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CORPORATE GOVERNANCE, INNOVATION, AND COMPETITIVE PERFORMANCE IN THE COMMERCIAL TURBOFAN INDUSTRY: THE CASE OF ROLLS-ROYCE

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ABSTRACT

Three companies – General Electric, Pratt & Whitney, and Rolls-Royce – effectively control the global markets for commercial aircraft engines. For some time observers of the industry have expected that one of the Big Three would eventually be forced to withdraw from the industry, and at the beginning of the 1990s, it appeared that the British-based company, Rolls-Royce, would be the one to go. But by 2000 Rolls-Royce had a larger share of new orders than Pratt & Whitney, even though both companies trailed far behind General Electric, which, through CFM, its joint-venture with the state-owned French company, SNECMA, also dominates the single aisle and regional jet markets. Rolls-Royce's position in the industry is based on its superior technological capabilities, embodied in the three-shaft architecture of its turbofan engines. The purpose of this study of Rolls-Royce is to document how the company has remained a power in the turbofan engine industry, notwithstanding its own troubled history and the relative lack of international success, more generally, of British companies in high-technology manufacturing industries over the past half century or so. Rolls-Royce made its initial investments in the three-shaft architecture in the 1960s (starting as early as 1963), when the eventual superiority of the technology was not at all assured. Since that time, Rolls-Royce has sustained its investments in these technological capabilities, despite dramatic changes in the company's ownership. Founded in 1906 (with origins dating back to the 1890s), Rolls-Royce was, until 1971, a publicly traded limited liability corporation that included both the original automobile division and the aircraft engine division. In 1971 the company went bankrupt because of its attempt to develop the RB211 for the Lockheed L1011 Tristar. When Rolls-Royce emerged from bankruptcy in 1973, it was as a nationalised company that had spun off its automobile business. Even as a nationalised company Rolls-Royce had to cope with the dramatic shift in the identity of its owner from the Labour governments of Wilson and Callaghan from 1974 to 1979 to the Conservative government of Thatcher from 1979 to 1987, when Rolls-Royce was privatised. Since 1987 Rolls-Royce has remained a publicly traded corporation, although one in which the British government has maintained a "golden share" that prevents a takeover of the company. One might expect that such major changes in modes of ownership as well as the company's relations with particular types of owners would have resulted in significant changes in corporate governance, including the ways in which the company allocated resources to the development of technology. The question that this study poses is how the technological development of the three-shaft engine was sustained from the late 1960s through the 1990s despite these dramatic changes in modes of ownership and changing pressures on the relations between managers and owners. The study shows how under very different governance and economic conditions, Rolls-Royce's management, dominated by career engineers, were able to sustain a development strategy that faced, and overcame, fundamental technological, market, and competitive uncertainties.

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1. Introduction: innovation and competition in the turbofan industry

Three companies – General Electric, Pratt & Whitney, and Rolls-Royce – effectively control the global markets for commercial aircraft engines. For some time observers of the industry have expected that one of the Big Three would eventually be forced to withdraw from the industry, and at the beginning of the 1990s, it appeared that the British-based company, Rolls-Royce, would be the one to go. A decade later, however, it was Pratt & Whitney, one of the two US-based companies, that appeared to be in the most vulnerable position (for the US industry, see Almeida 2001). As Table 1 shows, in January 2000 Pratt & Whitney had the dominant share of "in-service" widebody turbofan engines, with 45 percent compared to General Electric's 32 percent and Rolls-Royce's 23 percent. But Rolls-Royce had a larger share of new orders than Pratt & Whitney, even though both companies trailed far behind General Electric, which, through CFM, its joint-venture with the state-owned French company, SNECMA, also dominates the single aisle and regional jet markets.

Table 1. Shares of Commercial Aircraft Engine Markets, January 2000

Percent shares of each market

	Engine	In service	Orders	Total
Widebody				
General Electric	CF6/GE90	32	47	38
Pratt & Whitney	PW4000	45	21	35
Rolls-Royce	Trent/RB211	23	27	25
Not announced		0	5	2
Single aisle, Boeing				
CFM International	CFM56	63	91	69
Pratt & Whitney	PW2000	10	4	9
Rolls-Royce	BR700/RB211	26	3	22
Not announced		0	2	0
Single aisle, Airbus				
CFM International	CFM56	63	42	52
IAE	V2500	38	30	34
Pratt & Whitney	PW6000	0	7	4
Not announced		0	20	10
Regional jets				
Allied Signal (Honeywell)	LF507	20	1	10
CFM International	CFM56	51	56	54
Pratt & Whitney	PW3000	3	14	9
Rolls-Royce	AE3007	27	28	28

Notes:
1) CFM is a joint venture between General Electric and SNECMA.
2) IAE is a joint venture dominated by Rolls-Royce and Pratt & Whitney.
3) The regional jet market includes Avro, Bombardier, Embraer, and Fairchild aircraft only
4) Pratt & Whitney shares exclude aircraft in service with JT9D engines, for which there are no orders.
Source: Kingsley-Jones (2000, 63)

Rolls-Royce's current position in the industry is based on its superior technological capabilities, embodied in the three-shaft architecture of its turbofan engines. The modularity embedded in the three-shaft architecture has enabled Rolls-Royce to develop and stretch its Trent family of engines with an unmatchable range of power to meet different market niches and therefore deploy similar technological solutions across engines without incurring heavy additional development costs. Moreover, three-shaft engines are simpler, shorter, lighter, and more rigid than competing engines based on two-shaft architectures. These characteristics enable the three-shaft engine to sustain high levels of performance throughout its life, thus resulting in low maintenance costs (Williams 1995). Aviation authority Bill Gunston (1997, 196) has summed up the advantages of the Trent: "Although customers choose engines mainly for political/financial reasons, on technical grounds the Trent [with its three-shaft architecture] is hard to beat. It offers more than adequate thrust, unsurpassed fuel economy, outstanding ease of maintenance, and the lowest weight of all big fan engines." While Pratt & Whitney and General Electric Aircraft Engines have teamed up to develop a new engine for the Airbus A380, Rolls-Royce has relied on the embedded modularity of its three-shaft engine architecture to package a number of 'engine solutions', for example, the Trent 900 for the Airbus A380 and the Trent 500 for the Airbus A340-500/600 for which Rolls-Royce is the sole supplier.

The purpose of this study is to document how, at the beginning of the twenty-first century, Rolls-Royce has remained a power in the turbofan engine industry, notwithstanding its own troubled history and the relative lack of international success, more generally, of British companies in high-technology manufacturing industries over the past half century or so. Rolls-Royce made its initial investments in the three-shaft architecture in the last half of 1960s, when the eventual superiority of the technology was not at all assured. Since that time, Rolls-Royce has sustained its investments in these technological capabilities, despite dramatic changes in the company's ownership.

Founded in 1906 (with origins dating back to the 1890s), Rolls-Royce was, until 1971, a publicly traded limited liability corporation that included both the original automobile division and the aircraft engine division (see Figure 1). In 1971 the company went bankrupt because of its attempt to develop the RB211 for the Lockheed L1011 Tristar. Even as a nationalised company Rolls-Royce had to cope with the dramatic shift in the identity of its owner from the Labour governments of Wilson and Callaghan from 1974 to 1979 to the Conservative government of Thatcher from 1979 to 1987, when Rolls-Royce was privatised. Since 1987 Rolls-Royce has remained a publicly traded corporation, although one in which the British government has maintained a "golden share" that prevents a takeover of the company.[1] Nevertheless, as we show in detail Rolls-Royce has been highly dependent on external finance, including two major share issues in 1993 and 1995, to fund its growth. But despite the company's unquestioned technological and market successes as a publicly traded company, Rolls-Royce is by no means a favourite of stock-market investors: between January 1997 and January 2000, stock prices in the FTSE100 rose by 47 percent, while Rolls-Royce's stock price fell by 13 percent. In August 2000 Rolls-Royce's share price fell so low relatively to the FTSE100 that the company was not included (as it turned out, temporarily) among the 100 companies that make up the index. As of March 1, 2002, the FTSE100 was up 23 percent and Rolls-Royce stock was down 23 percent compared with their levels on January 1, 1997.

One might expect that such major changes in modes of ownership as well as the company's relations with particular types of owners would have resulted in significant changes in corporate governance, including the ways in which the company allocated resources to the development of technology. The question that this study poses is how the technological development of the three-shaft engine was sustained from the late 1960s through the 1990s despite these dramatic changes in modes of ownership and changing pressures on the relations between managers and owners. The study shows how under very different governance and economic conditions, Rolls-Royce's management, dominated by career

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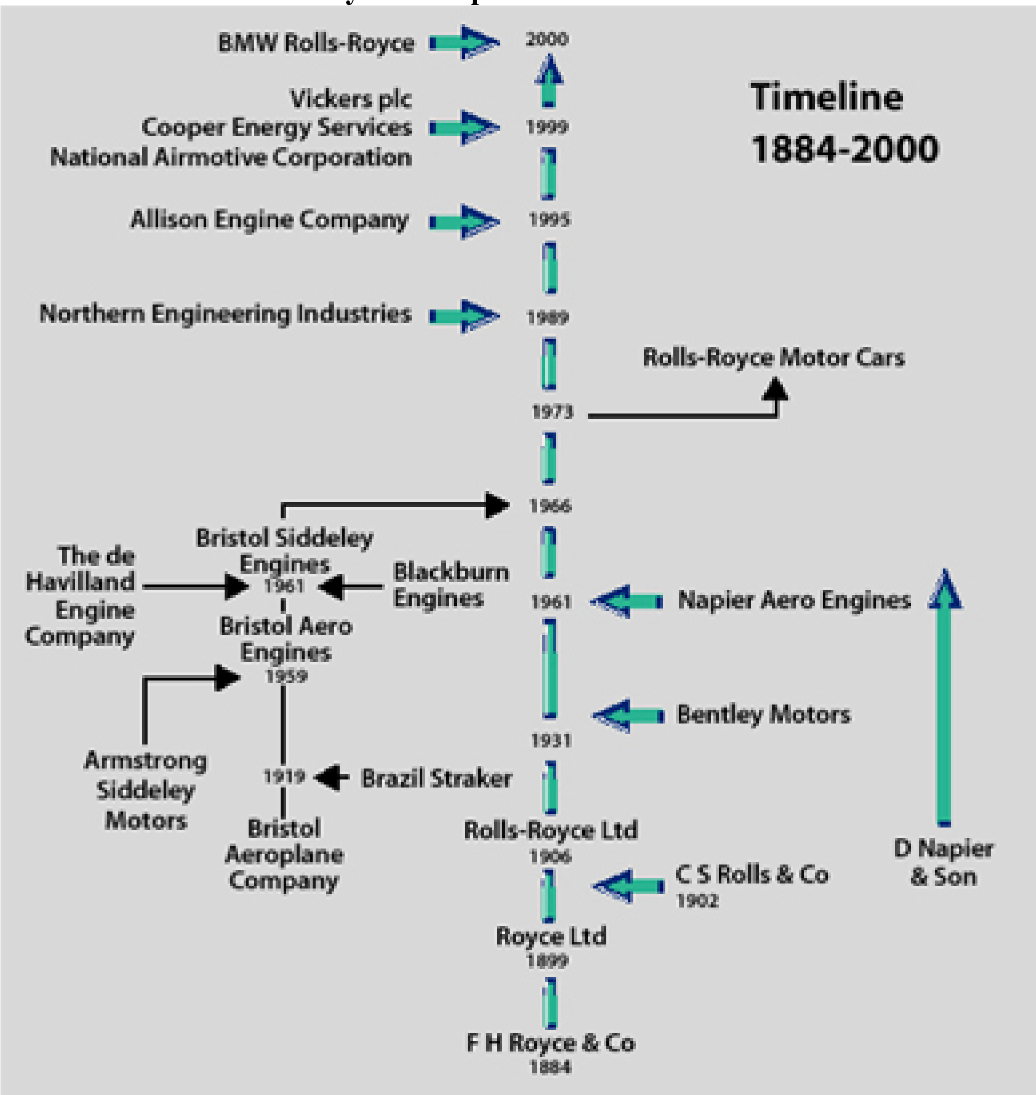
[1] In June 2002 the European Commission banned "golden shares", a ruling that will affect Rolls-Royce plc, among a group of 25 publicly traded European companies that have had this protection against takeover. ** REF

engineers, were able to sustain a development strategy that faced, and overcame, fundamental technological, market, and competitive uncertainties.

Figure 1. Evolution of Rolls-Royce Group 1884-2000



Source: Rolls-Royce website (http://www.rolls-royce.com/history/timeline/default.htm)

Our focus on corporate governance asks what interests both within and outside the company ensured that the commitment of financial resources to Rolls-Royce's innovative strategy was maintained, and how these interests ensured this commitment if and when they were challenged by other interests that would have preferred to see corporate resources and returns allocated in ways that did not expose the company to the uncertainty of the innovation process. For example, what were the roles of engineers whose careers were devoted to developing jet engines and of government bodies that wanted to maintain Britain's technological capability in aircraft engines? What were the roles of interests that wanted to take financial resources out of the company rather than invest in the development of a highly uncertain technology that could take decades to generate returns? Given competing interests over the allocation of resources and returns, we ask specifically what difference it makes whether a high-technology enterprise that must engage in organizational learning over a sustained period of time is owned by the government or by public shareholders.

2. Key performance characteristics of the jet engine

This section starts with a brief history of the jet engine. We then outline the key performance characteristics of the jet engine and compare the two engine design layouts that characterise the turbofan, namely the two-shaft and the three-shaft. The section concludes with a note on the cumulative and collective character of the processes required to develop the firm's productive capabilities, in the face of uncertainties concerning technological and market success.

2.1. A brief history of the gas turbine

The underlying principles of the gas turbine engine are described in the British Patent number 1833 that was granted to John Barber in 1791. The patent title is "A method for rising inflammable air for the purpose of producing motion and facilitating metallurgical operations" (quoted in Singh 1996). Numerous attempts to develop an engine prototype using those principles took place at the beginning of the twentieth century about 150 years after John Barber's patent. Elling from Norway, Stolze and Holzwarth from Germany, the French duo Armenguard and Lemale, Moss from the United States (and from General Electric Laboratories more specifically), and Lorin from France were amongst the pioneers of gas turbine technology (Singh 1996).

In 1930 the British engineer Frank Whittle took out a British Patent in 1930 for a jet engine based on gas turbine technology, and in 1937 ran the jet engine (Singh 1996). The Whittle engine completed its first flight in 1941 (Rolls-Royce 1985). Whittle's great breakthrough can be better appreciated by noting that his W2/700 engine was the basis for the first engines launched by the so-called Big Three, namely General Electric Aircraft Engines, Pratt & Whitney, and Rolls-Royce. In fact, the W2/700 formed the basis of the Rolls-Royce Welland, Derwent, Tay, and Nene. In turn, Pratt & Whitney used the Rolls-Royce Nene engine for its J42, while General Electric Aircraft Engines used the Whittle engine for its 1-A (Singh1996).

2.2. The basic principles of the gas turbine

The gas turbine is a heat engine that works by accelerating a working fluid to provide thrust. To accelerate the working fluid, first the pressure is increased, then heat is added, and finally continuous combustion at constant pressure is converted into kinetic energy (Rolls-Royce 1985). The working cycle of the gas turbine is similar to that of a piston engine. Both the gas turbine working cycle (also called the Brayton cycle) and the piston engine cycle (the Otto cycle) entail four phases: induction, compression, combustion, and exhaust. However, there are two main differences between the Brayton cycle and the Otto cycle. Firstly, in the Otto cycle combustion occurs at constant volume, whereas in the gas turbine it occurs at constant pressure. Secondly, the four phases are intermittent in the piston engine, whereas they are continuous in the gas turbine. This latter difference enables the gas turbine to burn more fuel in a given time, and thereby provide more power for a given size of engine (Rolls-Royce 1985). In technical terms, the gas turbine has a higher power-to-weight ratio than the piston engine.

The simplest gas turbine is the turbojet engine. It consists of a compressor to compress the working fluid, a combustion chamber to burn fuel, and a turbine to drive the compressor.

Once the power needed for compression has been extracted, the hot gas stream coming from the turbine is expelled to the atmosphere via an exhaust nozzle to create propulsive thrust (Gunston 1997, Part I).

2.3. Engine performance and efficiency

Early turbojets were characterised by very low thrust and efficiency; as Gunston puts it, these engines "looked too light and flimsy even to contain their noise, let alone the power they generated, but they burned fuel at a daunting rate" (Gunston, 1997, 10). Advances in the technologies underlying the gas turbine have substantially increased engine thrust and improved its efficiency. Today's turbofan engines are rated up to around 100,000lb showing an overall efficiency of about 35%.

There are different kinds of efficiency. Following Gunston (1997, 10-14), *thermal efficiency* is defined as "the useful power generated divided by the rate at which chemical energy is produced by burning fuel"; *propulsive efficiency* is "the percentage of the power produced by the engine that is actually put to use in moving the aircraft"; *cycle efficiency* is "the ratio of useful work obtained divided by the useful work obtained from an engine with an ideal working cycle". *Overall efficiency* is the product of *thermal efficiency* and *propulsive efficiency*. *Specific fuel consumption* is the ratio of fuel consumption to thrust and is defined in terms of pounds of fuel per hour per pound of net thrust.

It is worth noting that increases in *cycle efficiency* stem from improvements in *overall pressure ratio* and *turbine entry temperature.*[2] These improvements demand large investments in high-strength, high-temperature materials and cooling technologies. Increases in *propulsive efficiency* are mainly the result of different engine configurations. In particular, a dramatic improvement in *propulsive efficiency* occurred in the 1970s after the introduction of high by-pass ratio turbofan engines (Singh 1996). Therefore the quest for higher power and higher efficiency has not been limited to the introduction of new technologies within the same engine configuration. Indeed, higher engine efficiency, and particularly *propulsive efficiency*, has been achieved through the introduction of new engine configurations. The following sections illustrate in detail the operating characteristics of turbojet, turboprop, and turbofan engines and discuss their suitability for particular thrust applications.

2.4. Engine architectures

Turbojet and turboprop: technical characteristics and 'selected' applications

Jet engines come in different design configurations, notably turboprop, turbojet, and turbofan. The different design configurations give them peculiar technical features and performance characteristics that make them more or less appropriate for certain applications. Although all jet engines use the same operational principle -- they accelerate a flow of working fluid to provide thrust -- turboprop, turbofan, and turbojet engines make different 'use' of the working fluid (Gunston 1997, Part 1; Rolls-Royce 1985). In a turbojet the hot gas stream coming from the high-pressure turbine is expelled to the atmosphere via an exhaust nozzle to create propulsive thrust. In a turboprop the hot gas energy is converted via internal shafts in mechanical power to drive the propeller. As a consequence only a small

[2] The overall pressure ratio "is the ratio of the outlet pressure from the compression process to the inlet pressure to the compression process". The turbine entry temperature "is the temperature of the gas at entry to the first turbine rotor" (Gunston 1996).

amount of hot energy is exhausted. These different design configurations show different propulsive efficiency according to the aircraft speed. The propulsive efficiency of the turboprop is approximately 80% up to an aircraft speed of 400mph (Gunston 1997, Part 1; Rolls-Royce 1985). At higher aircraft speeds the turboprop's blade tips become supersonic causing the propulsive efficiency to fall. The case is reversed in the turbojet. At relatively low aircraft speeds the turbojet's propulsive efficiency is approximately 45% due its high jet velocity (Rolls-Royce 1985).[3] In the higher aircraft speed range, the turbojet reaches higher propulsive efficiency than a turboprop. In the case of the Concorde (2,000mph) the turbojet propulsion efficiency is about 90%.

