature, fan speed, and altitude, were now collected via electronic sensors in the form of transducers and thermocouples and communicated electronically to a computer, which managed all aspects of engine performance. This mirrored the development of fly-by-wire control systems for aircraft, described by Langeweische (2010, 99) as, ‘a marriage between electrical control circuits and digital computers’.

The switch to digital electronics provided a number of benefits, particularly in terms of engine durability and reliability. First, FADEC systems record any deviations from the ideal operating range of the engine, thereby facilitating more effective maintenance. Second, they ‘treat the engine very gently’ (Paddon 1988, 34) meaning that because a FADEC system is constantly monitoring a large number of engine parameters it can make minute adjustments to the engine, thereby ensuring it is functioning as close to its ideal operating conditions as possible, so as to minimise wear and tear on components. Finally, a FADEC system provides valuable system protection within the engine, so as to protect components from damage wherever possible thereby ensuring durability.

The cumulative effect of advances in engine technology meant that by the 1990s when the first of the current generation of engines like the Rolls-Royce Trent entered service they not only exhibited a level of performance in terms of thrust and fuel efficiency (Table 1) that was a very substantial improvement on 30 years earlier, but their durability was also vastly improved compared to first generation turbfans like the Rolls-Royce RCo42 Conway. The extent of this improvement was reflected in the demand for spares to replace worn and damaged components. Even in the early 1980s, a jet engine would consume a quantity of spares equivalent to the original value of the engine in about eight years (Whitford 2007), but engines like the new Rolls-Royce Trent that entered service at the end of the 1990s consumed this quantity of spares not in eight years, but in 25 years. For the engine makers, this represented a very big drop in demand for spares and therefore their revenues.

4.3. *Reshaping business strategy: from product-centric to customer-centric*

The dramatically reduced demand for spares brought on by advances in technology presented a particularly challenging problem for engine manufacturers like Rolls-Royce. With the profit margin on spares estimated to be seven times higher than that on new engines (The Economist 2009), it was not just a matter of the loss of revenue but the loss of their most profitable revenue. Faced with this, Rolls-Royce began to revise and reshape its business strategy. Hitherto, Rolls-Royce’s business strategy, like that of its American rivals Pratt and Whitney and General Electric, was a ‘product-centric’ strategy (Davies 2004, 733), that aimed to maximise the breadth of its product portfolio. By having the widest possible range of engines, it aimed to offer the largest