From a technical viewpoint, therefore, turboprops are more appropriate for short-haul aircraft, whereas turbojets are more appropriate for long-haul aircraft. Regulation has affected the selection of engine configurations, however. According to Mowery and Rosenberg (1982), during the 1950s and 1960s the heavily regulated industry environment hindered the development of turboprop engines. In the United States, airlines were not competing on fares, so that there were no incentives for airlines to adopt the economical turboprop for short-range uses (Caves 1962). In the words of Mowery and Rosenberg (1982) the turboprop engine represented a "missed opportunity". The fuel crisis of the 1970s and legislation that imposed more severe restrictions on aircraft noise have re-tipped the balance towards turboprop engines for short-haul aircraft (Gunston 1996). Turboprop engines were "rediscovered" in the early 1980s for long-haul aircraft as well. Improved turboprop technology has made possible the design of the multi-bladed propeller capable of turning at high speed without loss of propeller efficiency. This configuration has also been labelled prop-fan and is still under study.

The turbofan engine

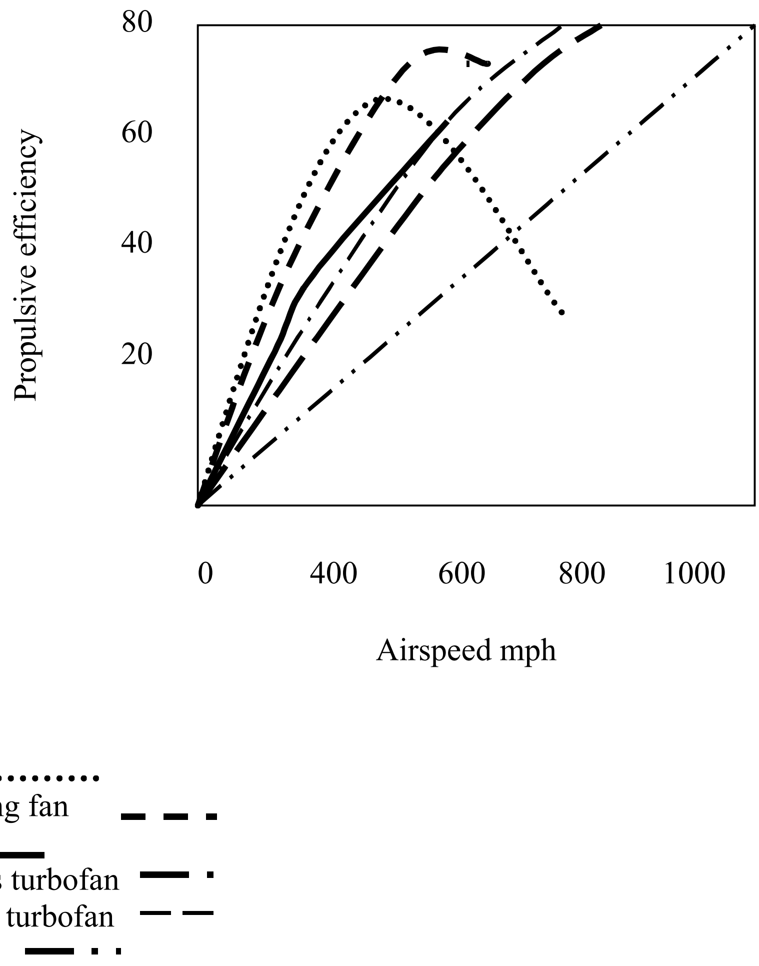
A turbofan is a jet engine configuration in-between a turboprop and a turbojet. In the turbofan the thrust is generated by the fan mounted at the front of the engine and by the core. The proportion of thrust generated by the fan depends on the amount of mass flow bypassing the core engine. This mass flow is usually expressed by a ratio, the by-pass ratio (BPR), that is the "numerical ratio of the mass flow entering the fan duct divided by that entering the core" (Gunston 1996). The fan is driven by a low-pressure turbine that uses some of the hot gas downstream of the high-pressure turbine. The bypass air is used via an exhaust nozzle to lower the mean jet temperature and velocity. As a result, the turbofan engine entails larger airflow and lower jet velocities compared with a turbojet (Rolls-Royce 1985). The bypass concept applied in turbofan engines has filled the gap between turbojet and turboprop in terms of propulsive efficiency. Figure 2 highlights this point. The turbofan also shows better specific fuel consumption as compared with the turbojet engine (Gunston 1997, Part 1; Rolls-Royce 1985).

Although Whittle invented the turbofan in 1936, it did not stimulate much immediate interest in Britain, but became key to the development of jet engines during World War II (Gunston 1997, ch. 10). Initially, this development effort was carried out in the United States, where

[3] Propulsive efficiency is affected by the "amount of kinetic energy wasted by the propelling system. Waste energy dissipated in the jet wake, which represents a loss, can be expressed as $W(v_j - V)/2g$ [where $(v_j - V)$ = the waste velocity, W = mass flow in pound per second, V = velocity of aircraft in feet per second, v_j = velocity of flow in feet per seconds, and g = gravitational constant]. . . . It is apparent that at the aircraft lower speed range the pure jet stream wastes considerably more energy than a propeller system and consequently is less efficient over the range. However, this factor changes as aircraft speed increases; although the jet stream continues to issue at high velocity from the engine its velocity relative to the surrounding atmosphere is reduced and, in consequence, the waste energy loss is reduced" (Rolls-Royce 1995, 223).

General Electric took the leading role. Although General Electric was not a manufacturer of aircraft engines, the company had been experimenting with gas turbine technology at GE Labs since 1903. In 1944 Rolls-Royce began developing the Welland engine based on Whittle's gas turbine technology. Early turbofan engines include the Rolls-Royce Spey and Rolls-Royce Conway, both launched in the early 1960s. Their by-pass ratio was lower than one,[4] and their thrust range varied between 10,000lb and 22,000lb. According to Gunston, two factors limited the by-pass ratio of the first turbofan engines. The first was that these engines had to be fitted in military aircraft, thus constraining the diameter of the fan. The second factor was that aerodynamicists wrongly calculated the drag of an engine installed under a wing or by the rear fuselage. Current turbofan engines are characterised by higher by-pass ratios, up to 12. Due to their low specific fuel consumption, low noise, and high propulsive efficiency, turbofan engines are the most common technological solutions in civil applications. This advantage holds true over a wide thrust range.

Figure 2. Broad-brush comparative propulsive efficiency



Source: Adapted from Gunston 1997, 15.

As we have already indicated, the most important criteria used to judge the suitability of an engine for an application are *specific fuel consumption*, *specific thrust*, *thermal efficiency*,

[4] The Spey has a BPR of 0.71, the Conway 0.42 (Gunston 1996).

and *propulsive efficiency*. In a jet engine the two most important design parameters are the *overall pressure ratio* and the *turbine entry temperature*. The turbofan has two extra design parameters, *by-pass ratio* and *fan pressure ratio.*[5] If these design parameters "are varied in order to maintain a constant specific thrust, then it is advantageous . . . to increase *turbine entry temperature* and *overall pressure ratio* together, which not only improves specific fuel consumption but also results in a small, light core" (Gunston 1996). There are, however, some technical considerations that impose an upper limit to increases to these design parameters. For instance, a high *by-pass ratio* requires a large-diameter fan that in turn implies amongst other things, installation problems, increased nacelle drag, and variable pitch-fan that may well offset the improvements deriving from the higher by-pass ratio. Likewise, *turbine entry temperature* cannot be increased *ad infinitum* due to limitations related to material properties and cooling technologies.

The two-shaft layout

In the mid-1960s engine manufacturers started studying engines for widebody aircraft, such as Boeing 747, Lockheed L1011 Tristar, and McDonnell Douglas DC-10. The thrust needed to power these aircraft was in the 40,000lb – 50,000lb range, over twice as high as the thrust levels that characterised the engines then in commercial service. The achievement of this thrust range required increases in important design parameters to unprecedented levels: *by-pass ratio* up to 6:1, *overall pressure ratio* up to 20-25:1, and *turbine entry temperature* from 1400K up to 1500K (Baseley 1992). Turbofan engines then in commercial service had a two-shaft design layout in which a low-pressure turbine uses some of the hot gas energy from the high-pressure turbine to drive the fan via a shaft. The fan and the low-pressure turbine form the low-pressure system. A high-pressure turbine positioned downstream to the combustion chamber drives the high-pressure compressor via a shaft. These two subsystems compose the high-pressure system.

The requirements for such high thrust engines called for stark improvements in engine design. To achieve higher *overall pressure ratios*, engine manufactures increased the fan diameter and added further stages in both the low-pressure and high-pressure compressors.[6] In a two-shaft design the low-pressure compressor and the fan run on the same shaft driven by the low-pressure turbine. The fan has to rotate relatively slowly in order to keep the fan blades' tip speed within viable mechanical limits. The slow rotation of the fan restricts the low-pressure turbine speed and therefore the compression achievable by the low-pressure compressor. As a result, most of the compression duty is left to the high-pressure compressor. To achieve such a high-pressure ratio, a two-shaft engine features a high-pressure compressor with as many as 16 stages (see below). The long compressors need a relatively large number of *variable stator vanes* to meet the large variation in aerodynamic requirements from front to rear of the high-pressure compressor (Baseley 1992).[7]

The longer the compressor and therefore the greater the number of stages, the more complex becomes its aerodynamic and mechanical design. The airflow passing through a compressor is highly unstable due to the differences in velocity of the inlet air and the rotor blades. The aerodynamic design of these compressors requires the "matching" of unstable airflow

[5] These two design parameters are 'locked together' since "for a given by-pass ratio there is a fan pressure ratio that optimises the energy transfer between the core and the bypass air flows, thus producing maximum thrust and minimum specific fuel consumption" (Gunston 1996).

[6] In the low-pressure compressors these stages are called boosters (Gunston 1997, ch. 2)

[7] Variable stator vanes are used to ensure that the incoming air meets the rotor blades at the correct angle to prevent stalling (Gunston 1997, 22-23; Rolls-Royce 1985).

passing through a relatively large number of rotor and stator stages. Recently, the use of supercomputer and computational fluid dynamics codes have permitted such matching. Nonetheless the calculation remains extremely complex and time consuming. As a Technical Director confirmed in an interview: "When you have eleven stages in a high-pressure compressor, the problem is to control the fluid dynamics of this non-homogeneous airflow. No one manages to calculate the eleven stages. . . we have a new three-dimensional method of calculation, but we are not able to do it, yet!" From a more historical viewpoint, Gunston (1997, 22-23) points out "in the early post-war era some prototype axial engines refused even to start. The designers therefore were forced to remove some of the HP stages and downgrade the p.r. [pressure ratio] per stage until they got some kind of result . . . . Gradually they learned how to make axials work. Apart from correctly designing the rotor and stator blades of each stage – itself no mean achievement in the days before electronic computers – the two chief palliatives were to make some of the blades with variables incidence, and to cut holes at various places in the casing".

The three-shaft layout

In a three-shaft design each compressor runs at its optimum speed. The fan runs at a relatively low speed and is driven by a low-pressure turbine. An intermediate-pressure compressor replaces the booster stages. This intermediate-pressure compressor runs on a third shaft at a higher speed. This produces a higher pressure ratio that thus reduces the duty on the high-pressure compressor. As a result the high-pressure compressor requires fewer stages (6 or 7 compared with 11 or 16) and fewer variable stator vanes. The shorter high-pressure compressor needs only a one-stage high-pressure turbine. The same holds for the intermediate-pressure compressor. The low-pressure-turbine is made up of three stages since it has to drive the fan.

In a three-shaft engine, the compression work is split across three compressors (low-, intermediate-, and high-pressure). Each compressor can be driven by its own turbine at its optimum speed. In a three-shaft design the mapping between functions and physical structures tends to be more one-to-one than in a two-shaft design. A three-shaft engine, therefore, is more modular than a two-shaft engine. As explained in the preceding section, in a two-shaft design the compression work is split between two compressors. The fan and the booster run on the same shaft. They rotate at relatively low speed to maintain the fan tip speed below supersonic, thus limiting the compression that can be achieved in the first part of the engine and leaving heavy duty work for the high-pressure compressor (Williams 1995).

2.5. Aircraft engine technological development and dynamics of innovation

An aircraft engine is a high-cost capital good composed of many interacting and often customised elements that belong to different technological fields. The number of components varies according to the size and thrust of the engine. The powerful engine powering such airplanes as the Boeing 747 and the Airbus A340 can encompass up to 40,000 components. The number of components can increase further over time, as firms have to cope with customers' evolving needs as well as ever-tighter regulations. In addition, although the same basic engine powers these two airplanes, certain engine parts need to be customised to each application. The software governing the engine control unit is a case in point since it has to be fine-tuned with the avionics system of the airplane.

Besides their multi-component character, aircraft engines are also multi-technology. Engine components belong to different and often distant technological fields such as thermodynamics, aerodynamics, tribology, heat transfer, combustion, structures, and materials (Mattingly *et al.* 1987). The multi-technology character of aircraft engines renders the innovative task of engine manufacturers particularly challenging because

(a) they must develop and maintain capabilities in multiple technological fields, including the ability to integrate across two or more fields. The process of building and renewing innovative and integrative capabilities tends to be cumulative since a failure to identify and develop new and promising technological fields may lock companies out of solutions that can give the firm a competitive edge (Dierickx and Cool 1989; Prencipe 1997);

(b) technological fields are characterised by uneven rates of change that result in different degrees of innovative opportunity; for example, microelectronics vs. civil engineering (Malerba and Orsenigo 1996). This unevenness requires engine manufacturers to monitor developments in promising areas to identify potentially disruptive technologies (Prencipe 2002);

(c) the number of technologies for the design, development, and manufacture of multi-technology products are too many to be managed entirely within a single-firm organisation: external sources of technology must be integrated in one way or another. Engine manufacturers compete also in terms of their ability to manage external relationships (Brusoni, Prencipe and Pavitt 2001).

The development costs of a new engine are extremely high, usually between US$500 million and US$2,500 million (Singh 1996). New engine programmes break even after 15-25 years. The failure of a programme will adversely affect the financial situation of an engine maker and may even push it into bankruptcy, as was the case of Rolls-Royce during the development of the RB211 engine in the late 1960s and early 1970s. Such huge financial outlays have led to financial collaborative agreements – risk and revenue sharing partnerships, or RRSPs -- between engine manufacturers and suppliers for the development of new engines.

3. The organisation of the aircraft engine industry: a multi-actor environment

The aircraft engine industry is characterised by a three-tier structure made up of engine manufacturers, risk and revenue sharing partners (RRSPs), and suppliers. As systems integrators, engine manufacturers design, develop, and manufacture engines according to the requirements of airlines, airframers, and regulators. They co-ordinate the activities of a large number of specialised suppliers, integrate components, and add value through their systems integration capabilities.

As already shown, at the engine manufacturer level, the industry is highly concentrated. The large turbofan market (over 35,000lb) is dominated by the so-called Big Three or Primes, General Electric Aircraft Engines, Pratt & Whitney, and Rolls-Royce. In the medium- and small-sized engines market (below 35,000lb), the main actors are AlliedSignal Engines, Rolls-Royce Allison, General Electric Aircraft Engines, Pratt & Whitney Canada, Williams International, and two international joint-ventures, CFM International, and International Aero Engines. CFM International was set up by General Electric and SNECMA, whereas International Aero Engine (IAE) is a joint venture amongst Pratt & Whitney, Rolls-Royce, Motoren und Turbinen Union (MTU), Fiat Avio, and Japanese Aero Engine (in turn a consortium of Japanese aerospace companies). In the turboshaft/turboprop market, in addition to the previously mentioned engine makers, the French company Turbomeca works in close collaboration with Rolls-Royce in the Adour engine programme. In the aircraft engine industry, East Asian firms play a relatively minor role. They are in fact suppliers or at most joint venture partners, such as Mitsubishi Heavy Industries, Kawasaki Heavy Industries, and Ishikawajima-Harima Heavy Industries in Japan and Samsung Aerospace in Korea (Nakamoto 1997).

In the last ten years mergers and acquisitions have further concentrated the industry. AlliedSignal Engines acquired Textron Lycoming and Garret Engines, and Rolls-Royce acquired Allison Engines. In 2001 a merger between General Electric and Honeywell, the parent company of Allied Signal Engines, was approved by the US antitrust authority, but blocked by the European Commission. Combinations have also taken place at the supplier level within the larger M&A movement of the entire aerospace sector.

In the form of RRSPs, an ever-increasing number of international collaborative agreements for the design, development and manufacture of new engines characterise the industry. This practice has been borrowed from the military side of the industry where collaborations amongst companies from different countries have been taking place since the early 1970s. The reasons why the development of new engines is shared amongst different companies lie in the increasing development cost and related risk of failure of any given programme. Competition in the large turbofan market is in fact severe and price-based, with engine list prices being heavily discounted by engine makers in order to gain access to the spare market business that represents the ‘gold mine’ of the industry.

First-tier suppliers are invited to join an engine programme early on and to buy a stake in it (and usually take on the design and manufacturing responsibility related to one or more components or an entire subsystem) in order to share the risks and future revenues (if any) of the programme. The shares held by suppliers have been increasing over time. On the one hand, engine makers want to ‘split’ risks and revenues across several suppliers to reduce their own stakes and to gain customers (i.e., airlines) via the involvement of suppliers of the same nationality as the customers. According to some industry experts, airlines (especially those that are state-owned or state-funded) are more likely to place engine orders when national component suppliers have been involved in the engine programme. On the other hand, component suppliers, especially from developing countries, push to get bigger engine programme shares in order to get experience in manufacturing a wider range of engine parts.

The world’s largest RRSPs involve MTU, SNECMA, and Fiat Avio. It is worth noting that the boundary between the RRSP and supplier categories is fuzzy. A supplier can be invited to buy a stake in an engine programme and become a RRSP, and at the same time be a mere supplier in another programme. According to the component suppliers interviewed, RRSP is a risky business as it links the revenues of the supplier to the success of the programme. The fierce competition between engine makers has drastically reduced the prices of the engines. In this way RRSPs end up relying on spare part sales to generate profits. In a supplier situation, however, suppliers’ revenues are linked to the supply contract regardless of the success of the engine programme.

3.1. National governments: military and commercial production

Mowery and Rosenberg (1982) have argued that government policy has influenced both demand and supply in the US commercial aircraft industry. On the supply side, the industry received government support via research on commercial applications undertaken at national laboratories such as NASA, direct funding of firms' internal research programmes, and spill-over from the military side. The demand side was influenced by the imposition of heavy regulations for safety and subsequently by environmental concerns.

Direct and indirect government funding for the development of new engine technologies remains strong. Governments in both developed and developing countries fund research as well as development programmes. Developed nations want to strengthen the technological leadership of their national champions, while developing nations want to improve their technological capabilities in this high value-added industry.[8] The governments of Europe and that of the United States differ in the ways that they support technical progress. In the United States, the support of the federal government still continues via direct and indirect initiatives. The Glenn and Langley Research Centres at NASA and the Wright Patterson Laboratory of the Air Force are considered centres of excellence for civil and military engine-related technologies respectively. Cuts in the defense budget have reduced the role of military-related research programmes in the development of new technologies. The focus is now on the development of dual-use technologies. The latest major programme, the Integrated High Performance Turbine Engine Technology (IHPTET), for instance, "addresses critical defense technology objectives" but also "develops dual-use technologies" (Sweetman 1999, 1). IHPTET is a US$4.5 billion programme funded by the US Government (65 percent) and industry (35 percent). It involves the US Army, Navy, Air Force, Defense Advanced Research Project Agency (DARPA), and NASA as well General Electric Aircraft Engines, Pratt & Whitney, Allison Engines, AlliedSignal Engines, Williams International, and Teledyne Ryan Aeronautical. IHPTET's time span (25 years), the areas it covers, and the magnitude of its goals also serve to make it a major programme (Sweetman 1989). It covers the major jet engine component technologies, such as turbine and combustors, as well as pervasive technologies, such as materials and processes. The underlying objective is not to develop engines per se, but to develop technologies that can be incorporated into demonstration and validation programmes or full scale development programmes. The achievement of each objective per engine technology has been scheduled into three stages with completion dates in 1991, 1997, and 2003 (Sweetman 1989).

The support of European governments for technological developments in the aircraft engine industry is less visible than in United States. Europe does not have organisations that can match the shear size of the NASA Research Centres and the Wright Patterson Laboratory. Nonetheless, it is well known that European governments support national engine manufacturers via direct funding of research programmes and new engine development programmes. Likewise, the European Union has funded important research programmes where industry and universities collaborate within the Framework Programmes. Special initiatives cover the specific sub-programme on the aircraft industry labelled 'Aeronautics' within the Brite–Euram Programme, the work of the "Aeronautics Task Force" to co-ordinate the various aeronautics research programmes, and the broad and heavily funded subprogram

[8] As confirmed by an industry expert, "the reasons government [in developing countries] will do that [i.e. ask engine makers to involve national companies in the development of new engines] are very many, but essentially two. The first is the aero gas turbines are closely related to defense and therefore a country has to have the ambition in the medium or long term to have a defense capability equal to the best. The other issue is the view, totally correct view, that if you invest in very high value added technologies like the aero gas turbine, you get a spreading of the capabilities which are research, design and even management, because we are managing a very complex technology. . . . So many developing countries will be opened to say why don't you invest in my organisation to develop gas turbine technologies for this country, because there will be spin off effects for many other people in the country".

on “Aeronautics” within the current Framework Programmes (Commission of European Communities 1996).

Although engines for military and civil purposes share some of the underlying technologies, the order winning criteria for the two markets diverge substantially. Whereas for military engines the emphasis is on improvements in performance (in terms of thrust-to-weight ratio and thrust-to-frontal area) and reduction in weight, for civil engines the emphasis is on initial cost and on fuel efficiency and reliability that directly impacts on the airlines’ operating costs (Dent and Kline 1995). These distinct emphases are translated into different emphases for the development of new technologies for the two markets.

3.2. Evolution of global competition in the large commercial aircraft engine industry

The key competitive drivers in the commercial aircraft engine industry have changed dramatically in the last 30 years. During the 1970s the main competitive driver in the aircraft engine industry was technology; engines were sold according to their technical superiority. Rolls-Royce and Pratt & Whitney dominated the industry,[9] and had sole-sourcing relationships with aircraft manufacturers. From the 1970s the engine/airframe interface became more modular so that engines became more interchangeable. This change enabled aircraft manufacturers to shift from sole sourcing to dual sourcing and multiple sourcing strategies. In this way aircraft manufacturers ceased to be hostage to engine manufacturers. Airframes started being offered with a choice of at least two (and sometimes three) competing engines. As a consequence, engine nacelles became a critical aircraft subsystem for the configuration and optimisation of the engine/airframe interface. Following these changes, General Electric Aircraft Engines, hitherto only a competitor in the military market, entered the civil market. Critical to General Electric’s entry into commercial production was its joint venture with SNECMA, begun in 1971 to supply Airbus (Doz and Gee 1996).

During the 1980s the industry shifted from sole source to multiple source supply of engines to particular aircraft. This shift greatly increased the bargaining power of airlines as the ultimate engine customers. During the 1980s, alternative sourcing entailed the development of fierce price-based competition among engine suppliers. With airframes offered with a choice of engines, competition drove down the price of engines, benefiting airframers, airlines, and ultimately passengers (through reduced fares). The consequences of such intense price-based competition were borne by engine manufacturers. Such fierce competition had three outcomes. The first was a tactical one. In order to win orders, engine manufacturers started to heavily discount engine list prices, even in some cases giving away engines “for free” (Singh 1996). They did so in order to secure a foothold in the aftermarket spare parts and service business. Engine reliability, however, is increasing, which in and of itself reduces the importance of the aftermarket business.[10]

The other two outcomes had a more strategic impact since they involved changes in the division of labour within the industry (Prencipe 2002). The first outcome concerned the increased use of RRSPs for the development of new engines. As mentioned earlier, to cope with spiralling development costs, engine manufacturers team up with suppliers as well as with each other to share the risks and revenues of engine programmes. The second outcome concerned the redefinition of the boundaries of the engine manufacturer’s businesses. The

[9] Pratt & Whitney had been the leading producer of piston engines from the 1930s before developing a dominant position in commercial jet engines after World War II.

[10] Engine reliability is measured by “in-flight-shut down rates” (Singh 1996).

1990s marked the beginning of a different type of competition, namely service-based competition. Engine manufacturers started signing long-term aftermarket deals with airlines. According to these agreements, it is the engine manufacturer that services, overhauls, and repairs the engine rather than the airline. The supply of the engine became part of these agreements. Engine manufacturers started offering integrated solutions that included product and maintenance service throughout the engine's life. In this way, engines are leased (and not sold) and the engine manufacturer becomes a service provider that charges the airline for the engine usage (so-called 'power-by-the-hour'). To implement this strategy, engine manufacturers started acquiring and/or partnering with independent engine maintenance companies, acquiring maintenance facilities from airlines, developing in-house capabilities for service engines (see Table 2).

A prime example of the shift of the competitive drivers of industry is the deal struck by General Electric Aircraft Engines and British Airways in the mid-1990s. General Electric was able to win a large order from British Airways (hitherto a loyal customer of Rolls-Royce) by offering a financial package for the provision of GE90 engines for the Boeing 777 that included the acquisition of British Airways maintenance facilities in Wales. The deal was unprecedented for two reasons. First, airlines have usually been very loyal customers because they are keen to exploit commonality across their fleets. In particular, engine maintenance required skills often specific to an engine brand. Such skills needed to be developed and nurtured over time. Switching to a different engine manufacturer therefore entailed the retraining of maintenance engineers as well as their certification by the airworthiness authority. Since, according to the deal, General Electric would provide maintenance service for the newly bought engines, British Airways would not have to retrain its engineers. Second, as a by-product of the deal, General Electric Aircraft Engines got access to the Rolls-Royce and Pratt & Whitney engines that were installed on British Airways planes.

Table 2. Acquisitions of service and repair companies by engine manufacturers
(year of acquisition in parentheses)

Engine manufacturer	Acquired company
General Electric	CELMA (1996)
	Greenwich Air Services (1997)
	UNC Inc. (1997)
	Augusta Airplane Maintenance Company (1998)
	Aero-Engines Co. (1999)
Pratt & Whitney	Propulsion Systems Division of the Nordam Group (1996)
	Flight Repair Group of Interturbine (1997)
	Airfoil refurbishment business of Howmet Corporation (1997)
	Universal Maintenance Centre (1998)
	Dallas Aerospace (1999)
	Great Lakes Turbines (1999)
	Cade Industries (2000)
Rolls-Royce	National Airmotive Corporation (1999)

Source: Constructed by authors based on data gathered from specialised press.

4. Strategy and innovation under different governance regimes at Rolls-Royce

During the 1990s, Rolls-Royce maintained its position, along with US-based Pratt & Whitney and General Electric, as one of the Big Three in the commercial aircraft engine industry. After sustaining losses in 1996, Rolls-Royce remained profitable from 1997 through 2001, with its turnover increasing by 63 percent between 1996 and 2001 (Table 3). Key to Rolls-Royce's success in the late 1990s was the technological superiority of its three-shaft engines.

In this section of the paper, we document how Rolls-Royce was able to sustain the cumulation of its innovative capabilities in gas turbine technologies over three decades, during which time very different corporate governance regimes prevailed:

1. In the last half of the 1960s, in the aftermath of the consolidation of the British engine industry that had begun in 1959, Rolls-Royce was 'governed' by engineers as it began the development of the three-shaft engine;
2. From February 1971, when the company went bankrupt, to May 1987, when the company was privatised, Rolls-Royce was a nationalised company that developed civilian technology, first as an add-on to its military efforts and then in the 1980s as a critical capability in preparation for privatisation;
3. From May 1987 to the present, Rolls-Royce has been a publicly listed managerial enterprise for which commercial turbofan engines is the most important single business (constituting 55 percent of the company's total sales and 56 percent of total profits in 1999, 54 percent of total sales and 107 percent of total profits in 2000, and 54 percent of total sales and 58 percent of total profits in 2001 (Rolls-Royce Annual Reports 2000 and 2001).

Table 3. Rolls-Royce Group financial performance 1996-2001

£ millions, except for percentages and earnings per share

	1997	**1998**	**1999**	**2000**	**2001**
Group turnover (GT)	4323	4471	4634	5864	6328
Annual GT growth rate	11.2%	3.4%	3.6%	26.5%	7.9%
Order book	10100	12600	13200	14500	14400
Earnings per share (EPS)	15.16p	16.91p	19.52p	19.38p	20.20p
Annual EPS growth rate	19.4%	11.5%	15.4%	-0.7%	4.2%
Group operating profits	271	316	376	290	435
Profits before taxation	276	325	360	166	192
Net R&D expenditures*	268	310	337	371	358
Net R&D as percent of sales	6.2%	6.9%	7.2%	6.3%	5.7%

* Net R&D expenditures = gross R&D expenditure less known recoverable cost on contracts or contributions to shared engineering programs

Sources: Rolls-Royce Annual Reports, 1997-2001.

The historical analysis reported below aims to scrutinise the different corporate governance regimes in terms of the actors responsible for the process of allocation of resources and distribution of returns as well as the types of investments in productive capabilities that were made, with particular reference to human resources (for this perspective on corporate governance, see Lazonick and O'Sullivan 2000). Put simply, we want to identify the structures of strategic control that ensured that over a period of more than three decades, often in the face of severe financial adversity, the commitment to the development of the RB211 engine architecture was maintained.

4.1. The late 1960s and 'engineer control'

The British national context

In the post-war period the British aircraft (airframe and aircraft engine) industry was over-sized, heavily fragmented, and "dominated by strong and powerful personalities – the founders and the hero designers" (Hayward 1989, 51). Twenty-seven airframers and eight aircraft engine manufacturers populated the industry.[11] Although the Labour government was inclined to nationalise some industries, it was sceptical about the nationalisation of the aircraft industry. From the government's perspective, it already had enough control of the aircraft industry through the allocation of research and development funds and procurement contracts. A certain number of competent design centres guaranteed both a degree of competition and some spare capacity in case of an emergency. But the need for a rationalisation of the industry loomed large for a number of reasons.

With the introduction of electronics (later labelled avionics), aircraft systems were becoming more sophisticated and complex. This change was compounded by a demand for aircraft systems with higher speeds and capabilities. As a result, development lead times grew longer and technological uncertainty and development costs increased. Such an increase in size, cost and complexity of development programmes required larger market shares that allowed for higher production levels that, in turn, demanded that economies of scales be reaped. Compared with the larger US airframers and engine producers and the US military and commercial markets to which they had access, the relatively small British aircraft firms found themselves at a distinct competitive disadvantage. In the British industrial tradition (Rosenberg 1976), moreover, British aircraft products were tailored to national specifications, thus making British products less attractive on the global market and undermining the incentives of British producers to introduce mass production principles.

Rationalisation of the industry occurred between the end of the 1950s and the beginning of the 1960s. According to Hayward (1989, 67), it was "the Sandys Defence White Paper of 1957 [that] provided the catalyst for rationalisation of the aircraft industry". A series of combinations reduced the number of firms to three (Hawker Siddeley Group, British Aircraft Corporation, and Westland Aircraft) in the airframe industry and two (Rolls-Royce and Bristol Siddeley Engines) in the aircraft engine industry.[12] As discussed later, however, industrial restructuring through further combinations as well as nationalisation did not come to an end. Further rationalisation followed the guidelines provided in the Plowden report published in 1965 on the state of the British aircraft industry and was affected by unexpected events such as the bankruptcy of Rolls-Royce.[13]

The roots of Rolls-Royce's success: the three-shaft engine architecture

Already in the mid-1940s Rolls-Royce had proved to be the most successful and competent British aircraft engine firm (Hayward, 1989). It was independent of airframe manufacturers (unlike the others, such as de Havilland and Siddeley Armstrong Motors), so that it could exploit commercial opportunities originating from any of the airframers. After the war,

[11] This section is based on Hayward 1989.

[12] While Rolls-Royce remained unaffected by the mergers and acquisitions, Bristol Siddeley Engines was the result of the merger of the engine divisions of Bristol, Hawker Siddeley, Blackburn and de Havilland. Other firms that remained unaffected by the flurry of mergers were Alvis, Handley Page, and Auster Aircraft (Hayward 1989).

[13] The title of the Plowden report is 'Report of the Committee of Inquiry into the Aircraft Industry', with Lord Plowden as Chairman of the Committee. See Pugh 2001, 94-95.

Rolls-Royce decided to remain focused on its existing businesses, namely aircraft engines and quality motor cars, and in particular to develop the civil engine market. Rolls-Royce's chief executive in the 1960s, Sir Denning Pearson, stated that "with the end of the last war we set out to build up from zero a civil aviation business" (quoted in Hayward 1989, 50). Although Bristol Siddeley Engines proved to be a strong domestic competitor, Rolls-Royce maintained its lead. Together with Pratt & Whitney, it cornered the non-communist market for airliners, and in the 1950s its civil business rose from 40 percent to 67 percent of its aircraft engine turnover (Hayward 1989, 50).

In 1966 Rolls-Royce decided to take over Bristol Siddeley Engines after that company had entered negotiations with SNECMA to build the Pratt & Whitney JT9D engine for the Airbus.[14] Both Bristol Siddeley Engines and the government welcomed the take-over. According to Hayward (1989, 123), the take-over had the potential to bring "several economic, technological and competitive advantages, not the least of which would be to remove the danger of an American 'Trojan Horse' implied by the Bristol Siddeley Engines/SNECMA arrangement". Similarly Harker (1976, 152) argued: "There were many good reasons to justify the acquisition of the Bristol Engine Company, one of the chief ones being to form a company big enough and with sufficient experience to compete on the world markets with Pratt & Whitney, the highly successful American competitor. Also we had to make the best use of the rather limited financial resources of the British government for Engine Research and Development".

Nevertheless, there were big differences in philosophy and style between the two British engine companies. Also, as discussed later, the financial costs of the take-over turned out to be detrimental for Rolls-Royce during the 'painful' development of the RB211 engine (see Pugh 2001, 100-102). As Cownie (1989, 232) noted: "The Department of Trade and Industry report of 1973 states that 'it is difficult to escape the conclusion that the acquisition was primarily defensively motivated' and that 'Rolls-Royce paid about £22 million for goodwill but profits earned fell far short of forecast'".

The development of Rolls-Royce's civil business rested on two important decisions: (1) to develop a new and large turbofan aircraft engine, and (2) to break into the United States market, a much larger market than the European one, that would allowed longer production runs required to sustain high development costs. In 1992 Philip Ruffles, who in 1997 was to become Director of Engineering and Technology, recalled: "The company [Rolls-Royce] also learned that developing an engine to meet the specialised needs of domestic airlines, as with the Spey turbofan for the British European Airways Trident airliner, was likely to limit its sales on world markets" (Ruffles 1992, 23). Gray (1971, 79) underlined that "Rolls-Royce needed to develop the RB211, or a similar engine, if they were to maintain their position as one of the big three aero-engine manufacturers in the western world; the enormous cost of such development demanded a large market; and the largest market, America, was exceedingly difficult to penetrate, owing to the inbuilt advantages enjoyed by the American companies." The need to develop a large turbofan engine for the US market became a clear strategy for Rolls-Royce. Sir Denning Pearson, Rolls-Royce Chairman, stated: "Building a new engine would not guarantee we stayed in business. Not building one would certainly guarantee that we went out of business" (quoted in Gray 1971, 76).

[14] Rolls-Royce bought Bristol Aeroplane Company Limited, which owned 50 percent of Bristol Siddeley, and bought the other 50 percent from the Hawker Siddeley Group Limited (Cownie 1989; Pugh 2001, 96-98).

In 1965 a study indicated a large market in the future for engines rated over 30,000lb. At Rolls-Royce the first programme for a larger turbofan engine was based on the two-shaft Conway turbofan engine. The engine, labelled RB178, was rated at 28,500lb and had a relatively low by-pass ratio. The company's view was that the fuel consumption benefits of a high by-pass ratio would be more than offset by the fuel consumption costs attributable to the larger size of the fan, the greater weight of the engine, and the higher installed drag that a high-by-pass ratio would entail (Cownie 1989; Pugh 2001, 105).

Such a view changed, however, when "tests in the US demonstrated that the installed drag penalty of the nacelle was less than half that assumed in European studies" (Ruffles 1992, 3). As a result, the by-pass ratio of the RB178 was increased up to 8, which in turn led Rolls-Royce's engineers to choose "a three-shaft configuration as the best for both aerodynamic and mechanical reasons" (Ruffles 1992, 4). This design layout, labelled RB178-51, would provide much higher thrust than the previous RB178. A demonstrator programme was launched to test the new technological solution, with the first engine test run taking place in July 1966 (Cownie 1989). The tests revealed a number of mechanical defects related to the revolutionary character of the three-shaft architecture. A shortage of finance meant that the demonstrator programme was dropped. Meanwhile, Rolls-Royce started a smaller three-shaft engine programme, the Trent, which permitted the company to gain some experience on a lower-rated version of a three-shaft engine. The Trent programme was, however, cancelled in 1968. As reported by Cownie (1989, 232), "many believed that some of the problems later experienced in RB211 development could have been solved earlier if running had continued with the RB178 demonstrator". Sir David Huddie, managing director of the Rolls-Royce aircraft engine division at the time, later recalled that the termination of the RB178 programme was "one of our biggest mistakes" (quoted in Pugh 2001, 109).