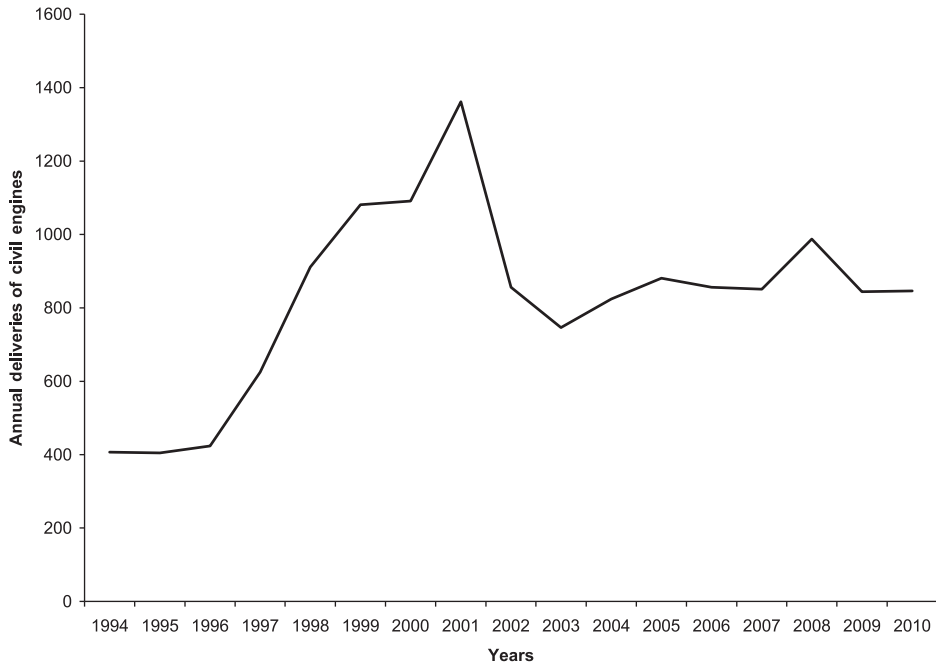


Figure 4. Annual deliveries of Rolls-Royce civil engines 1995–2010.
Source: Rolls-Royce Annual reports 1998–2010.

number of airframe applications for its engines thereby maximising the number of potential airline customers who could use its products. Not only that, having developed advanced technologies, such as its innovative hollow titanium wide-chord fan, Rolls-Royce could then apply them to different types of engine. As Figure 3 shows the wide chord fan initially developed for the 535E4 variant of the RB211 was also fitted to Rolls-Royce's 524 engine that powered the Boeing 747, the V2500 that powered the Airbus A320, A321 and A319 and the Tay engine that powered the Fokker F70 and the Gulfstream business jet. This 'dual use' (Robins 2004; Ruffles 1986) approach to new technologies served to spread R&D costs across different engine programmes leading to economies of scope (Swann 2009).

Rolls-Royce's vigorous pursuit of this product-centric business strategy meant that whereas in 1980 it sold engines for just four civil airframe applications, by 1996 this had risen to 27 (Rolls-Royce 1997, 8) and as Figure 4 shows deliveries of commercial engines which at the start of the 1990s had been around 400 per year had trebled to more than 1200 per year by the start of the new millennium. By the early 2000s, the company had even displaced one time market leader Pratt and Whitney (Bluestone, Jordan, and Sullivan 1981) to take second place in the worldwide market for aero engines (Lazonick and Prencipe 2005) just behind arch rival General Electric.

However, just at the point when Rolls-Royce's product-centric business strategy was finally yielding success, the company like its rivals, General Electric and Pratt and Whitney, began to feel the impact of the cumulative advances in engine technology, in particular the cumulative improvements in engine durability. Faced with this, in the 1990s Rolls-Royce, while continuing to pursue a broad product portfolio, began to reshape its strategy along the lines of what Davies (2004, 732) terms a 'customer-centric' business strategy. This aimed to extract greater value from

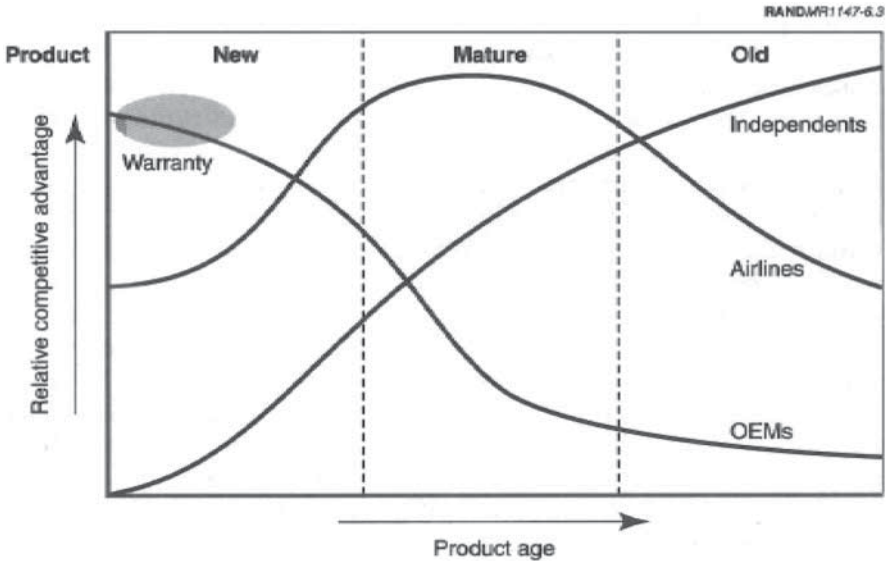


Figure 5. After-market competitiveness.
 Source: Lorrell et al. (2000, 129).

one of the company’s most important assets, namely its installed engine base. This greater value was to come from offering not merely spare parts, but maintenance services as well, though offered on a very different basis from conventional maintenance, repair and overhaul (MRO) services with fixed price contracts linked to guarantees of engine availability.