When Boeing launched the 747 in 1986, Rolls-Royce submitted an engine proposal (the RB178-51) to power the widebody aircraft (Ruffles, 1992). Boeing selected the Pratt & Whitney JT9D, however, mainly because of its larger size. After failing to sell the RB178-51 to Boeing, Rolls-Royce became even more convinced that the future of its aircraft engine business depended on the development of large turbofan engines. Forecast studies showed that sales of Rolls-Royce's existing engines would fall from £58.9 million in 1969 to £3.5 million in 1975, and revenues from the aftermarket from £36.5 to £31.9 million (Cownie 1989). Towards the end of the 1960s, Rolls-Royce had in place two large three-shaft engine projects, namely the RB207 and the RB211. The RB207 was the larger one, rated at over 50,000lb and proposed for the twin-engined European Airbus, US airbuses, and the BAC Two-eleven projects. The RB211 was relatively smaller, rated at 30,000lb, and proposed for three-engined airliners.

4.2. Development of the RB211

Rolls-Royce entered negotiations with Lockheed that was launching the L-1011 three-engined widebody aircraft (Pugh 2001, ch. 4). The first engine proposed was rated at 33,260lb (Cownie 1989). Rolls-Royce marketing team (led by David Huddie) focussed its campaign on technological superiority and lower prices. Technological superiority was supposed to derive from not only the revolutionary three-shaft architecture but also the all-composite (Hyfil) fan blade. These technological advances would result in an engine that was "lighter, cheaper to run, simpler in construction (with 40 per cent fewer component parts) and easier to maintain than existing turbo-fan engines" (Gray 1971, 84). Also, given lower wages in Britain and the further devaluation of the British pound against the US dollar, the RB211 engine was offered at £203,000 compared with £250,000 for the General Electric engine and £280,000 for the Pratt & Whitney engine. Pratt & Whitney pulled out of the race, while General Electric cut its price to £240,000. After tough and intense negotiations, Rolls-Royce won the contract by cutting its price to just under £200,000 (Reed 1973). Lockheed announced the launch order for the RB211 in March 1968. Lockheed ordered 150 'ship sets' of RB211 engines (totalling 450 engines), with TWA and Eastern Air Lines as launch airline customers. Air Holding of United Kingdom ordered 50 Lockheed aircraft, which was politically advantageous for Rolls-Royce because it offset the offshore purchase of British engines and therefore helped the US balance of payments (Cownie 1989).

The news of the Rolls-Royce-Lockheed deal was very well received in Britain. Anthony Wedgewood Benn, Minister of Technology in the Labour government, stated that the contract was "a terrific boost to British technology and its export potential" (quoted in Gray 1971, 86). Also the City welcomed the deal, and Rolls-Royce's share prices moved up from £2.225 to £2.35 adding £30 million to Rolls-Royce's market value (Reed 1973). As pointed out by Gray (1971, 86), however, the praise was based on the mistaken assumption that, through the company's newly developed computer centre, "Rolls-Royce's success was due to the careful control of costs" (1971, 86). In fact, Rolls-Royce's success was based on price cutting, a strategy that, as Gray (1971, 86), put it, "did not require a computer".

The development of the RB211 was unique for Rolls-Royce. As Harker (1979, 176) summed it up: "This was a mammoth task; the engine itself was much bigger in overall dimension than anything the company had produced before; it was a different shape and the diameter of the fan was eighty-six inches, which necessitated large machinery to cut metal and required new techniques in welding" (see also Cownie 1989, 234). The task became even more complex when the design specifications of the engine were modified to accommodate changes in the design of the aircraft. By the time the engine was ordered, aircraft performance requirements had increased, with the thrust required from the RB211 rising to 40,600lb. In 1972, the thrust requirement climbed again to 42,000lb because of increased weight of both aircraft and engine. This thrust was twice as much as that of the largest engine that Rolls-Royce had previously produced. Engine specifications changed in terms of cost, weight, and noise guarantees as compared with the engine proposed. The technology to be incorporated was unproven since the demonstrator programmes had been dropped due to the shortage of finance. In particular, test failures meant that the all-composite fan made up of Hyfil carbon-fibre had to be abandoned. The heavier conventional titanium fan blades further increased the engine weight.

This was not the first time that Rolls-Royce had had problems during the development of a new engine. Both the Dart turboprop and the Spey turbofan had experienced a number of technical problems in the development process. The Dart was designed to weigh 600lb and to provide 1000lb thrust. The first prototype weighed 1000lb and provided 600lb thrust (Gray 1971). Rolls-Royce was, however, able to tackle these design problems, and in 1953 the Dart-powered Viscount was the first turboprop aeroplane to go into regular airline service (Gray 1971). The Spey was developed in the 1960s with an investment of £20 million to power the BEA's scaled down Trident aircraft. Although, the Trident was not a market success, the Spey went on to generate substantial revenues, particularly in the military market. Sir Denning Pearson, Rolls-Royce Chairman, proudly stated: "If we'd been run by an accountant we'd never have gone ahead with the Spey" (quoted in Gray 1971, 76).

The RB211 development programme turned out to be a much more difficult and painful task, however, than those for either the Spey or the Dart. Rolls-Royce had never managed a development programme of such a size. While Rolls-Royce invested £20 million in the Spey, the original estimate of the launching costs of RB211 programme was £65.5 million (Department of Trade and Industry 1972). The government's initial contribution was 70 percent of the launching costs of the RB211, totalling around £47 million. It was an exceptional contribution since the government had set a limit to launching aid at "normally not more than 50%" of the launching costs (Department of Trade and Industry 1972, Annex A). [15]

To make things worse, the initial launching costs had been seriously underestimated. The as yet unproven technologies being introduced in the RB211 resulted in soaring development costs. *In primis*, the Hyfil carbon fibre that made up the fan blades failed the so-called 'bird strike test'. The fibre was reinforced to strengthen the leading edge of the blades, but this solution caused stresses at the root of the blade (Gray 1971). As a result, the all-composite fan blade was abandoned, and the 'old' solid titanium blades with snubbers were reintroduced. This change, however, added 300lb to the weight of the engine, thus necessitating expensive redesign activities. The shear size of the engine also required the construction of new testing facilities. As a result, the progress of the programme was delayed, and it became highly likely that Rolls-Royce would incur the heavy late-delivery penalties that the Lockheed contract mandated.

Rolls-Royce's financial situation

Rolls-Royce financial situation started deteriorating towards the end of 1969. In May 1970, Rolls-Royce asked the Industrial Reorganisation Corporation for a loan of £10 million. Changes in management were made: first Lord Beeching and Ian Morrow joined the board; then Sir David Huddie, one of the architects of the successful RB211 campaign, stepped down and Hugh Conway (from the Bristol division) replaced him. Also, 3,500 men were made redundant and a small factory (employing 100 men) was closed down. In November 1970, in the face of Rolls-Royce's mounting financial difficulties and a revised estimate of the launching costs of the RB211 to £135 million, the government increased its launching aid by a further £42 million, thus totalling £89 million equivalent to 70 percent of the revised cost estimate. Also, the Bank of England, Midland Bank, and Lloyds Bank agreed to lend £18 million to Rolls-Royce (Department of Trade and Industry 1972, 7–8). This £60 million financial package was, however, subject to a reassessment of the development programme (Department of Trade and Industry 1972). A further change was made to Rolls-Royce management. Sir Denning Pearson, Rolls-Royce chairman and another architect of the RB211 campaign, stepped down and was replaced by Lord Cole, who had just retired from Unilever.

Notwithstanding changes in management, redundancies and augmented financial aid from the British Government, Rolls-Royce was not able to overcome the problems with the RB211 development programme. Rolls-Royce internal assessments (reported to the Ministry of Aviation Supply) showed that due to a number of design modifications and subsequent changes in the production process, development and production targets could not be met. These delays meant a postponement of at least six months for engine deliveries (Department of Trade and Industry 1972). The Department of Trade and Industry estimated that "a further

[15] "Launching aid is an interest-free financial contribution to the launching costs of a civil aircraft or aero-engine project, repayable as a levy on sales and licences to the extent that these are achieved" (Department of Trade and Industry 1972, Annex A).

£110 million cash flow would be required, as compared with the £60 million estimated in September 1970" (Department of Trade and Industry 1972, 11). The incoming Conservative government that, while in opposition, "had adopted a policy of 'disengagement' from industry with references to the need to end public support for 'lame ducks'" (Hayward 1989, 138) had to decide whether to continue to support Rolls-Royce financially or allow it to go bankrupt. They opted for the second alternative and on 4th February 1971 Rolls-Royce went into receivership.

The causes of Rolls-Royce's bankruptcy

What went wrong? As mentioned earlier, although Rolls-Royce was able to recover when they faced similar problems during the development of the Spey engine, the complexity of the problems involved in the RB211 programme were of a completely different magnitude. The problems were technical, financial, managerial, and contractual. The use of Hyfil carbon fibre for fan blades turned out to be a failure. Also, the technological viability of the RB211's revolutionary three-shaft architecture had yet to be demonstrated. As mentioned earlier, the RB178 demonstrator programme had been cancelled due to financial shortage, leaving the design team dependent on parametric studies of the Spey and smaller turbo-fan engines. Worse still, the premature death of Adrian Lombard deprived Rolls-Royce of one of the finest 'trouble shooting' engineers in the industry (Hayward 1989, 137).[16]

At the time that the RB211 programme was launched, Rolls-Royce was involved in the development of the larger RB207 engine for the European Airbus as well as in a number military programmes (Harker 1979). Although the two civil engines shared a common architecture and several design features, "development of two large engines, and especially the RB211 to Lockheed's stringent contract terms, was straining [Rolls-Royce's] resources" (Hayward 1989, 136). Also, the acquisition of Bristol Siddeley Engines absorbed financial resources; Rolls-Royce's purchase of Bristol cost £63.6 million, £26.6 million of which was paid in cash to Hawker Siddeley Aircraft (Hayward 1989, 123). The valuation included about £20 million in 'goodwill' and shares in British Aircraft Corporation and Westland, which Rolls-Royce later sought unsuccessfully to sell. The Bristol acquisition placed considerable demands upon managerial resources for rationalising the engine divisions. Harker (1979, 177) reported that at the time of the merger Bristol Siddeley "had a mixed bag of engines to look after, engines which had been inherited from past mergers". The acquisition price had taken into account estimates of future profits from BSE [Bristol Siddeley Engines] projects, which proved to be considerably overoptimistic. In fact, Rolls-Royce would have to provide additional capital to support the Bristol side of the business at a time when its own liquidity was under pressure from its fateful contract with Lockheed. Hayward (1989, 123) stated that "[w]ith hindsight, it is evident that the determination to prevent P&W [Pratt & Whitney] obtaining a European foothold led Rolls into a precipitated and ill-judged act. Although the merger [with Bristol Siddeley] was not the main cause of Rolls' later problems, it would be a significant contributory factor."

As for the Lockheed contract, the main problem was that Rolls-Royce had agreed to a relatively low fixed price with, as Hayward (1989, 136) put it, "strict and onerous penalties for delay, giving Rolls very little leeway in the event of serious technical or financial problems." Similarly, Harker (1979, 186) emphasised that "[s]ix hundred engines were

[16] This view was echoed by Harker (1979, 178): "A very tragic blow hit the company during this period; Adrian Lombard, our brilliant and popular director of engineering, died suddenly and very unexpectedly of a stroke. He was quite irreplaceable at this time; I am sure that many of the troubles that were to beset the development of the RB211 could have been overcome sooner had we not lost him."

contracted, but the price did not make sufficient allowance for the unexpected inflation that ensued in the economy or the unanticipated development costs that arose." As Sir David Huddie was to put it in an interview in 1999:

> We had promised a bit more than we could perform. Things were not deplorable. Flight engines were four months late. Four months is four months but it is not deplorable. The deplorable thing was the cost . . . The accountants never got cash-flow into our heads. (quoted in Pugh 2001, 156)

Engineer control: a two-edged sword

"A basic engineering training is a good training for management and for top engineering decisions" (quoted in Gray 1971, 75). This statement attributed to Sir Denning Pearson summarises Rolls-Royce's management philosophy. Several commentators underlined the fact that Rolls-Royce was an engineering company run by engineers who were devoted to engineering excellence. This value informed every single allocative decision taken within the firm. Engineering excellence was pursued strenuously, sometimes irrespective of time and cost constraints. As mentioned by an industry expert, allegedly, having laid their hands on a Pratt & Whitney engine, Rolls-Royce engineers were appalled by the crudity of the engineering solutions embedded in the engine. They were also appalled, however, by the fact that the competitor's engine worked.

Also, Rolls-Royce was a paternalistic company. To get a job in Rolls-Royce was made easier if the applicant had a relative already working for the company. Employees tended to stay with the company for their entire working lives. This attachment occurred not only at the top management level, but also on the shop floor. As underlined by Gray (1971, 75): "Before Rolls-Royce merged with Bristol Siddeley in 1966 only one of their eight directors had been with them for less than twenty-five years. Such links with the past were to be found on every level: in 1964 over a third of the workers in the Derby factory had been employed there since before the Second World War." Also, Rolls-Royce did not adopt job rotation policies, so that engineers tended to stay within the same department for years, and sometimes decades, with the likelihood that they would become experts in a specific component and/or subsystem of the aircraft engine.

4.3. The era of nationalisation

On the same day that the Rolls-Royce Receiver was appointed, Frederick Corfield, the Ministry of Aviation Supply stated: "To ensure continuity of those activities of Rolls-Royce which are important to our national defence, to our collaborative programmes with other countries and to many air forces and civil airlines all over the world, the Government has decided to acquire such assets of the aero-engine and marine and industrial gas turbine engine divisions of the company as they may be essential for these purposes" (quoted in Department of Trade and Industry 1972, 14). A new company, Rolls-Royce (1971) Limited was therefore formed that took control of the assets of Rolls-Royce acquired by the government (Department of Trade and Industry 1972).

At that point the development of the RB211 was almost cancelled. As described by Peter Pugh (2001, 147) in his recent history of Rolls-Royce:

> While Lockheed was trying to convince [Rupert] Nicholson [the appointed receiver from Peat Marwick Mitchell & Co.] that there was a great future for the RB211, the

> Government seemed determined to undermine that future. Frederick Corfield, Minister of Aviation Supply, argued in the House of Commons that continuance of the engine was not essential to Britain remaining in 'the big aero engine league'. Furthermore, he did not believe that there was 'an enormous potential market' for the engine, which was 'to a large extent behind engines of equivalent power and performance', by which he meant Pratt & Whitney's JT-9D and General Electric's CF6.[17]

But Lord Carrington, the Minister of Defence, commissioned a technical and cost study that involved veteran Rolls-Royce engineers Fred Morley, Stanley Hooker, and Arthur Rubbra and that gave an optimistic assessment of the RB211 (Pugh 2001, 230). The study argued that the RB211's development problems could be overcome with a six-month delay and a cash flow injection of a further £120 million (Department of Trade and Industry 1972). According to Gunston (1997, 195), the nationalised company took "the RB211 on board, funded on a cheeseparing daily basis." The British government entered talks with Lockheed to renegotiate the RB211 contract. After a lengthy negotiation involving the British and the US governments, Rolls-Royce (1971) Limited and Lockheed signed a new contract for the completion of the RB211 programme. Under this new agreement, Lockheed agreed to buy RB211 engines at increased prices. Meanwhile, the US Senate had authorised a Federal rescue package for Lockheed (Hayward 1989), and the British government provided the necessary cash to complete the RB211 programme.

According to the 1971 Memorandum of Understanding that outlined the relationship between the British government and Rolls-Royce, the government, as the sole shareholder, maintained ultimate control over strategic planning and financial issues related to the launch of new engine development programmes (Hayward 1989). In particular, "any investment decisions over £25 million (US$41 million) had to be referred back to the government for approval" (Verchère 1992, 33). The government was, however, not greatly involved in the company's day-to-day management, although the Rolls-Royce board agreed to keep it informed about its operations (Hayward 1989).

A number of the Government appointments to the new board of Rolls-Royce (1971) Limited were clearly supporters of the RB211 programme. Foremost among them was Sir Stanley Hooker who came out of retirement to become Rolls-Royce's head of engineering. Also appointed were Sir William Cook, a former scientific advisor to the Ministry of Defence, and Sir St John Elstub, Chairman of Imperial Metal Industries, both of whom had already advised the Heath government on the viability of the RB211 (Pugh 2001, 234-235). Yet, as summed up by Hayward (1989, 140), the bankruptcy and bailout entailed a dramatic challenge to engineer control:

> [I]t was soon evident that Rolls required a long period of convalescence and a sharp taste of internal reform. Pearson, Huddie and the Rolls board took the full brunt of the post mortem. There had been fatal flaws in Rolls' management structure and the dominance of engineers at the top of the company was singled out for particular criticism. As one Rolls man would later put it, "the first thing we had to learn was that the company was not just a playground for engineers to amuse themselves". Rolls-Royce had to be rebuilt and Sir Kenneth Keith's appointment as chairman in

[17] Pugh (2001, 147) continues: "Corfield, a pig farmer by profession, was out of his depth. The ultimate success of the RB211 showed that he did not know what he was talking about."

> September 1972 marked the start of the process. According to Sir Stanley Hooker, Sir Kenneth found a lack of discipline which appalled him and took on a seven year stint which would lay the conditions for Rolls' revival.

With government and board support for the RB211 programme, engineers regained complete control over the evolution of the programme itself. In the aftermath of the bankruptcy, a number of Rolls-Royce's most illustrious engineers, including Sir Stanley Hooker, who, among other things, had led the development of the engine for the Concorde while working at Bristol Aero Engines (Pugh 2001, 90-92), had come out of retirement to become both Technical Director and a member of the Rolls-Royce board of directors with the charge of getting the RB211 programme back on track. In the words of Harker (1979, 189), who had himself been chief engineer at Rolls-Royce:

> The period immediately after the crash was an unhappy one; morale was low at all levels. Many of the senior officials such as myself, who knew everybody in the industry and who were known world-wide, were made redundant. There was almost nobody left of the old school on the main board of the nationalised aero-engine company; apart from Stanley Hooker, they were all new. Fortunately, the engineering quality was still there; the old wartime Merlin team of Lovesey, Hooker, Rubbra, and Fred Morley was called in to put the RB211 to rights; they were officially retired, but they answered the call and were totally successful.

Cyril Lovesey and Arthur Rubbra were both well over 70 years old, and worked with Hooker as was he called "a kind of Chief of Staff committee" (Pugh 2001, 235, quoting from Hooker 1984). Hooker himself described how, as chief engineer, he re-mobilised the RB211 development effort in the wake of the bankruptcy:

> Under me the great team of engineers, and indeed the whole vast Derby works, was completely demoralised. Many were looking for someone else to blame. I called a meeting of the entire engineering staff and explained the exact situation. I then appealed to their loyalty to the good name of Rolls-Royce to get the RB.211 quickly certificated and delivered to Lockheed. I promised 100 per cent support to their efforts and asked any doubters to leave at once . . . Rather remarkably, within days of first being called up to Derby a few weeks before, I had been able to put my finger on several crucial faults and to have them rectified very quickly indeed. But one cannot truly know a piece of machinery as complex as the RB.211 without living with it from the start. So I did not attempt to run the show but left the day-to-day programme to Ernest Eltis, whom I had displaced as Technical Director, but who gave me the most loyal support, and to his assistant (and an old colleague of mine from Barnoldswick [a Rolls-Royce facility]) Johnnie Bush. They proved an inspiration to their teams, and worked closely with Chief Designer Freddie Morley and his assistant John Coplin.

When the Labour government took office in 1974, however, the spectre of bureaucratic interference reappeared. Rolls-Royce was put under the control of the National Enterprise Board (NEB) whose role was to overlook the company's operations. Indeed Rolls-Royce was the main holding of NEB, which in turn came to symbolise Labour's foray into industrial policy. Rolls-Royce management disliked this intrusion; Sir Kenneth Keith, its chairman believed that the National Enterprise Board added a redundant bureaucratic layer between Rolls-Royce and the government: "two people cannot run a business. Rolls-Royce is a complex business. We understand it – and we cannot be backseat driven by people who do not" (quoted in Hayward 1989, 159).[18] Tony Benn, as Minister of Trade and Industry after Labour returned to power in February 1974, had his first meeting with the Rolls-Royce Chairman in March of that year. Keith told Benn that when he had accepted the Rolls-Royce position in 1972 he had told the Prime Minister, Edward Heath, that he would "take it on so long as I am not buggered about by junior Ministers and civil servants and officials." Benn responded that "while I am in charge I will not accept chairmen of nationalised industries indicating to me that they won't be mucked about by junior Ministers and civil servants: Rolls-Royce is a nationalised company and must be accountable for what it does." Benn wrote in his diary:

> It was a bitter exchange and at the end [Keith] said, 'I hope we can get on well together with you as my Minister.' I added, 'And the owner of your company.' So he said, 'But not my employer'. I said, 'I am inclined to say to you what my sergeant said to me in the war: "You play ball with me and I will play ball with you." (quoted in Pugh 2001, 256-257).

During 1979, over a period that included the election of the Thatcher government in May, there was open hostility between Sir Kenneth Keith and the NEB Chairman, Sir Leslie Murphy. In late 1979 Murphy told Sir Keith Joseph, Thatcher's Minister of Industry, that the Rolls-Royce Chairman should be sacked in the light of the company's poor financial performance.[19] In the event, Sir Kenneth retired as chairman, while Sir Keith took control of Rolls-Royce away from the NEB (resulting in the resignation of the entire NEB board), and placed the company in the hands of the Department of Industry.[20] In September 1979, *The Economist* asked whether Joseph would give Rolls-Royce the money it needed to continue engine development. "Rolls is optimistic," the article went on to say.

> Sir Keith is a fan of Rolls-Royce's prospects. He recently approved the NEB's project to spend £20m on the titanium granules plant necessary for making Rolls engines. He is giving the nod to the £250m RB-211 development support package promised last April by the Labour government. But Sir Keith will be anxious to avoid sneers that he is making another policy U-turn. He will demand improvements in Rolls's dismal productivity, as well as in its profit forecasts.

In 1980 Rolls-Royce's 1000th RB211 went into production. But from 1979 the company's financial situation worsened. With uncovered foreign exchange as the value of the pound appreciated under the first Thatcher government as well as a prolonged strike, Rolls-Royce recorded losses of £58m in 1979 (Hayward 1989; Pugh 2001, 299). During the early 1980s, a severe recession in the civilian aerospace industry meant that Rolls-Royce was persistently losing money.[21] In 1983 Rolls-Royce lost £193m, and in 1983 and 1984 delivered only 126 new RB211s, even though the "worst-case" scenario in the company's 1982 plan had been

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[18] See also 'Rolls-Royce: middle-man or medler?, *The Economist*, December 27, 1975, 42; 'National Enterprise Board: Rolls-Royce of a problem,' *The Economist*, February 11, 1978, 112.

[19] 'NEB and Rolls-Royce: Who needs a lame-duck hospital?' *The Economist*, November 17, 1979, 108.

[20] See 'Industrial policy: Mrs Thatcher's awkward inheritance,' *The Economist*, May 5, 1979, 120; 'Rolls under Whitehall's wing,' *The Economist*, November 24, 1979, 83.

[21] According to a 1984 report in the *Wall Street Journal*, Rolls-Royce lost the equivalent of $253 million in 1983, and "Rolls-Royce last posted a profit – currently equivalent to $9 million – in 1978. Its best year since then was 1981, when it posted income before extraordinary items of $18 million, but a net loss of $4 million after an extraordinary charge of $22 million due to restructuring costs. It had a net loss of $176 million in 1982" (Ingrassia 1984).

350 engines (Pugh 2001, 297, 304). Between 1980 and 1984 Rolls-Royce cut its labour force from 62,000 to 41,000, mainly through voluntary severance and with no industrial disputes (Pugh 2001, 300, 321, 325).

From 1971 to 1979, Rolls-Royce reportedly had received £425m in state aid.[22] From 1979 through 1988 successive governments provided Rolls-Royce with £437 million in launch aid, of which £117.7 million was repaid from sales levies (Hayward 1989). The new chairman, Sir Frank McFadzean, appointed at the end of 1979, stated, however, that "as a chairman of this company I have no intentions of going and clearing everything with civil servants; otherwise I would never run the company. You would never run a business on that basis" (quoted in Hayward 1989, 160). During this period Rolls-Royce maintained to its strategy to develop a family of engines in both military and civil businesses with, according to McFadzean, the aim of keeping the company in every market "from the smallest in helicopters to the very largest in jumbo jets" (quoted in Hayward 1989, 162).

In 1984, however, under the chairmanship for Sir William Duncan,[23] and in the aftermath of a string of unprofitable years stretching back to 1979 that Sir William described at "the worst recession in airline history" (Lambert and Makinson 1984, 10), Rolls-Royce entered into two RRSP agreements with General Electric whereby GE took a 15 percent stake in the development of the medium-sized RB535E4 engine, to power the Boeing 757, while Rolls took a 15 percent stake in the development of a GE engine designed to exceed 60,000lb (Pugh 2001, 311-319). As reported in an article entitled "Rolls faces up to reality" that appeared in the *Financial Times* the day after the agreement was announced: "By swapping a share in one of its new engine's for a stake in one of General Electric's, Rolls has finally moved away from the course which it has followed in the civil engine market for the past 20 years – a course which has taken this proud engineering company into bankruptcy, and which more recently has left it with an increasingly weak position in the market for high thrust commercial engines" (Lambert and Makinson 1984, 16). The article cites Ralph Robins, who was at the time Director – Civil Engines, as saying (in the words of the journalists) "that to develop the RB-211 series up to the [60,000lb+] size range would have effectively required the designers to start with a clean sheet of paper. On this basis the project could have cost $1-1/2bn or more".

As a journalist was to write from the vantage point of 1990 on the eve of the first test of the Trent engine, the 1984 RRSP deal had been made because Duncan "believed that any attempt by Rolls to go it alone in developing high-thrust engines would threaten a repetition of the 1971 RB211 crisis. His answer was for Rolls to stay in the game by opting for minority partnership with one of it American rivals" (Lorenz 1990). Or as another journalist, also writing in 1990, remarked, looking back at the Duncan agreement, "implicit in the deal was the understanding that Rolls would stay out of the big engine end of the market – shutting it out of the highest growth area and limiting it to a subordinate role" (Crooks 1990, 10).

By 1986, however, some two years after the high-thrust RRSP with GE, Rolls-Royce was marketing its own high-thrust engine, the RB211-524D4D in direct competition with not only Pratt and Whitney's PW-4000 but also GE's CF6-80C2, in which Rolls-Royce still had a 15 percent stake. In August 1986, much to the displeasure of General Electric, the RB211-524 secured a £600m order from British Airways for its new long-range jumbo jets. GE

[22] 'The real problem is money,' *The Economist*, November 17, 1979, 108.
[23] Duncan, a chemical engineer who had spent his career at ICI, had come to Rolls-Royce as Chairman in April 1983 after losing out to John Harvey-Jones for ICI chairmanship (Cuff 1982).

claimed that its pact with Rolls-Royce precluded it from bidding for the BA order, but Rolls-Royce claimed that such was not the case (Donne and Cassell 1986). Subsequently the GE-Rolls high-thrust RRSP fell apart, with the collaboration being terminated in November 1986 (Crooks 1990; Pugh 2001, 314-319).

Why the reversal of strategy? The improvement in the market for turbofan engines from 1985 clearly had much to do with it; in 1986 the company had pretax profits of £120m and outstanding order worth £3.1b (Pugh 2001, 323). Rolls-Royce's engineers also found, over the course of 1984 and 1985, that they could upgrade the RB211 for the big-engine market with increasing the fan diameter, with dramatic savings in development costs compared ith Robins earlier estimate (Pugh 2001, 314). Whether or not a change in the top management of Rolls-Royce was a factor in the reversal of strategy is difficult to say. In late October 1984, some eight months after the high-thrust RRSP, Duncan, the Rolls-Royce architect of the agreement, announced that, as of December 1, Ralph Robins would become Managing Director of the company, the number two position. A week after the announcement, Duncan suddenly died at the age of 61. He was replaced as Chairman by Sir Francis Tombs, who had been appointed to the Rolls-Royce Board as a non-executive director in 1982, and hence was involved in the direction of the company when the pact with GE had been made. From the perspective of 1990, Tombs was able to argue that the agreement with GE "was leading us nowhere. The decision to pull out was a watershed" (quoted in Lorenz 1990). Whereas in 1984, Robins, as Director – Civil Engines, had apparently supported the RRSP with GE on the grounds that Rolls-Royce could not afford to develop the high-thrust engine on its own, he could later argue that "we took that decision [to develop the high-thrust RB211 on its own] to stay in business" (quoted in Lorenz 1990).

As a result of the reversal of the decision to take a subordinate role to GE in the development of the high-thrust engine, Rolls-Royce increased its market share of the world civil engine market from five percent at the time of its 1987 privatisation to 20 percent in 1990. The basis of the company's success was, as Crooks (1990) put it, "Rolls' massive advantage in having the RB211 engine." As he went on:

> Sporting such desirable technical features as a wide-chord fan and a three-shaft core, it is substantially more sophisticated than its rivals., and it can be enhanced for the new high thrust market at a fraction of the cost of developing a new engine, Rolls can crank up the RB211 to provide 95,000 pounds of thrust of even more, though it was originally designed to produce just 32,000; and this upgraded engine, to be called the Trent, is costing just £400m to develop.
>
> It is not just a matter of cost. The RB211 is quieter than its rivals, and in many cases more fuel-efficient. Rolls engines are more reliable too: they need less servicing and have never lost a turbine blade in flight.

Or as Lorenz (1990) summarised the advantages of the RB211 that, by 1990, had resulted in the Trent engine:

> "… the RB211 engine core, whose development costs put the company into receivership, has become the key to its survival and success. Its revolutionary design, using three shafts rather than Pratt and GE's two, has proved so flexible that in successive upgradings since 1971 the engine power has been doubled without incurring the huge expense of significant design changes.

> The three-shaft is shorter than two-shaft engines, more rigid and therefore more durable. It wears less in service, preserving its outstanding fuel economy over its full life. Along the way Rolls developed a new, wide fan blade, the "wide-chord" fan, which needs fewer blades to produce the same, or more, power, is quieter and more fuel-efficient than conventional fans. Only with the Trent did the original RB211 fan diameter have to be increased, but no other fundamental change has been made. As a result, the Trent development is likely to cost about £400 (with about 25% being funded by Rolls' partners in the project, including BMW and two Japanese companies). By contrast, industry estimates suggest the GE90 project will cost more than £1 billion.

4.4. After privatisation

From 1979 Thatcher administration had wanted to privatise Rolls-Royce as part of the Tory policy "to reduce government intervention in industry and to spread 'popular capitalism' through wider share ownership" (Hayward 1989, 160). As one minister put it, "the business of aerospace must pay its way. Defence considerations apart, there is no reason why aerospace should not be subject to the financial disciplines and opportunities of the marketplace" (quoted in Hayward 1989, 160). Or in the words of Norman Tebbit, the Minister of Industry who succeeded Keith Joseph, "the aerospace industry is for making profits, it is not a form of occupational therapy" (quoted in Hayward 1989, 160).

With losses piling up in the early 1980s, Rolls-Royce was not yet ready to throw away the protection of government ownership. But in late 1984 a recovery in the civil aerospace markets began, and in 1985 and 1986 Rolls-Royce posted substantial profits. In May 1987 Rolls-Royce was privatised with the flotation raising £1.36 billion for the government for the sale of its shares to the public. In addition, at the request of Sir Francis Tombs, Rolls-Royce newly appointed chairman, the government authorised an additional share issue that injected £283 million. Notwithstanding the privatisation, the British government retained in perpetuity a 'golden share' of Rolls-Royce that gave it the power to veto any takeover attempt. In an effort to limit the possibility of such a situation arising, the privatisation limited foreign ownership of Rolls-Royce to 15 percent of its outstanding shares on a first come, first served basis (Hayward 1989). This limitation on foreign ownership was challenged by the European Commission, and was subsequently increased to 29.5 percent in 1989 and then to 49.5 percent in 1998.[24]

Once privatised Rolls-Royce searched for productivity gains through heavy organisational restructuring that entailed focusing on core businesses, outsourcing, downsizing, and cost-cutting schemes. This restructuring was pursued with the aim of making the customer, especially civil airlines, central to the strategy of the company. Restructuring also involved an increasing involvement of suppliers and Universities as partners in development and research programmes.

Restructuring

Organisational restructuring was pursued also via several internal programmes informed by lean manufacturing, total quality control, and business process re-engineering principles. The aims of these programmes were to improve the efficiency of business processes

[24] 'Investor Limit Up at Rolls-Royce,' *New York Times*, July 20, 1989, D5; "BAe, Rolls-Royce foreign ownership limit raised to 49.5 pct from 29.5, *AFX News*, March 12, 1998.

throughout the company and to modify the management structure to improve accountability. At the beginning of the 1990s, Rolls-Royce embarked on a internal quality-enhancing programme, labelled *Project 2000*. The programme was clearly inspired by the Japanese quality movement and aimed at identifying and eliminating all non value-added business processes throughout the firm (Verchère, 1992). In particular, the programme aimed to revise working practices and reorganise factories and people according to the cellular approach. The aim of another internal programme implemented in 1993 was to introduce the process-led approach at the shop-floor level (through reduction of floor space and inventory) as well as at the management level. The latest company-wide restructuring programme, labelled *Better Performance Faster*, was introduced in 1996. According to company's sources, this programme "moved from net investment to net savings in 1999" (Rolls-Royce Annual Report 1999).

The supplier base was also rationalised through the reduction of the number of first-tier suppliers and the introduction of a supplier ranking system. Also, in 1998 a major reorganisation occurred. The newer organisational structure contemplated two types of business units: (a) customer-facing business units whose responsibility is to identify and meet customer needs, and (b) operating business units whose responsibility is to deliver sub-systems on time and to cost and specification. It was expected that this flatter structure would enable clear accountability of the business units (Rolls-Royce Annual Report 1998).

This intense and profound restructuring entailed job-cutting policies throughout the 1990s. As shown in Table 4, the average number of Rolls-Royce's employees has steadily declined throughout the decade. In ten years there was a net reduction of about 20,000 employees, accounting for about a third of the work force in 1990. The table also breaks down the average number of Rolls-Royce's employees according to their geographical location and area of business. The net reduction of personnel has come entirely from the UK. After being reduced nearly by half in the mid-1990s, the overseas' workforce showed an increase towards the end of the decade, particularly in 2000 due to the acquisition of Rolls-Royce Deutschland. Layoffs have also been a result of cuts in the defence budget. As Sir Ralph Robbins, Rolls-Royce Chief Executive throughout the 1990s, stated: "We're downsizing to meet a much smaller military business and have taken out a tremendous number of people" (quoted in Verchère 1992, 34).

Table 4. Rolls-Royce Group Employees, by Geographic Location and Industrial Activity, 1990-2001
(calculated as average weekly number of employees in thousands)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Total	65.9	61.4	55.0	49.2	43.5	43.2	42.6	42.6	42.0	40.9	46.6	43.3
UK	54.9	50.7	46.0	41.4	36.8	33.3	31.5	31.6	31.4	30.0	30.2	27.3
Overseas	11.0	10.7	9.0	7.8	6.7	9.9	11.1	11.0	10.6	10.9	16.4	16.0
% UK	83.3	82.6	83.6	84.1	84.6	77.1	73.9	74.2	74.8	73.3	64.8	63.0
Aerospace	36.5	33.8	30.7	27.9	24.5	25.5	25.1	26.9	29.3	30.4	33.8	31.5
Other*	29.4	27.6	24.3	21.3	19.0	17.7	17.5	15.7	12.7	10.5	12.8	11.8
% Aerospace	55.4	55.0	55.8	56.7	56.3	59.0	58.9	63.1	69.8	74.3	72.5	72.7

** includes primarily energy and marine businesses and secondarily financial services*

Note: The annual reports do not provide data on employees by industrial activity prior to 1990. In 1987 Rolls-Royce employed on average 42,000 people, of whom 92.6% worked in the UK; in 1988 40,900 (92.4%); in 1989, 55,475 (85.6%).

Source: Rolls-Royce Annual Reports, 1990-2001

Diversification strategy: aerospace, industrial power and service-based competition

When Rolls-Royce was privatised in 1987, most of the companies sales came from its military and civil aerospace business, but it also had about 175 industrial customers that were using its gas turbine engines for power generation, gas and oil pipeline pumping and other industrial uses. In addition, 25 nations used its gas turbines to power some of their naval vessels (Pugh 2001, 323). At the beginning of the 1990s, Rolls-Royce was organised around two main divisions, aerospace and industrial power. In 1990, aerospace employed 55.4 percent of the company's personnel (Table 4) but generated 63.8 percent of its revenues (Table 5). During the first half of the 1990s 61 percent of revenues, but a much lower percentage of operating profits, came from aerospace, reflecting the stagnation in aircraft engine markets (see Table 5). During the second half of the 1990s about 73 percent of revenues, and even a higher proportion of operating profits came from aerospace. The proportion of revenues from aerospace was still higher on average in 2000-2001, while the proportion of operating profits from aerospace in each of these years was affected by the changes in operating profits from other segments (from a loss of £174m in 2000 to a gain of £200m in 2001) rather than the profitability of aerospace per se (Table 5).