Historically, Rolls-Royce along with other original equipment manufacturers (OEMs) had undertaken MRO work on a fairly minor scale. Indeed, one study observed that, ‘until the 1990s, repair and overhaul of its engines was not viewed as a mainstream activity’ (Pugh 2002, 194). The OEMs limited their exposure to MRO to warranty work in the early part of an engine’s life (Figure 5), leaving the market to the in-house engineering divisions of major airlines and independent MRO providers. The latter had become a more important part of the MRO market as airlines increasingly outsourced their maintenance work in order to focus on their core business. When outsourced in this way, MRO work was undertaken on a ‘time and materials’ basis (Ward and Graves 2007, 467) where the contract price was determined by actual costs in terms of staff time and spare parts used.

In 1993, Rolls-Royce took its first tentative steps towards a customer-centric strategy with the setting up of a separate company, Rolls-Royce Aero Engine Services Ltd., designed to pool together the repair and overhaul facilities that had hitherto operated independently at sites in Derby, Bristol, Coventry and Scotland in the UK and overseas in Canada and Brazil. The company then set about putting in place an appropriate infrastructure with which to deliver MRO services on a global basis. Additional facilities for repair and overhaul work were acquired around the world, chiefly through a succession of joint ventures with airlines (Table 2). By 2001, this expansion had grown the company’s repair and overhaul business from a modest \$400 million in 1993 with just six sites of which two were overseas to \$1.6 billion (Pugh 2002) with 16 sites around the world (Wilson 2003). Thus, over an eight-year period Rolls-Royce created the infrastructure to enable it to offer MRO services on a worldwide basis, with major facilities across the world.

Table 2. Rolls-Royce’s principal MRO-related collaborations.

Year	Venture	Form	Partner	Location
1996	Hong Kong Aero Engine Services Ltd (HAESL)	JV	HAECO	China
1998	Texas Aero Engine Services Ltd (TAESL)	JV	American Airlines	USA
1998	International Aero Engine Component Overhaul (IECO) Pte Ltd	JV	Singapore Int. Airlines	Singapore
1998	Data Systems & Solutions	JV	Science Applications International Corp.	UK
1999	National Airmotive	Acquisition	n/a	USA
2004	N3 Engine Overhaul Services	JV	Lufthansa Technik AG	Germany

Source: Pugh (2002); Rolls-Royce Annual Reports 1994–2004.

However, reorganisation of its repair and overhaul operations was only a one part of the company’s new customer-centric strategy. A key part of reshaping the company’s business strategy was extracting significantly more value from its installed base of engines. To do this, Rolls-Royce developed a completely different type of service offering. Rather than services provided on a conventional ‘time and materials’ basis like its competitors, the in-house engineering divisions of the bigger airlines and the independent MRO providers, Rolls-Royce broke new ground by offering its customers an ‘integrated solution’ (Wise and Baumgartner 1999, 138) in the form of fixed price maintenance based on engine availability. This new type of performance-based service contract was initially marketed as ‘power-by-the-hour’.

4.4. Power-by-the-hour for the US navy

An example of the new style performance-based contracts being offered by Rolls-Royce was its contract with the US Navy signed in September 2003 (Rolls-Royce 2005a) for the provision of maintenance and logistical support for the Rolls-Royce Turbomeca F405 Adour engines that powered the navy’s 200-strong fleet of Boeing/BAE Systems T-45 Goshawk advanced naval jet trainer aircraft.