Table 5. Rolls-Royce Revenues and Operating Profits by Business Segment, 1988-2001

£ millions

	Revenues			Operating Profits			
	Aerospace	Industrial power & other	Percent aerospace	Aerospace	Industrial power & other	Percent aerospace	% Profits/ % Revenues ratio*
1988	1682	291	85.3	302	31	90.7	1.06
1989	2054	908	69.3	301	82	78.6	1.13
1990	2340	1330	63.8	74	99	42.8	0.67
1991	2033	1482	57.8	-6	73	-9.0	-0.15
1992	2143	1419	60.2	-200	54	-137.0	-2.28
1993	2139	1379	60.8	20	68	22.7	0.37
1994	1962	1201	62.0	34	66	34.0	0.55
1995	2390	1207	66.4	35	52	40.2	0.61
1996	2570	1086	70.3	185	57	76.4	1.09
1997	3085	1263	71.0	253	36	87.5	1.23
1998	3476	1020	77.3	370	-28	108.2	1.40
1999	3682	952	79.5	413	82	83.4	1.05
2000	4553	1311	77.6	463	-174	160.2	2.06
2001	4843	945	83.7	522	200	72.3	0.86

** Ratio for aerospace; when greater than one aerospace contributes to Group operating profits in greater proportion to its contribution to Group revenues.*
Sources: Rolls-Royce Annual Reports, 1988-2001

The aerospace division included civil and military engine production. The company was involved in R&D, design, manufacturing, and maintenance of engines. The consolidation of maintenance operations started in 1991 and culminated with the creation of a new company Rolls-Royce Aero Engine Services Limited in 1993, dedicated to engine overhaul and repair (Rolls-Royce Annual Reports 1991-1993). The industrial power division included all the non-aerospace activities, ranging from electrical power generation, transmission and distribution, to nuclear engineering, and from industrial and marine gas turbine, to dock, harbour, and marine equipment. Most of the activities of the industrial power group were managed by North Engineering Industries (NEI) acquired by Rolls-Royce in 1989.

In the mid-1990s, the company focused its group strategy on exiting from any activities that were not directly related to gas turbine technology. This focus had two main effects. The first was the disposal of a number of businesses within the Industrial Power division, such as material handling, steam power generation and power transmission and distribution deemed no longer core. As a result, the Industrial Power division became much smaller and its employment in 2000 was 44 percent of its level in 1990.

The second effect was the strengthening of the Aerospace division, particularly in the small and medium engine market segments, through joint ventures and acquisitions. In 1990 a joint venture labelled Rolls-Royce-BMW – 51 percent owned by BMW and 49 percent by Rolls-Royce – was formed to develop an engine for the corporate and regional market. In 1999 BMW's stake was acquired and the company was renamed Rolls-Royce Deutschland. The US-based aircraft engine manufacturer, Allison Engines, was acquired in 1995 from General Motors. This acquisition provided the UK-based company with long-sought manufacturing presence in the United States and filled gaps in its product line in turboprops, small turbofans and turboshaft engines. In 1997, Rolls-Royce acquired Lucas Western Geared Systems and merged it into Allison. Lucas Western Geared Systems, based in the United States, designs and manufactures accessory and high-power gear systems for turboprops and turboshafts. As part of this strategic refocus around gas turbine technologies, Rolls-Royce outsourced systems and computing activity to Electronic Data Systems in 1994.

The segmental analysis as reported in more recent annual reports is based on five main businesses, namely civil aerospace, defence, marine systems, energy, and financial services. Civil aerospace is by far the largest and in 2001 accounted for 54 percent of the company's revenues and 57 percent of its operating profits. Four business areas, civil aerospace, defence, energy and marine system, are technologically related, while financial services engages primarily in the leasing of Rolls-Royce equipment to customers. Rolls-Royce seeks to exploit this relatedness through the re-use of gas turbine technologies for different applications. In 1999 Rolls-Royce acquired Vickers plc, a company that operates in the marine propulsion systems. This acquisition has strengthened the marine systems business. Energy business is also technologically related. With the disposal of steam power and power distribution and transmission companies, the main intent of this division is to exploit gas turbine technologies for industrial applications.

Competing in the service-based economy

Shrinking margins, high development costs, and long time periods to recoup initial financial investments prompted engine makers to explore new ways of pricing engines that would better reflect engine life cycle costs and stabilise their revenue streams. A leasing agreement, where manufacturers lease their engines instead of selling them, represents an option. Rolls-Royce in the 1970s had already invented the 'power-by-the-hour' agreement for operators of corporate jets. According to this agreement, the customer airline pays a fixed rate that includes both capital and operating costs. This agreement provides an incentive to the manufacturer to improve engine reliability and reduce maintenance costs because it manages the entire engine life cycle. The aim of engine manufacturers is to provide an integrated system solution. Airlines benefit too, since with improved engine reliability they have less down time. This results in a radical change in the engine business. Although engine manufacturers already offer cost-per-hour maintenance agreements, in these deals purchase and maintenance are separate. The current acquisition race for maintenance companies (see Table 2) can be read therefore in the context of the change in the strategic behaviour of engine manufacturers. In order to offer power-by-the-hour agreements, engine manufacturers need a sufficiently large number of ground maintenance facilities spread around the world. They can obtain these capabilities either through acquisitions or through agreements with existing independent maintenance companies.

To operate in such a changing business environment, in the late 1990s Rolls-Royce put particular and increasing emphasis on the aero repair and overhaul business and the development of service capabilities. Rolls-Royce acquired National Airmotive Corporation Inc., then renamed Rolls-Royce Engine Services – Oakland. It also formed joint ventures with a number of partners operating in different service-based industries. Rolls-Royce joined airlines (such as American Airlines, Singapore Airlines, SR Technics part of Swissair) to service Rolls-Royce engines. In 2001 40 percent of Rolls-Royce's sales came from service and aftermarket activities (Rolls-Royce Annual Report 2001, 7). Rolls-Royce owns, either in whole or in part, 15 aircraft engine maintenance facilities world-wide that service more than 50 engine types for about 400 operators.[25]

The entry into services has become central to the development of new organisational as well as technological capabilities. Information related to engine behaviour has become extremely valuable and a real time engine monitoring system, based on service facilities, is the tool to garner it. Digital engine control systems equipped with engine health diagnostics have become necessary for engine manufacturers wanting to offer power-by-the-hour agreements. The Rolls-Royce Trent 500 engine is equipped with a health monitoring system (based on artificial intelligence technology). This system developed in collaboration with Oxford University provides real time information for engine management and maintenance planning that therefore affects the operation of the engines.

Rolls-Royce formed Data Systems & Solutions, a joint venture with an information technology service provider, Science Applications International Corporation, to offer integrated asset management and maintenance solutions to customers in aerospace, defence, marine, and energy markets. Products offered by Data Systems & Solutions include e-business solutions for predictive maintenance and data management. For example, *enginedatacentre.com* supplies service data to customers, *aeromanager.com* provides facilities for fleet management, and *powerplantmanager.com* provides information power generation facilities. As the company puts it, "By predicting the behaviour of components in service, we can minimise interruption to operations and maximise the availability of the asset to the customers" (Rolls-Royce Annual Report 2000, 14). This move downstream has enabled Rolls-Royce to offer and/or lease package solutions, also labelled *Total Care*, that include product and maintenance service throughout engine's life.

During the 1990s, therefore, competition in the aircraft engine sector became service-based. While, as far back as the 1970s, Rolls-Royce pioneered service-based packages to sell solutions (engines plus service) to airlines (e.g. power-by-the-hour agreements), the company lags behind General Electric, which has particularly leveraged the resources of its powerful financial arm, GE Capital, in the provision of engine service.

[25] 'Rolls-Royce Leads Industry Consolidation', *Helicopter News*, 25, 21, November 5 1999.

The continuity of the engineering tradition and culture: R&D and training

Not surprisingly, investments in new technology plays a critical role at Rolls-Royce. The absolute amount of investment in R&D increased constantly increasing over the 1990s, with net R&D as a percent of sales in the 6-7% range (see Table 3). Over the past few years, the emphasis has been on the generation of technologies that can be exploited across the company's different businesses. Technologies originally developed for aerospace applications are being exploited for energy applications and more recently in the marine business (in particular, computational fluid dynamics tools are being applied to marine propulsion design). New technologies are being researched to reduce the adverse environmental impacts (in terms noise and emissions) of products. As discussed earlier, new technologies are also being used to support the more recent move towards the provision of customer support and service.

Notwithstanding organisational restructuring entailing huge layoffs during the last decade, Rolls-Royce has recognised the importance of a committed and trained labour force. For example, the 1996 Annual Report contains the following statement: "Delivering excellence in products and services, to meet a growing range of needs in more market, places heavy demands on all our people. Ultimately, our competitive edge lies not in hardware but in the quality of our people" (Rolls-Royce Annual Report 1996, 17). Or as the 2000 Annual Report put it more concretely: "Rolls-Royce is fortunate to have extremely talented and dedicated employees. In the UK, the average length of service is approaching 20 years. This is important in an industry where development and production programmes may have lives of more than 50 years and in which the customer relationship with an individual product may be 25 years or more" (Rolls-Royce Annual Report 2000, 16).

Rolls-Royce invested £27 million in training in 2000 and £26 million in 2001 (Rolls-Royce Annual Report 2001, 19). Training schemes have been introduced at the shop floor level as well as at the managerial level, and include company-wide workshops on quality improvement and business awareness. Rolls-Royce has also recruited trainees throughout the decade. The aerospace group resumed trainee recruitment in 1994, employing 112 new people, while the industrial power group recruited 120 trainees during the same year. In 1997, the company recruited 480 trainees, of which 246 were university graduates, while in 2001 it recruited 176 graduate trainees and 73 modern apprentices (Rolls-Royce Annual Reports 1994, 1997, 2001, 28).

Besides internal management development programmes, beginning in 1996 Rolls-Royce launched the collaborative programmes with London Business School, the Open University, and the Kelly Business School of Indiana University. In 1999 Rolls-Royce opened two Learning and Development Centres, one in Britain and the other in the United States.

Research collaboration and University Technology Centres

Rolls-Royce has been funding university research since the mid-1960s in such fields as combustion aerodynamics, vibration, heat transfer and cooling. In the 1970s Rolls-Royce began funding university research in the areas of compressor, turbine aerodynamics, aerothermal systems, and system mechanics, while it launched such funding for computational fluid dynamics in 1985 and combustion processes in 1989. Since 1990, Rolls-Royce has institutionalised research collaboration with UK-based universities through the creation of University Technology Centres (see Table 6).

University Technology Centres (UTCs) are "long term, research-based partnerships with selected departments in UK universities" (Kelly 2000). They are part of the Advanced Engineering External Research Strategy whose aim is to augment Rolls-Royce's capability acquisition process. Each UTC supports a well-defined research field in one of more of Rolls-Royce's core competencies. More recently, Rolls-Royce has extended the UTC principles to create University Technology Partnerships that include both academic and industrial partners. In 1998 Rolls-Royce in collaboration with BAE Systems set up a University Technology Partnership with three universities on different aspects of design. The current objective is to extend academic links to the other countries where Rolls-Royce divisions operate (i.e., Germany, United States, and Spain). Rolls-Royce provides the core funding for the UTC for the initial five years. As stated in the 2000 Annual Report, "Working with these universities is an efficient way to progress our own research and development requirement. They also provide the opportunity to identify top quality recruits." (Rolls-Royce Annual Report 2000, 16).

Table 6. Rolls-Royce University Technology Centres

Launch date	Research and technology field	Host university
January 1990	Solid mechanics	Oxford
October 1990	Vibration	Imperial College
March 1991	Combustion aerodynamics	Loughborough
April 1991	Turbomachinery and powerplant aerodynamics	Cambridge
July 1991	Combustion processes	Cranfield
October 1991	Titanium-based materials	Birmingham and Swansea
July 1992	Computational fluid-dynamics	Oxford
October 1992	Heat transfer and aerodynamics	Oxford
October 1993	Control systems engineering	Sheffield
October 1993	Systems and software engineering	York
April 1994	Nickel-based materials	Cambridge
October 1994	Aerothermal systems	Sussex
January 1997	Power engineering	Strathclyde
April 1997	Mechanical transmission systems	Nottingham
January 1998	Performance engineering	Cranfield
October 1998	Material damping technology	Sheffield
October 1998	Design (Human factor)*	Sheffield
October 1998	Design (Knowledge management)*	Cambridge
October 1998	Design (Optimisation)*	Southampton
October 1999	Gas turbine noise	Southampton
October 1999	Manufacturing technology	Nottingham

*part of BAE Systems – Rolls-Royce University Technology Partnership

Source: Kelly, 2000

5. Corporate strategy and financial markets

As a nationalised company, Rolls-Royce prepared a corporate strategic plan for government approval every year, and relied on corporate revenues, short-term and long-term borrowing, and government support in the form of defence contracts and "launch aid" (in effect interest-free loans from the government) to maintain its organisation and fund expansion. With the privatisation of the company in May 1987, Rolls-Royce still had access to these sources of funds, although launch aid would only be forthcoming if other sources were unavailable. The main difference was that, as a publicly traded company, the management of Rolls-Royce was now accountable to the corporation's public shareholders, the vast majority of whom had a purely financial interest in the company.

According to Verchère (1992), after privatisation senior managers felt more under public scrutiny by the investment community and private shareholders. As a Rolls-Royce senior manager stated: "We're becoming much more of a financial and accountability culture than before" (quoted in Verchère 1992, 34). From the beginning of the 1990s Rolls-Royce engaged in "a three-tier planning discipline comprising a 10-year review of market trends backed by five-year financial and strategic plans" (Verchère 1992, 34). The third tier was a two-year operating plan and budget that is, in turn, informed by quarterly and four-week financial budgets that, according to Verchère (1992, 34) have had "the net effect of tightening financial controls at all levels, including the shop floor".

The expressed concern, or lack thereof, of Rolls-Royce's management with catering to the interests of shareholders can be detected by surveying the company's Annual Reports. Of particular importance are the corporate profiles that appear on the first page of each report and the Chairman's annual statements. It was not until the 1992 report, published almost five years after the privatisation, that we find the first mention of "shareholders" in the Chairman's annual statement. In explaining the need to reduce the workforce as part the company's restructuring programme, the Chairman affirmed: "our prime responsibility is to secure the long-term future of the business for our continuing employees, shareholders, and customers" (Rolls-Royce Annual Report 1992, 3). In 1995, the corporate profile states that the company's "strategic intent" is "[t]o be a world leading power systems business, meeting the needs of our customers, shareholders and employees for the next century" (Rolls-Royce Annual Report 1995, 1).

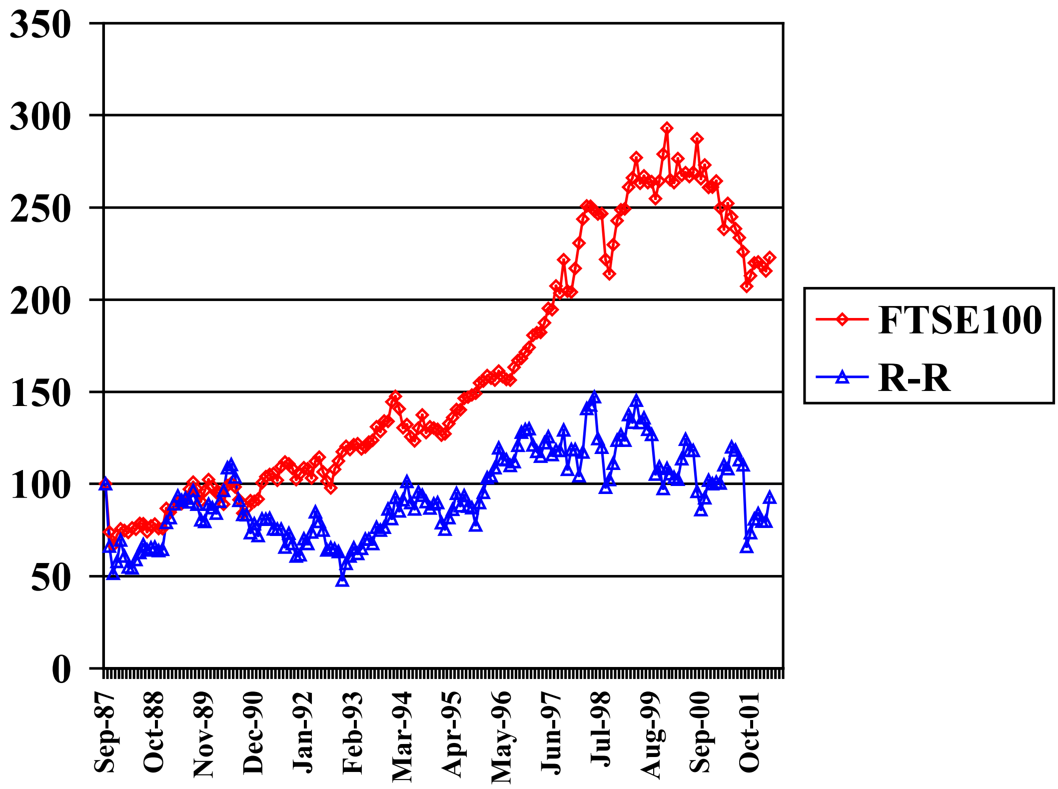
From 1996 – a year in which Rolls-Royce's stock performed particularly well on its own terms and relative to the FTSE100 – the annual reports include a section with the heading "shareholder value" that summarises the performance of the company's stock over the past year (Rolls-Royce Annual Report 1996, 16). Between 1997 and 1999, shareholder value took centre stage in Rolls-Royce's mission statements. The 1997 corporate profile read: "Our objective is to deliver shareholder value through a strategy of continuously improving our performance, investing to secure leading positions in growth markets and becoming the most efficient suppliers in the industry" (Rolls-Royce Annual Report 1997, 1), and similar statements appeared in the corporate profiles of the 1998 and 1999 Reports. Under the heading, "People: Investing for the Future," the 1997 Report stated: "We are changing processes and improving skills to create shareholder value" (Rolls-Royce Annual Report 1997, 10). The Chairman's statement concluded: "We are confident that our continued investment in new products and capability will create enhanced value for shareholders" (Rolls-Royce Annual Report 1997, 3). The 1998 Chairman's statement, entitled "*Delivering Value"*, announced that "Rolls-Royce is committed to delivering shareholder value. In 1998 the company demonstrated its ability to create value in the short term while investing for the long term" (Rolls-Royce Annual Report 1998, 3). In 1999, the Chairman stated that "[t]he company made continued progress with its consistent, long-term strategy of building shareholder value by increasing its share of clearly defined growth markets, both through organic growth and acquisitions." (Rolls-Royce Annual Report 1999, 3).

The year 2000 marked a change in the company's corporate profile. Shareholder value was no longer mentioned, while customer requirements, manufacturing and servicing facilities, and exceptional people were highlighted as the keys to a successful company (Rolls-Royce Annual Report 2000, 1). In 2001 the profile stressed that "Rolls-Royce is a global company providing power for land, sea, and air . . . employing over 43,000 people and operating from more than 30 companies (Rolls-Royce Annual Report 2001, 1). In the Chairman's statement for 2001, there is no mention of shareholder value, although the statement ends by noting that the level of dividends for the year represents a 23 percent increase on the previous year (Rolls-Royce Annual Report 2001, 3).

One can surmise that Rolls-Royce turned to the rhetoric of "shareholder value" in the late 1990s in an attempt to convince the stock market to boost the value of the company's shares in keeping with the general boom in the stock market. If so, the company failed in this endeavour; between January 1997 and January 2000, stock prices in the FTSE100 rose by 47 percent, while Rolls-Royce's stock price fell by 13 percent (see Figure 3). As of March 1, 2002, the FTSE100 was up 23 percent and Rolls-Royce stock was down 23 percent compared with their levels on January 1, 1997.

Figure 3: Rolls-Royce Stock-Price Performance Compared With FTSE100 September 1987-May 2002

(closing prices on first day of each month)
September 1, 1987 =100



Source: Yahoo Finance

Managerial rhetoric of shareholder value, therefore, tells us little if anything about resource allocation or performance. Rather, to assess the influence of the change in governance regime on Rolls-Royce, we need to analyze how a concern with the price of its stock actually affected managerial decision-making at the company and the impacts on the generation and distribution of revenues. It may be that, as a publicly traded company, Rolls-Royce's management was more attuned to costs than had been the case when it had been under government ownership, although as we have seen the company dramatically reduced the size of its workforce when faced with losses in the early 1980s. But in and of itself cost-cutting cannot account for Rolls-Royce's performance as a privatised company. As we have already indicated in previous sections of this paper, since privatisation, Rolls-Royce has made a number of strategic investments that have enabled it to enhance its position among the Big Three turbofan producers. What roles, if any, did the stock market play in either supporting or discouraging these strategic investments?

In work that stems from the larger project on Corporate Governance, Innovation, and Economic Performance (see www.insead.edu/cgep) of which this paper is a part, Lazonick and O'Sullivan (2002) provide a framework for analysing the four functions that the stock market can perform in the industrial corporation. Firstly, it can structure the relation between owners and managers in exercising strategic *control* over corporate allocation decisions. Secondly, it can provide the corporation with *cash* that can be used to restructure the corporate balance sheet, fund operations (including R&D), invest in plant and equipment, or acquire existing physical and intangible assets. Thirdly, it can provide the corporation with its own *combination* currency that can be used instead of or in addition to cash in mergers and acquisitions. Fourthly, it can provide the corporation with its own *compensation* currency that it can use, instead of or in addition to cash, to reward employees and other stakeholders.[26] As we shall see in the following account of the relation between Rolls-Royce's corporate strategy and financial markets, the stock market has played all four roles at Rolls-Royce during the past fifteen years.

5.1. Ownership and control

The privatisation of the company in 1987 transferred ownership of the Rolls-Royce's shares from the British government to institutional investors and households. Table 7 shows the size distribution of holdings of ordinary shares at December 31, 1988 and December 31, 2001.

Table 7. Size Distribution of Ordinary Shares
December 31, 1988 and December 31, 2001

	December 31, 1988			December 31, 2001		
Size of holding	Number of holders	% of total holdings	% of total shares	Number Of holders	% of total holdings	% of total shares
1-150	612,545	72.32	11.43	120,611	37.93	0.96
151-1,000	210,226	24.82	8.28	203,960	61.44	7.63
1,001-10,000	22,491	2.66	6.88	1,400	0.43	2.43
100,0001-1,000,000	1,099	0.13	5.00	482	0.15	10.35
1,000,001 and over	474	0.06	20.34	160	0.05	78.63
TOTAL	846,835	100.00	100.00	326,623	100.00	100.00

Sources: Rolls-Royce Annual Report 1988, 34; Rolls-Royce Annual Report 2001, 72.

As can be seen from Table 7, from 1988 to 2001 the number of shareholders in all size categories declined, while the concentration of shareholdings among the largest shareholders – all institutional investors – increased dramatically. Whereas in 1988, 474 holders of more than one million shares had 20 percent of Rolls-Royce's shares, in 2001 160 of the largest shareholders had 79 percent of the shares. As of March 6, 2002 the largest shareholder was,

[26] For other applications of this framework, see Carpenter, Lazonick, and O'Sullivan (2002); Larrue, Lazonick, and O'Sullivan (2002).

with holdings of 12.08 percent of the outstanding ordinary shares, Franklin Resources, Inc., a major US-based institutional investor that manages the Franklin-Templeton investment funds.[27] The second largest shareholder was BMW AG with holdings of 9.89 percent. The German automobile company had acquired these shares as a result of Rolls-Royce's purchase of BMW's stake in a joint aircraft engine venture (see Rolls-Royce Annual Report 2001, 29 and the discussion of stock as a combination currency below).

It is possible (although we do not have direct information on this issue) that, especially given Rolls-Royce's underperforming stock price, the growth and concentration of institutional shareholdings has put pressure on the company to increase its dividend rate. As Table 8 shows, after continuously raising the dividend per share during the prosperous years from 1987 to 1990, Rolls-Royce cut its dividend dramatically in the tight years of the early 1990s, holding the rate at 5.00p per share from 1992 through 1995. Since then, the company has once again raised the dividend rate in every year, with the rate equalling its previous peak of 7.25p in 1999 and rising to a record 8.18p in 2001. As Table 8 also indicates, these increases in the dividend rate have been paid out of higher levels of earnings per share. Nevertheless, for the period 1997-2001, the dividend yield was both lower than the previous period of high dividend rates in 1987-1991 and was overwhelmed by the negative stock-price yield. As a City financial analyst observed in 1999: "My British hat says Rolls-Royce is a tremendous achievement. My analyst's hat says it's a terrible investment" (Skapinker 1999, 19).

Table 8. Dividend Per Share, Dividend Yield and Stock-Price Yield, 1987-2001

Year	Dividend/share (pence)	Earnings/share* (pence)	Dividend yield (percent)	Stock-price yield (percent)	Total yield (percent)
1987	5.25	19.10	3.84	-42.09	-38.25
1988	6.30	21.72	4.22	13.64	17.86
1989	7.00	21.75	3.36	10.15	13.51
1990	7.25	19.15	3.35	-17.32	-13.96
1991	7.25	8.32	4.20	-2.37	1.83
1992	5.00	6.40	3.10	-13.50	-10.40
1993	5.00	5.90	2.94	52.29	55.24
1994	5.00	6.56	2.31	-14.83	-12.52
1995	5.00	7.94	2.43	31.08	33.52
1996	5.30	12.70	1.92	17.07	18.99
1997	5.90	15.16	2.08	-13.75	-11.67
1998	6.55	16.91	2.22	18.36	20.62
1999	7.25	19.52	2.46	4.73	-12.27
2000	8.00	19.38	3.20	-4.30	-1.10
2001	8.18	20.20	3.48	-20.97	-17.49
Average 1987-2001	6.33	14.71	2.97	1.87	4.84
Average 1987-1991	6.82	18.01	3.79	-2.29	1.50
Average 1992-1996	5.06	7.96	2.54	14.42	16.97
Average 1997-2001	7.18	18.23	2.70	-7.08	-4.38

** net basis, before exceptional and non-operating items*
Sources: Rolls-Royce Annual Reports, 1988-2001.

[27] For example, as of February, 2002, Templeton Growth Fund held 53.0 million Rolls-Royce shares (3.3 percent of Rolls-Royce's outstanding shares), while Templeton Foreign Fund held 44.8 million Rolls-Royce shares (2.8 percent of Rolls-Royce's outstanding shares). (http://pub.franklintempleton.com/public/mutual).

Notwithstanding the growing concentration of shareholding at Rolls-Royce, throughout the period 1987-2001 Rolls-Royce's management was dominated by insiders who -- protected from takeover by the British government's 'golden share' -- remained firmly in control of corporate allocation decisions. The key executive over this period was Sir Ralph Robins. Upon graduating from Imperial College in 1955, Robins, aged 23, had joined the company as an apprentice engineer. He became Managing Director in 1984, Chief Executive in 1991, and Chairman in 1992, a position that he still holds (although he has announced his retirement in 2002 when he turns 70). A 1999 profile of Robins in *The Financial Times* noted that "Sir Ralph . . . has been in charge throughout the glory years." The article went on to say that, while the City remains unimpressed with Rolls-Royce's stock market performance, "no one in the City has a bad word to say about the slim, pinstriped, impeccably courteous Sir Ralph." The profile went on to quote one unnamed City analyst who remarked: "He's everybody's favourite uncle. But his priority is to maintain Rolls as an independent British company. Shareholder value is secondary to him" (Skapinker 1999, 19). Or more recently, as stated in a newspaper report in March 2002 that followed Robins announcement of his retirement: "Sir Ralph Robins, chairman of Rolls-Royce, is no great fan of the City and it of him by the look of the 7 per cent surge in the Rolls-Royce share price that greeted news of his retirement."[28]

Like Robins, most of the other top executives at Rolls-Royce in the fifteen years after privatisation had built their careers with the company. As of December 31, 2001, the other seven executive directors besides Robins on the Rolls-Royce Board of Directors (which also included five non-executive directors) included:

a) John Rose, Chief Executive since 1996, a non-engineer who joined the company in 1984 at the age of 32, was appointed to the Board in 1994, and was Managing Director – Aerospace Division in 1995-96;
b) John Cheffins, Chief Operating Officer since 2001 and President – Civil Aerospace since 1998, an engineer who joined the company in 1967 at the age of 20 and became President and CEO of Rolls-Royce Industries Canada in 1991 and Director – Civil Engine Business in 1993;
c) Colin Green, President – Defence Aerospace since 2001, an engineer who joined the company in 1968 at the age of 20, has held a number of executive positions since 1989, and was appointed to the Board in 1996;
d) James Guyette, President and CEO of Rolls-Royce North America since 1997 and a Board member since 1998, an engineer who was an executive at United Airlines in 1994 when he was 46 years old;
e) Paul Heiden, Finance Director since 1999, a non-engineer who in 1992 at the age of 36 came from Hanson plc to Rolls-Royce as Finance Director – Aerospace Group and was appointed Director – Industries Businesses and Board member in 1997;
f) Michael Howse, Director – Engineering and Technology and Board member since 2001, an engineer who joined the company in 1969 at the age of 26, and has been, among other executive positions, Chief Development Engineer RB211 Development, Head of the Advanced Engineering – Aerospace Group, and Director Engineering and Technology – Civil Aerospace;
and

[28] "Outlook: Prickly Sir Ralph Deserves His Place in History," *The Independent*, March 8, 2002, 23.

g) Richard Turner, Group Marketing Director since 1991 and Board member since 1992, a non-engineer who originally joined Rolls-Royce in 1965 at the age of 23.

It should be noted that in October 2001 the person who Michael Howse replaced as Director – Engineering and Technology was Philip Ruffles, an engineer who had joined the company in 1961 at the age of 23. In addition, Ruffles' predecessor as Director – Engineering and Technology was Stewart Miller, an engineer who had joined Rolls-Royce in 1954 at the age of 21 and had been appointed to the Board in 1984 before retiring after 41 years of service in 1996. Counting Robins and Ruffles, of the nine executive directors who were with the company in 2001, six had joined the company in 1969 or before at an average age of 22.5 years and had on average 37 years of service with the company. Five of these six were engineers. Rose and Heiden, who joined Rolls-Royce in their 30s, both had finance backgrounds, while Guyette joined the company from the United States subsequent to the Allison acquisition.

These executives, who effectively control Rolls-Royce's resource allocation decisions, are managers, not owners. As of December 31, 2001, the 13 Directors of the company together held .044 percent of Rolls-Royce's outstanding shares, while the largest shareholder among them, Chief Executive John Rose, held .010 percent.

5.2. Stock as a source of cash

The higher dividend rates that Rolls-Royce has paid since the mid-1990s have, all other things equal, reduced the amount of internally generated revenues that Rolls-Royce has been able to allocate to the accumulation and development of the company's productive capabilities, and thus, potentially makes the company more dependent on external financial markets, including the stock market, as sources of funds. To what extent, for what purposes, and under what conditions did Rolls-Royce rely on the stock market as a source of cash in the period 1987-2001?

Table 9 shows key data on the sources and uses of funds at Roll-Royce since privatisation. Over the period 1987-2001, in most years the company sold relatively small amounts of shares (categorised as SSO in Table 9) ranging in total value from £1m to £18m to employees who were exercising their stock options (a subject to which we return below). In addition, in three years, 1987, 1993 and 1995, Rolls-Royce did large public share issues (categorised as PSI in Table 9). The identification the circumstances under which each of these public share issues took place and how they were carried out provides insights into the relation of Rolls-Royce to the stock market at those points in time when it relied on the market as a source of cash.

1987 stock issue: Financial terms of the Rolls-Royce privatisation

Through the privatisation, the government raised £1.3b from the sale of the already existing shares that it owned. At the same time the government issued for the benefit of Rolls-Royce additional new shares, worth £283m that, after expenses, injected £274m into the company. In addition, the government paid off all of Rolls-Royce's outstanding debt in the amount of £233m, of which £70m was long-term and £163m short-term.[29] In 1987 Rolls-Royce also established a £250m line of credit known as the Multi-Option Facility.

[29] 'The expletives that Rolls-Royce deleted,' *Economist*, 04/11/87, 67.

Table 9. Rolls-Royce plc, Sources and uses of funds, 1987-2001 (selected items)

£ millions

SOURCES	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987
FFO	418	479	392	395	311	182	193	41	37	124	100	254	278	217	191
DEP	198	238	110	113	92	103	116	109	105	104	64	69	55	43	41
LTB	69	510	734	177	2	69	4	0	208	181	335	161	162	155	9
ΔLTD	56	-223	530	162	-5	59	-150	-76	48	3	174	-1	-38	146	-70
ΔSTD	39	-146	91	-19	65	0	17	6	-29	214	57	48	-62	-2	-163
SS0	16	10	4	14	4	18	15	4	8	0	4	1	0	0	0
PSI	0	0	0	0	0	0	332		317	0	0	0	0	0	274
DFA	168	46	187	213	89	52	153	40	38	12	15	19	8	4	2
USES															
CPX	211	292	381	387	222	142	94	105	130	126	119	112	113	65	82
AOA	1	45	653	0	9	3	217	0	0	0	0	0	0	0	0
RLTD	13	733	204	15	7	10	154	76	160	178	161	162	200	9	79
CDS	84	74	88	65	78	69	57	51	44	64	45	69	55	45	14
COMPARE															
Net R&D*	***358***	***371***	***337***	***310***	***268***	***217***	***206***	***218***	***253***	***229***	***216***	***237***	***161***	***149***	***187***

FFO = Funds from operations; DEP = Depreciation; LTB = Long-term borrowing;
ΔLTD = Change in long-term debt (=LTB-RLTD); ΔSTD=Change in short-term debt;
SS0 = Sale of ordinary shares to employees exercising options;
PSI = issue of ordinary shares to the public (net of expenses);
DFA = Disposal fixed assets; CPX - Capital expenditures; AOA = Acquisition of assets;
RLTD = Reduction of long-term debt; CDS = Cash dividends

** As an operations expense, the cost of net R&D is covered by revenues that are deducted in arriving at the "funds from operations" figure, and is not an item in the cash floe (i.e., "sources and uses of funds") accounts. Given its importance to the company, however, the net R&D figures are included in Table 9 so that they can be compared with the cash flow items that are in the sources and uses accounts.*
NA = not available
Sources: Rolls-Royce Annual Reports, 1988-2001.

Starting from this favourable financial position at the time of privatisation, Rolls-Royce made substantial profits from 1987 through 1990. As a result as, can be seen in Table 9, from 1987 through 1990, the company's funds from operations totalled £732m, almost double its total capital expenditures of £372m. Internal funds also covered the company's expenditures on net R&D (already deducted from cash flow in deriving the funds from operations figures), which totalled £734m during the years 1987-1990.

1993 stock issue: External finance for rationalisation and development

After the boom years of the late 1980s, a slowdown hit both the military and civil segments of the aerospace industry. After suffering an operating loss of £172 in 1992, Rolls-Royce found itself facing the high costs of both sustaining the development of the high-thrust widebody Trent and rationalising its existing activities. The first Trent 700 engines for the Airbus 330 were to be delivered in the winter of 1994, and the higher-thrust Trent 800 that was being developed for the Boeing 777 would be tested in September 1993.[30] The

[30] 'Rolls-Royce plc Interim Results 1993,' *PR Newswire European*, September 2, 1993.

rationalisation programme, which was announced in March 1993, entailed the closing of six of twelve of the company's main manufacturing sites and layoffs of 2900 people, a six-percent workforce reduction (Tieman 1993).

The company had taken on considerable debt in the lean years of the early 1990s (see Table 9). But the company still needed to raise funds from the markets. According to the report in *Extel Examiner*, "[Sir Ralph] Robins [the Chairman of Rolls-Royce] said that it was expected that the rationalisation programme alone will result in a cash outflow of £130 million over this year and next. Against this background Robins said the board had decided to increase the equity base thereby restoring it to a level which, in its opinion, is more appropriate to the sales and activity of the Group."[31] Instead of taking on more debt, in September 1993 Rolls-Royce announced a rights issue which would raise £307m net of expenses. One new share would be offered to the company's existing shareholders for each four shares that they currently held. A Rolls-Royce press release explained why the company was going to shareholders for more equity capital:

> In July this year the financial resources of the Group were strengthened by a successful $300 million bond issue. However the Board of Rolls-Royce does not wish to place undue reliance on bank and other forms of debt financing. The Board believes it appropriate to finance the Group's long term activities predominantly through equity capital rather than debt. This approach was adopted in the Group's capital structure at the time of privatisation in 1987 when the Group came to the stock market with no net debt. The requirement for a rights issue should be seen in the context of turnover which has risen from £1973 million in 1988, when shareholders' funds were £949 million, to £3562 million in 1992 on a similar equity base.[32]

The Rolls-Royce rights issue was not unusual; it was one of 129 cash calls in the UK that raised a record £9.6b for hard-hit British companies in first three-quarters of 1993 (Pretzlik 1993, 28). According to one reporter, "recession has burnt into the souls of directors that they must not take risks with debt" (McCrone 1993), while another press report spoke of "rights fears" adding to the lacklustre performance of industrial stocks (Pain 1993a, 29). Rolls-Royce had seen its market share of civil aircraft engines rise from 22 percent in 1992 to 28 percent in the first half of 1993 – placing it just ahead of Pratt & Whitney, and even with General Electric – but market conditions, intense competition, and the imperative to sustain R&D raised concerns among shareholders about when they would see a resurgence of Rolls-Royce's share price to its post-privatisation levels (Tieman 1993).[33] *The Times* editorial on the rights-issue announcement observed that "Rolls-Royce asks a great deal from its shareholders," and went on to sum up the future they apparently faced:

> Having cut the dividend in March, it is now demanding £307m in fresh equity to fund the continuing development of its Trent engines. Furthermore, although the shares have performed strongly since the dividend cut, they are, at 152-1/2p, still a third below their peak of 229p, in 1990.
>
> Investors could justifiably ask when they will see the rewards for such suffering. Certainly not in the near future. The collapse in the military order book means that

[31] 'Royce-Royce 1 – Right Issue Offsets Rationalisation Costs,' *Extel Examiner*, September 2, 1993.
[32] 'Official Correction: Rolls-Royce – Rights Issue,' *Extel Examiner*, September 2, 1993.
[33] 'Extel Financial Exclusive: Rolls-Royce to Fund "R&D at Highest level Ever" – Chairman,' *Extel Examiner*, September 2, 1993.