Under the terms of the contract, Rolls-Royce was to be the sole provider of logistics support, receiving a fixed price for each hour the engines were in the air. This meant that Rolls-Royce providing all the engine maintenance, support, trouble-shooting, parts supply and logistics support for the aircraft at three naval air stations in Meridian in Mississippi, Kingsville in Texas and Patuxent River in Maryland. Performance was measured almost exclusively against the fleet metric of providing a minimum level of ready-for-issue (RFI) engine availability, which previously had averaged 70%, meaning that aircraft were out of action for nearly one-third of the available time. As part of the new contract, Rolls-Royce guaranteed an improved RFI engine availability rate of 80%.

For the US Navy, the switch to performance-based maintenance contracts of this type offered three potential benefits. First, it meant that as the aircraft operator it avoided the uncertainty of unpredictable breakdowns and repair costs. Instead, maintenance became a known and certain fixed cost against which it could plan. The second potential benefit was an improved level of service, manifest in increased RFI engine availability and therefore flying time. Finally, these services were now provided at a lower cost.

The success of the initial one-year contract led to a significant improvement in maintenance quality and performance reliability, with all the performance metrics being met. As a result, the US Navy exercised its option to renew the contract for a further four years. Two years into the contract in 2005, the programme manager for the US Navy’s Undergraduate Flight Training Systems at Patuxent River, Maryland, commented that RFI engine availability on the T-45 Goshawk trainers had risen above the target rate of 80% in the initial year reaching 85%, while the average time between engine removals had increased from 700 hours to over 900 hours and the expected engine removal rate had fallen by 15% (Terino 2005). As Captain Daniel Ouimette, Commodore of Training Air Wing ONE, commented, ‘Before signing the contract with Rolls-Royce we had aircraft on the ground because of engine availability, but this has never happened under the new regime’ (Rolls-Royce 2005b, 19).

It was not only in operational terms that Rolls-Royce’s power-by-the-hour contract proved beneficial to the US Navy, there were financial gains as well. The contract brought significant cost savings over the previous arrangements. As Figure 6 shows in the contract’s first three years, the Navy’s savings amounted to \$15 million, \$18 million and \$5 million, respectively (Kratz 2008), with total savings over the five-year life of the contract projected to total \$61 million. In 2008, upon the conclusion of the fifth year of the contract, a new expanded five-year contract was signed, worth \$90million per year (Rolls-Royce 2009) on similar terms but under the MissionCare™ label, the new name for Rolls-Royce’s aftermarket services for the Defence sector.

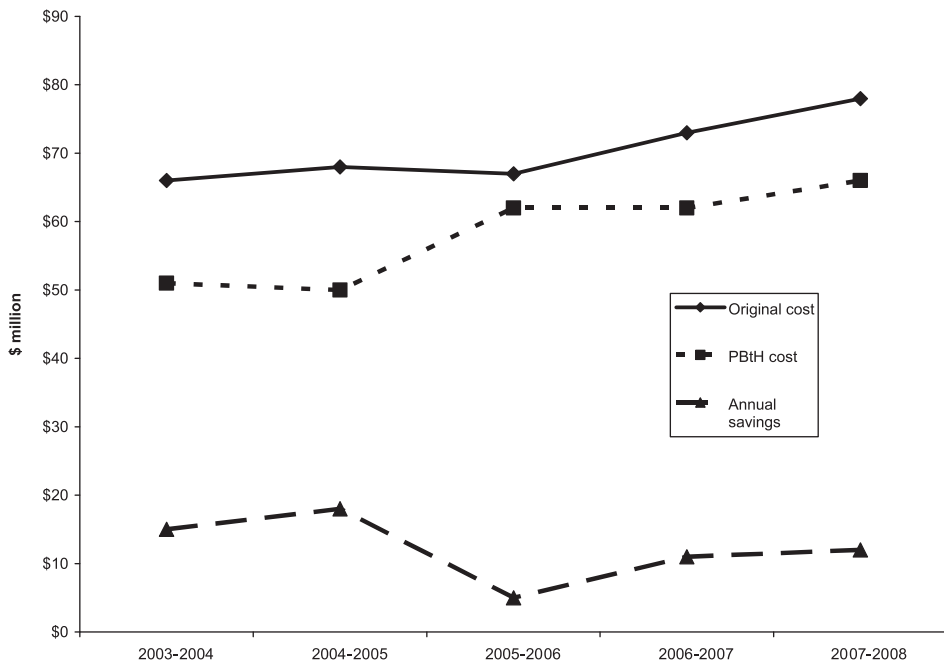


Figure 6. T-45 engine costs: Power-by-the-hour® v. original.
 Source: Kratz (2008).
 Note: Power-by-the-hour costs for 2006 and 2007 are estimates.