> profits will be slim for the next two years at least. During that time, cash is likely to continue leaking out of the business, which makes the rights issue so necessary.
>
> The long-term issue is whether Rolls will be able to earn proper profit margins on its new Trent engines. The engine is an attractive product, as Rolls's long order book proves, and the group is also rationalising its cost base. However, the market for civil aero engines is suffering from structural overcapacity, concealed for years by cross-subsidisation from profitable military sales.
>
> For now Rolls is content to chase market share, which has risen six points to 28 per cent in the past year. It argues that an engine sold cheap today will require profitable spares in the future, but the group is cutting such potential profits in its drive towards producing more reliable engines.
>
> Continuing cuts in industry capacity and a recovery in military sales from 1996 should improve Rolls's financial performance in the second half of the decade. Less patient investors should seek out more immediate recovery candidates.[34]

In *The Times* full report on the condition of Rolls-Royce, reporter Ross Tieman (1993) observed that "the last time Rolls-Royce needed more cash to develop a new aero-engine, it went bust. This time it is asking shareholders to contribute." But Tieman continued:

> The need for money is fundamentally different to that which existed 22 years ago, when Edward Heath's government was obliged to bail the company out of its cost over-runs on the development of the RB211 airliner engine. Today, the problem is one of success. But ironically, the RB211 is still at the root of Rolls's financial embarrassment.

The problem, Tieman argued, went beyond the development costs incurred by Rolls-Royce to remain among the Big Three. The very technological superiority of the RB211 undercut future sales of spare parts, and it was in this aftermarket where, over the long run, industry profits were made. As Tieman summed it up:

> It was a rather special engine, the RB211. There were two novel features: a three-shaft design and wide-chord fan blades. Even the designers cannot have realised what a marvellously flexible engineering solution they had devised. The RB211 has proved the most reliable jet engine ever designed. It has also been evolved to produce far higher power output than envisaged. As the power has gone up, so the relative advantages of the three-shaft design have increased.

Ideally, the prices that Rolls-Royce could secure from the airlines in the new engine market would reflect the improvements in reliability that would save on future servicing and replacement costs. But the generally depressed market conditions since 1989 had led airlines to ground older planes with "spares-hungry" engines while creating intense competition among the Big Three for new orders, including engines for the Boeing 777, in a multisourcing world (Tieman 1993). It was under such economic conditions that, in 1993, Rolls-Royce went to its shareholders for cash.

[34] 'Pay now, fly later,' *The Times*, September 3, 1993.

On the announcement of the rights issue, the price of Rolls-Royce shares fell by almost seven percent to 152-1/2p. The rights issue was offered at 130p, a 20.5 percent discount from the market price on the announcement date. Those British shareholders who did not want to take up the rights issue had a window of opportunity to sell the rights to those who did. At the same time, foreign holdings had reached the maximum of 29.5 percent, thus restricting foreign sales (Rudd 1993, 17).[35] In the event, the deep discount on the rights issue meant that 87.2 percent of the 211.6 million new ordinary shares offered were taken up by existing shareholders, with the broker underwriting the rest of the issue and offloading the shares at 145p, mainly to two large institutional investors (Kibazo et al. 1993, 50). In the process, the proportion of shares that were foreign-owned dropped to 25 percent (Pain 1993b, 22).

1995: Acquisition of Allison Engine

In January 1995 Rolls-Royce paid $525m, equivalent to £328m, to acquire Allison Engine Company, a US military engine supplier that had been founded in 1915 and that from 1929 to 1993 had been a subsidiary of General Motors. Rolls-Royce had made a previous bid for Allison in 1993, but GM had sold the company to a management buyout team for $370m.[36] When Rolls-Royce had announced its plan to buy Allison Engine on November 21, 1994, the news was, according to *Investors Chronicle*, "welcomed by the City, with Rolls-Royce's share price moving up 2p to 185p.[37] Financial analysts apparently believed the Allison acquisition would be done in Rolls-Royce shares, whose price had risen substantially over the past year and which were listed on the New York Stock Exchange in the form of American Depository Receipts.[38] Allison's current owners were not, however, interested in accepting Rolls-Royce's shares in payment. To finance the acquisition, therefore, in March 1995 Rolls-Royce did a £331m rights issue (net of expenses) – after having raised £307m from shareholders in a rights issue just 18 months earlier – this time offering one ordinary share at 154p for every 5.4 ordinary shares held on March 16, 1995.

The March 1995 rights issue differed significantly from that of September 1993. Instead of offering new shares directly to existing shareholders, Rolls-Royce, through its sole underwriter N M Rothschild & Sons, offered the 227.3 million shares to City institutional investors at 154p, which was a discount of just over 5 percent on the opening price of 164p – and hence less than one-fourth of the discount that the 1993 rights issue had imposed on the company's shares (Rodgers 1995, 17).

5.3 Stock as an acquisition currency

In late October 1988 Rolls-Royce secretly purchased a 4.7 percent stake in Northern Engineering Industries (NEI), a power station equipment and heavy engineering group based in Newcastle (Garnet 1988, 33). Rolls-Royce then entered into talks with NEI concerning a friendly bid for the company that would total £360 and be paid mainly in cash, to be covered by Rolls-Royce's cash balances and the proceeds from the Eurobond issue.[39]

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[35] Some foreign investors had already been forced to sell their holdings to comply with the limit. Meanwhile Rolls-Royce lodged a request with the government to raise the limit to 49.5 percent.

[36] 'Rolls-Royce Buys Allison Engine.' *European Information Service*, January 5, 1995; 'Clayton, Dubilier & Rice Completes Sale of Allison Engine Company to Rolls-Royce,' *PR Newswire*, March 24, 1995.

[37] 'Popular Shares: R-R ahead of Allison OK,' *Investors Chronicle*, February 10, 1995, 54.

[38] ADRs track a foreign-based company's share-price movements on its home stock market, but obviate the need for US holders of these securities to assume the exchange-rate risk of holding the actual shares.

[39] 'Rolls-Royce Revs Up for £350m Northern Engineering Cash Bid,' *Sunday Telegraph*, November 6, 1988, 32: "A bid by Rolls would be predominately in cash. The group's low stock market rating precludes an

Subsequent merger talks between the two companies appeared to have come to an end in late December (Gibben 1988, 19). When the merger was agreed in April 1989, however, no cash was involved. Between the aborted discussions in December and the merger agreement in April, Rolls-Royce's share price rose from 128p to 185p, an increase of 45 percent, that, compared with the FTSE100, enabled it to outperform the rising stock market by 29 percent.[40] Instead of cash, seven new Rolls-Royce shares were exchanged for every ten NEI shares, thus valuing NEI at £306m.[41] In using its shares for the merger, Rolls-Royce was able to maintain control over its cash flow.

The NEI purchase price represented a 23 percent premium over the price of NEI shares on the date before the disclosure of Rolls-Royce's 4.7 percent holding in NEI. The new shares issued by Rolls-Royce entailed a 16.7 percent increase in its issued ordinary share capital, thus placing a substantial burden on the NEI acquisition to generate sufficient earnings to maintain existing earnings per share. In 1988 NEI had reported pre-tax profits of £38.5, equivalent to 22.9 percent of Rolls-Royce's level of pre-tax profits in that year.[42] Thus, the NEI acquisition promised to pay its own way. More importantly, the NEI acquisition started the company on a diversification strategy that, as already described, became focused in the last half of the 1990s around the application of gas turbine technology to energy and marine uses as well as aerospace.

As we have seen, in the acquisition of Allison Engine, the Allison shareholders would not accept Rolls-Royce shares as the mode of payment, even though these shares could have been issued as ADRs listed on the New York Stock Exchange and denominated in US dollars. Instead Rolls-Royce did a rights issue, and used the proceeds to pay for the Allison acquisition. Unable to us its stock as a combination currency, Rolls-Royce was nonetheless able and willing to use cash raised in the stock market to finance the acquisition.

In contrast, in the case of its biggest acquisition in the 1990s, that of Vickers plc, Rolls-Royce did not use the stock market either as a source of cash or to provide a combination currency – most likely because, despite the company's profitability in the late 1990s, its stock price was performing poorly at the time of the acquisition (see Figure 3),. Alongside Rolls-Royce, Vickers was the other major British engineering company to survive the pressures of competition and consolidation over the course of the twentieth century, and indeed the relation between Rolls-Royce and Vickers went back to 1919 when the first non-stop transatlantic flight was made in a Vickers Vimy aircraft powered by Rolls-Royce Eagle engines (Lister 1999). Vickers had bought Rolls-Royce Motors in 1980, seven years after the car company had been floated on the stock market in the aftermath of the Rolls-Royce bankruptcy of 1971, and had then sold the car company to Volkswagen in 1998 (Cowell 1999). In September 1999, Rolls-Royce announced its proposal to acquire Vickers for £576m in cash -- a premium of 53 percent over Vickers' market capitalization at the time -- in order to gain access to its capabilities in marine power systems.[43] As Sir Ralph Robins

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ordinary paper offer, but it has ample cash resources with about £120 million in net cash, with £150 million from a Eurobond issue, and a £250 million loan facility."

[40] 'View from City Road: NEI an "add-on" for Rolls-Royce,' *The Independent*, April 11, 1989, 25.

[41] 'Rolls-Royce and NEI to Merge,' *PR Newswire European*, April 10, 1989. Also N. Garnett, "Rolls-Royce to But NEI in Deal Worth £300," *Financial Times*, April 11, 1989, 1.

[42] Ibid.

[43] "Rolls-Royce plc: Proposed recommended offer for Vickers plc from company for £576m," *Global News Wire*, September 20, 1999.

told reporters: "Our strategy is to get to No. 1 or 2 in the various markets in which we operate. We are there in aerospace, this will put us there in marine" (Cowell 1999). Vickers shareholders were also given the option of receiving, in lieu of cash, Loan Notes issued by Rolls-Royce, redeemable at the holder's option in whole or in part at six-month intervals directly from Rolls-Royce, but not listed or traded on a stock exchange.[44] With revenues strong in 2000, the company was able to reduce substantially the debt taken on to acquire Vickers (see Table 9).

In 1999 Rolls-Royce made three other acquisitions. To build capabilities in the energy sector, it acquired the rotating compression business of Cooper Cameron, named Cooper Rolls, for £132m in cash. It acquired National Airmotive, a service and repair facility in Oakland California, for £47m cash. Finally on December 31, 1999 Rolls-Royce purchased the 50.5 percent shareholding that BMW AG held in BMW Rolls-Royce GmbH for 33.3 million shares and the waiver of a £180m loan that BMW owed to Rolls-Royce, for a total acquisition value of £289m. The business was renamed Rolls-Royce Deutschland GmbH. (Rolls-Royce Annual Report 1999). It was as a result of this deal that BMW acquired a 10 percent stake in Rolls-Royce and was, as we have seen, its second largest shareholder as of March 2002.

5.4. Stock as a compensation currency

After its privatisation, Rolls-Royce had two stock-based compensation schemes: a) an Employee Sharesave Plan that, for example in 1995, was available to about 40 percent of the company's UK employees and 30 percent of all employees; and b) an Executive Stock Option Plan that covered 46 senior executives in 1987 and 124 in 1999, but was extended to 363 senior executives in 2000 (Rolls-Royce Annual Reports 1988-2001). Under the executive plan, the vesting period was three years with expiration after ten years, and certain company performance criteria had to be met before stock options could be exercised. As stated in the 2000 Annual Report:

> Depending on performance, executives are eligible to receive options on an annual basis. Options are granted at the mid-market price on the day before the day of issue and normally have to be held for a minimum of three years before they are capable of exercise. They expire after ten years. In line with the [remuneration] committee's view that an increasing proportion of remuneration should be performance related, the exercise of options is subject to a performance condition that the Group's growth in earnings per share (EPS) must exceed the UK retail price index by three percent per annum, over a three-year period.

The annual reports provide information on the stock option awards to executive directors, including the number of awards in a particular year, exercise prices, and the number of options exercised. From this information it is possible to derive fairly accurate estimates of the extent to which executive directors were able to augment their salaried income (which included bonuses) through the exercise of stock options. For example, Sir Ralph Robins was able to increase his income over the period 1987-2001 by 8.27 percent through the exercise of stock options, while John Rose increased his income as an executive director (1991-2001)

[44] "Vickers plc – Recommended cash offer – Part 1," *Regulatory News Service*, September 20, 199.

by 4.46 percent. In fact, most options awarded in the early years expired without being exercised.

That having been said, over the period 1987-2001 executive directors received increasingly generous pay even without gains from the exercise of stock options, as Table 10 shows. In 1987 the pay of the highest paid Rolls-Royce executive was 9.0 times that of the average pay of all Rolls-Royce employees, while the average pay of all executive directors was 6.1 times that of all employees. By 2001 these figures had risen to 25.0 and 16.5.[45] In addition, in 2001, and in certain cases for 2000, executive directors began receiving quantities of stock option awards that were far in excess of what they had received previously. For example, perhaps as a retirement bonus, Robins received 1,025,618 option awards in 2001, up from 172,674 in 2000 and a previous high of 694,618 in 1995. Rose received 1,680,702 option awards in 2001, up from 408,276 in 2000 and a previous high of 355,392 in 1995 (Rolls-Royce Annual Reports).

Table 10. The Relative Pay of Rolls-Royce Executives and Rolls-Royce Employees, 1987-2001.

Year	Pay of Highest-Paid Executive to Average Pay of All Employees	Average Pay of Executive Directors to Average Pay of All Employees
1987	9.0	6.1
1988	11.2	6.9
1989	12.5	6.6
1990	14.8	9.5
1991	14.3	7.7
1992	14.4	9.7
1993	14.5	10.6
1994	16.6	11.0
1995	13.3	9.3
1996	14.4	10.7
1997	19.2	12.7
1998	18.5	13.0
1999	18.9	14.9
2000	20.1	13.2
2001	25.0	16.5

Sources: Rolls-Royce Annual Reports 1987-2001.

5. Conclusions

This case study shows that despite dramatic changes in the forms of enterprise ownership from the 1960s through the 1990s, Rolls-Royce was able to remain one of the Big Three in the turbofan industry. Indeed, as a result of continuous investments in the three-shaft RB211 programme from the mid-1960s through the 1990s, the company was able to emerge as the industry's technological leader in widebody engines, notwithstanding the fact that it was Rolls-Royce's initial investments in this programme that helped to drive the company into

[45] Although the Annual Reports only give details on individual pay for directors, the 2001 Report provides an indication, in one case at least, of the magnitude of the pay increase that comes with the promotion of a Rolls-Royce senior executive to the rank of executive director. On October 18, 2001 Michael Howse, who had been with the company since 1969 and had served in a number of high-level executive positions, was appointed to the Board of Directors. His basic salary for 2001, presumably reflecting his non-director pay, is reported as £59,000. The average basic salary for 2001 of six other non-executive directors, not including the Chairman and Chief Executive, is £339,000. Rolls-Royce Annual Report 2001, 33.

bankruptcy at the beginning of the 1970s. We have argued that the continuity of this development effort can only be understood in terms of the influence of the company's engineers over the allocative decisions of the company combined with a national technology strategy that stressed the importance of maintaining capabilities in this critical high-technology area. The fact that Rolls-Royce was nationalised over half the period of the programme and privatised over the other half had little, if any, impact on this technological trajectory. That having been said, over most of the three decades in question it was by no means certain that the RB211 programme and its three-shaft architecture would either be sustained, or if sustained, be a success.

Before and after nationalisation, strategic control of resource allocation at Rolls-Royce was generally in the hands of the engineers who rose through the managerial ranks to executive positions, although in the 1960s the financial constraints on the company's R&D activities were very severe. Even in the throes of bankruptcy in the early 1970s, when top managers, including architects of the RB211 programme, were forced to step down and political support for the programme was in jeopardy, the critical event was the return of Sir Stanley Hooker and his team of engineers, coming out of retirement, to ensure the continuity of the development effort. After the bankruptcy and under national control, the salaried engineers within the company had to contend with government ministers from very different political parties, but they gained strength from the ongoing political commitment to ensure that Britain would maintain and extend its capabilities in jet engine technology. That commitment continued after privatisation, protected the British government's "golden share".

After the lean years of the early 1980s, as we have seen, the company was on the verge of withdrawing from the competition to remain one of the Big Three engine producers by accepting a subordinate position to GE in the development of high-thrust engines. But even before privatisation, the improvement in engine markets, Rolls-Royce's financial situation, and savings in development costs directly related to the three-shaft architecture of the RB211, enabled the company to reassert its independence as a producer for the big engine market. Central to that reversal of strategy was Ralph Robins, a "lifetime employee" of Rolls-Royce who over the past 15 years has led an executive board made up of similar career employees, most with engineering backgrounds, in building the company's competitive strategy on the RB211 technology. Six of the nine executive directors in 2001had been working at Rolls-Royce prior to the 1971 bankruptcy; like the company, their careers have depended on the success of the RB211.

Since privatisation, financial commitment for the development of the technology has come from Rolls-Royce's internal revenues leveraged to some extent by government subsidies, with the most important being the financial terms of the privatisation process. Also of critical importance for sustaining the company's strategy of developing its capabilities around RB211 technology were the two large rights issues, done 18 months apart in 1993 and 1995, at a time when revenues were down and the alternative of using debt-finance risked a repeat of the bankruptcy some two decades before. Over the fifteen years since privatisation, however, the critical source of committed finance for Rolls-Royce has come from its ability to raise its market share in the large turbofan civilian engine market from about eight percent in 1987 to about 30 percent in 2002.

Rolls-Royce is a large organization, employing over 43,000 people. How important has this organization been to the ability of the company to confront and overcome technological, market, and competitive uncertainties? The identification of the precise forms of the organizational capabilities that have enabled Rolls-Royce to develop technology and win markets would require much more detailed research than we have been thus far able to carry out with the resources, and data[46], available to us. Such research, which is critical to understanding *how* the company actually innovated, will require an understanding of "organisational integration" – the set of organisational incentives that mobilises the skills and efforts of personnel in the pursuit of organisational goals (Lazonick and O'Sullivan 2000) -- that is both functional (see Clark and Fujimoto 1990) and hierarchical (Lazonick 1990, 1998).

Finally, looking into the future, this case study raises questions about the position of European aircraft engine producers in a highly competitive but highly concentrated global industry. Rolls-Royce's emergence as a strong player among the Big Three revived an old rumour that it might lead in the consolidation of European-based engine manufacturers, that is, Motoren und Turbine Union (MTU), SNECMA, Fiat Avio, and Volvo Aero. MTU, the German supplier of low-pressure engine subsystems (with some systems integration capabilities in the military business) was not part of the merger that involved its parent company, Daimler-Benz Aerospace, and the French Aerospatiale-Matra in the formation of the large aerospace and defence conglomerate, labelled EADS, thus suggesting that MTU is in search for a partner or a new parent company. MTU, SNECMA, Fiat Avio, and Volvo Aero, however, all have strong links with the US-based engine manufacturers, which may preclude a European consolidation led by Rolls-Royce.

The other possibility for European leadership is that SNECMA, which has built its strength through CFM International, its longstanding joint venture with General Electric, might take the lead in such a consolidation process. Since the late 1990s SNECMA, which is state-owned, has been planning a partial privatisation so that it might use its stock as a basis for making acquisitions and become a systems integrator for large turbofan engines, independent of its joint venture for engines in the 10,000lb to 50,000lb range with General Electric. The problem is that, as documented at the outset of this paper, in the widebody turbofan industry, "three is a crowd", and four would be a mob. Nevertheless, the once-dominant Pratt & Whitney has of late become vulnerable, so even if the large turbofan market remains crowded, it is not beyond possibility that the identity of the Big Three might change.

[46] In early 2000, the authors attempted, without success, to secure the interest of Rolls-Royce's top management in this research project with a view to gaining access to company records and personnel.

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