4.5. *The growth of aftermarket services*

The contract with the US Navy is typical of the performance-based contracts that Rolls-Royce now provides as part of its range of enhanced aftermarket services. In the civil aviation sector, these services are offered as TotalCare[®], comprising a range of packages that allow airlines to select from a menu of aftermarket services on an agreed scale of costs per flight hour. In these deals Rolls-Royce maintains the airlines' engines on a planned maintenance basis on behalf of the customer (Rolls-Royce 2003, 13). Similar arrangements are available in the defence and corporate sectors offered as Mission Care and Corporate Care, respectively. In each instance the services form a comprehensive set of through life engine maintenance arrangements.

To support these service packages, in March 2004 Rolls-Royce opened an Operations Centre at its Derby headquarters capable of remotely monitoring an airline customers' engines on a 24-hour basis (Rolls-Royce 2005a). It provides an integrated decision support system, coordinating data from aircraft, engine and overhaul shops with logistics support and engineering knowledge. The Operations Centre maintains the 3500 engines that Rolls-Royce has under management whether on the ground or in the air, on a real-time basis via telemetry systems. Thus if an engine's performance falters for any reason while it is airborne, this will be picked up by the Operations Centre. Staff at the Operations Centre can then pull up the engine's history and mobilise appropriate maintenance resources on the ground ready to service the aircraft when it lands.

The growth of aftermarket services such as the new style performance-based maintenance contracts resulted in increased revenue for Rolls-Royce. By delivering integrated solutions, the company was providing significantly more value. No longer was it just a spare parts supplier, it was now providing a range of maintenance and repair services as well. The increased revenue that these services brought in was reflected in a significant increase in the proportion of Rolls-Royce's total revenue derived from services.

Twenty years ago in 1991, services represented just 25% of the company's total revenue (Rolls-Royce 2002, 17). By 2000, the proportion of revenue derived from services had risen to over a third (Rolls-Royce 2001, 12), representing 37.5% of its total revenue of £5.56 billion. Although part of the growth was accounted for by finance and leasing activity, nonetheless a significant proportion was accounted for by repair and overhaul work. This had doubled in value over the previous five years (Rolls-Royce 2001, 12). By 2011, revenue from services had continued to grow reaching £6.02 billion and amounting to more than half (53.4%) of Rolls-Royce's total revenue (Rolls-Royce 2012, 13) of £11.28 billion (Figure 7).

4.6. *Changing competitive positions in the market for aftermarket services*

Aftermarket services in the form of MRO had traditionally been provided by the airlines themselves, by independent firms or by the OEMs. MRO was something that historically all three engine manufacturers had collectively neglected over the years. Indeed, the traditional view in the sector had been, '... if you have a Chevrolet, you don't take it back to Detroit to fix it' (Lewis 1999, 54), but by the 1990s all three manufacturers were starting to 'recognise lifecycle opportunities'. With the OEMs keen and able to increase their share of this market through the provision, as the US Navy example illustrates, of better and more effective maintenance, changes in the competitive positions of the service providers resulted. Hence by 2003 it was being reported that, 'the trend has been for airlines to increase outsourcing, OEMs to increase their share of MRO work, and independents to increasingly disappear' (Wilson 2003, 4).

In reality, the picture was a little more complex. Not all airlines chose to outsource their MRO work to OEMs. Doganis (2006, 285) notes that some of the larger international carriers saw in

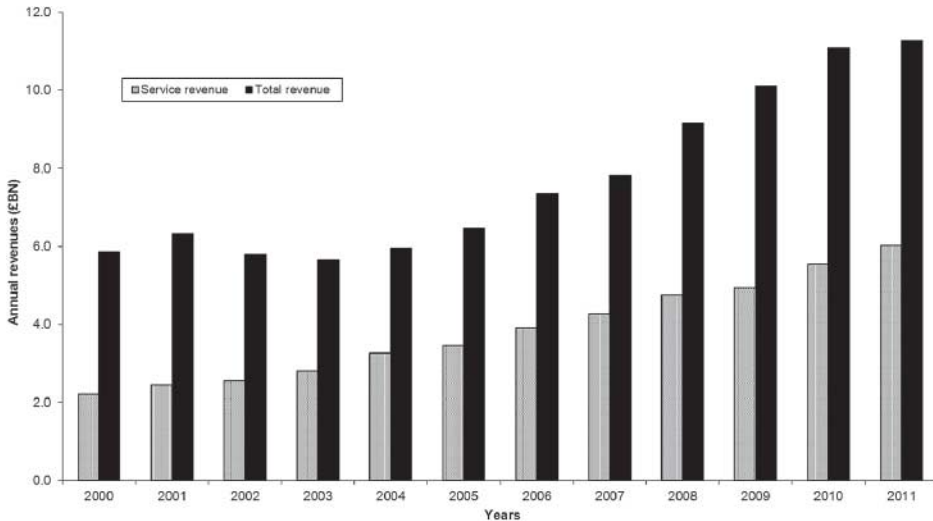


Figure 7. Rolls-Royce's total/service revenue 2000–2010 (£m).
Source: Rolls-Royce annual reports.

MRO, 'the potential value of these activities as profit generators in their own right'. As a result, carriers like Lufthansa in Europe and Singapore Airlines in Asia, 'set about transforming what were previously internal departments into specialist companies'. However, such instances tended to be the exception rather than the rule. Most of the small- and medium-sized airlines were too small to provide all the MRO services economically, especially as the greater technological sophistication of modern jet engines required them to invest in increasingly sophisticated maintenance equipment and more highly trained staff. For such carriers outsourcing MRO made economic sense. It also allowed them to focus on their core activities, something that military customers like the US Navy also preferred to do.

It was a similar story with the new and rapidly expanding low-cost carriers (LCCs) such as Ryanair (Barratt 2004) and easyJet (Jones 2005). Given their business model, which relied on keeping processes simple and costs low (Holloway 2008), LCCs were keen to lower their direct operating costs, with the result that they sought to outsource as many activities as possible and maintenance was an obvious choice. By so doing, they could avoid 'top-heavy maintenance administration, or costly hangars and maintenance facilities of their own' (Doganis 2010, 142), and the OEMs were well placed to take on the MRO work being outsourced in this way. The Irish LCC Ryanair was typical. In 2004, it announced that it was outsourcing the maintenance and overhaul of all the CFM56-7 series engines powering its fleet of Boeing 737–800 aircraft to GE Engine Services as part of a 10-year contract involving a maintenance-cost-per-hour system (Professional Engineering 2004, 12).

Independent MRO firms found themselves increasingly squeezed. The introduction of a new generation of technologically more sophisticated and reliable engine in the early 2000s provided what Wilson (2003, 4) described as, 'a double hit on independent shops – higher investment and lower demand'. Higher investment was required because of the new technologies being used, such as FADECs, while the decline in demand was the product of airlines switching to OEMs. As the general manager of one independent noted, 'the OEMs are trying to gain a larger share of the market by buying or co-venturing with independents or putting them out of business' (Wilson 2003, 5).

Hence in the last 10 years, we have seen that the OEMs gain market share at the expense of the airlines and the independents especially. These changes in competitive position were largely attributable to advances in technology. New technologies made it possible for OEMs, by virtue of the data they were now able to collect and analyse regarding their engines, to offer a better and more effective service, while at the same time making it harder for small and medium airlines and independents to compete on the same terms, a situation compounded by the introduction of new business models by the LCCs.

5. Analysis

Rolls-Royce was not alone in feeling the impact of a significant drop in the demand for spares. The two other engine manufacturers with the capacity to produce a full range of civil and military engines, Rolls-Royce's American rivals, General Electric and Pratt and Whitney, were faced with very similar issues in terms of the decline in the demand for engine spares.

As the case study shows, General Electric and Pratt and Whitney had also contributed significant advances in engine technology, both in terms of new manufacturing processes and component improvements. Consequently, by the 1990s they too were feeling the impact of the steady and continuous improvements in engine performance both in terms of efficiency and durability. As one commentator explained, 'by designing and producing ever more reliable and competitive powerplants, engine manufacturers have fallen victim to their own success' (Lewis 1999, 54). A similar theme was echoed at General Electric. Brian Rowe, former head of GE Aircraft Engines speaking of the new ultra high-thrust GE90 engine that came into service in the late 1990s commented, '... the engines just seem to run forever' (Rowe 2005, 144). It was a similar story at Pratt and Whitney where Jim Keenan, senior vice president of commercial engines noted in 2003 that, 'today's generation of engine enters the shop nominally about one third as often as a typical engine 25 years ago' (Wilson 2003, 5).

Rolls-Royce was perhaps the first to feel the impact of the improvements in engine durability, because having only recently increased its share of the world market for commercial engines from 10% in the mid-1980s to 30% in the late 1990s (Pugh 2002, 306), its installed engine base was relatively 'youthful'. As such its installed engine base included a higher proportion of newer and therefore more durable engines with a much lower spares requirement.

Nonetheless, by the late 1990s, all three manufacturers had launched new large diameter, wide-chord fan engines for the new generation of large twin jet airliners being introduced by Boeing and Airbus. These engines all incorporated the latest technology including FADEC electronic control systems, with the result that all three saw a decline in their most profitable revenue stream – replacement parts. This led all three to take a new perspective on MRO work.

However, as one commentator noted at the time, 'General Electric, Rolls-Royce and Pratt and Whitney have taken slightly different approaches to the changing MRO market, although all three are seeking a greater share of the pie' (Wilson 2003, 6). While Rolls-Royce relied on joint ventures with international airlines particularly ones from Asia, General Electric, having first consolidated its Engine Services department and its Commercial Spare Parts operation into a single organisation, General Electric Aircraft Engine Services (GEAES), utilised a series of take-overs designed to complement its existing facilities in California and Kansas in the USA and create a worldwide engine service network. It purchased British Airways engine overhaul facility at Cardiff in Wales (Pugh 2002; Rowe 2005), followed by the purchase of Greenwich Air Services in the USA, a 70% stake in Malaysia Airlines' Aero Engines Repair and Overhaul, a 20% stake in EVA Airways' Evergreen Aviation Technologies in Taiwan and a 95% stake in the engine service

arm of the Brazilian airline Varig (Lewis 1999, 55). Pratt and Whitney on the other hand took a different approach again. As the former market leader with 90% market share in the 1960s, it already had an established worldwide network of some two dozen existing MRO facilities around the world and it used these facilities to create five specialist engine overhaul and repair centres (Wilson 2003, 6).

It was not merely a case of the engine manufacturers doing more MRO work. A report at the end of the 1990s noted that, 'manufacturers are not looking simply to develop and extend their geographical coverage, but also the commercial scope of their aftersales activity' (Lewis 1999, 54). Bill Vareschi, president of GE Engine Services described the new services as, 'We're bringing airlines new procedures and processes that optimise workscope, lower the cost of operations and reduce the time taken for engine repair and overhauls' (Lewis 1999, 54). Extending the scope of their aftermarket activities meant General Electric followed Rolls-Royce in offering services like on-wing support, maintenance hour's agreements and total care packages alongside conventional repair and overhaul services. Pratt and Whitney followed too, leading one independent MRO provider to note, 'the OEMs are selling total repair, power-by-the-hour packages; that's the strategy on all new engines coming out of the OEMs' (Wilson 2003, 6).

Hence, the reshaped business strategy developed by Rolls-Royce and described in the case study had by the decade of the 2000s, been adopted by all three of the main engine manufacturers that dominate the aero engine sector, and in each instance technology was a powerful influence in the reshaping of business strategy.

Signs of a similar trend in other sectors are limited. Technologies very similar to those employed in the aero sector, involving remote monitoring, have been introduced in Formula 1 motor racing. Groups of technicians located at a team's headquarters often on the other side of the world closely monitor each racing car's systems during races to ensure optimum performance and maximise the chances of winning. But this remains a very limited and highly specialised application. Such technologies have yet to be used more generally in the automotive industry, where institutional factors mean that maintenance and repair services remain the province of the dealer network (Maxton and Wormald 2004). Servitisation is, however, found in sectors producing high value, long-lived capital goods. Examples include manufacturers of trains, mobile communication systems and flight simulators. But in these instances, a study by Davies (2004) suggests that changes of strategy are the product not of advances in technology but changing customer demands.

6. Conclusions

While much has been written about the movement of manufacturers into services, this study breaks new ground by considering the contribution of technology to this process. At the outset a single question was posed. What role did technology play in inducing the aero engine manufacturer Rolls-Royce to reshape its business strategy? The principal finding is that in Rolls-Royce's case advances in technology played a very important part in the company's decision to reshape its business strategy utilising servitisation.

The advances in technology were not major technological discontinuities (Tushman and Anderson 1986) or radical in character, resulting in what Christensen (1997, xiii) terms 'disruptive innovation'. Rather the advances in technology were the product of cumulative incremental innovations in materials, design and manufacturing that formed 'sustaining technologies' (Christensen 1997, xv) that helped to foster improved performance in established products along lines valued by mainstream customers.

The improved performance focused on greater durability and reliability, and reduced the demand for spares, which had long been the company's most profitable revenue stream. This led Rolls-Royce to look to servitisation to make up for this loss and the case study shows that technology was a powerful enabling factor facilitating the move to servitisation in this sector. Technology, particularly developments in digital electronics in the form of FADEC systems, transformed the scope of the maintenance services provided by the engine manufacturers. The engine health monitoring capabilities made possible by the introduction of electronic FADEC systems facilitated the introduction of service innovations such as fixed price per hour maintenance contracts.

While the study suffers from the limitation that one cannot generalise from a single case, nonetheless it is evident from the analysis section of this study that as far as the aero engine sector is concerned Rolls-Royce was not an isolated case. Not unsurprisingly in this highly oligopolistic sector, Rolls-Royce's rivals, General Electric and Pratt and Whitney were similarly affected and followed broadly similar strategies, though it was generally Rolls-Royce that led the way certainly in terms of some of the service innovations that resulted from greater knowledge of engine performance data.

What the case study lacks in terms of scope for generalisation, like many cases studies (Stake 1995), it makes up for in the value of the insights it provides. In particular, there are a number of important implications that follow from this study. The first is in terms of the provision of a better quality service. In the past where MRO was concerned there was a misalignment between the interests of OEMs and users of their products. For the former, MRO was an important source of profit because of the high prices charged for replacement parts, while for the latter MRO was a cost that ate into profit. Now, as providers of fixed price maintenance services it is very much in the OEMs' interest to take every opportunity to learn where and how things go wrong and revise and improve their products, so as to reduce the cost of providing repairs and maintenance, something that is similarly in the interests of users.

Second, the enormous amount of data on engine performance that is now available in real time thanks to FADEC systems presents new opportunities when it comes to the development of new services. The challenge is to develop appropriate knowledge management techniques to utilise this data. This will require OEMs to develop new areas of expertise, and it is interesting to note that Rolls-Royce has set up a joint venture with Data Systems and Solutions, a subsidiary of US-based Science Applications International Corporation (Hutchinson 2003) in order to expand its expertise in the area of aftermarket information systems.

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