Defence Contractors and Diversification into the Civil Sector: Rolls-Royce 1945-2005

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ABSTRACT

A number of studies have shown that defence contractors have exhibited a marked reluctance to diversify away from defence and develop civil applications. However the aero engine manufacturer Rolls-Royce is one defence contractor to whom this does not apply. Over a sixty year period it has moved from being almost entirely dependent on defence work, to a point where defence now constitutes barely one fifth of its turnover. This paper examines the development of the company's civil aerospace business over the period since 1945. The paper focuses specifically on the strategies used by Rolls-Royce in the civil aerospace field. These strategies are explored in the context of changes in market conditions, technology, and governance arrangements. The effectiveness of the various strategies, including their contribution to the company's current position, is evaluated.

Keywords
Aerospace industry, defence diversification, strategy, technology, gas turbine, Rolls-Royce

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INTRODUCTION

Despite an industrial policy in the 1960s that explicitly sought civil applications for military technologies[1], and reductions in the UK's defence commitments over many years that led to a decline in defence expenditure as a proportion of GNP[2], some defence contractors appear to have shown little interest in developing civil work, preferring instead to focus on their core business.

One leading UK defence contractor has run counter to this trend, namely the aero engine manufacturer Rolls-Royce. In the immediate post-war period Rolls-Royce was predominantly a manufacturer of military engines[3]. Despite setbacks and some significant reverses, the civil side of its business has grown to the point where military aerospace now constitutes a little over one fifth of its total turnover[4]. This paper sets out to explore how Rolls-Royce developed from an overwhelming dependence on defence work to the point where today defence is only a comparatively modest part of the enterprise.

DEFENCE DEPENDENCY

Examples of defence contractors that conform to a pattern of defence dependency include the helicopter manufacturer Westland, the submarine builder VSEL, airframe manufacturer British Aerospace and electronics manufacturer Ferranti. Westland moved into the helicopter field in the years after World War Two. Although it established itself as the leading UK helicopter manufacturer by producing versions of American Sikorsky helicopters built under licence, between 1945 and 1960 a mere 5.4 per cent of the company's output for the home market went to the civil sector[5]. As the North Sea oil and gas exploration market emerged in the 1960s, Westland failed to grasp the opportunity, despite a one-off success in selling its Wessex helicopter to Bristow Helicopters, a civil operator run by an ex-Westland employee[6]. In the 1970s, though its Sea King helicopter was well suited to the needs of this market, Westland failed to adapt it to the needs of North Sea operations. Westland's American rival, Sikorsky, showed no such misgivings and by the 1980s dominated the market with its S61 helicopter. Belatedly Westland developed the W30, adapted from its military Lynx design, but it proved too little too late. Lacking the range and capacity required for the North Sea, the project was written off in 1985 at a cost of £100m[7].

If Westland provides an example of a defence contractor that failed to recognise the opportunities presented by the growth of commercial aviation, the shipbuilder VSEL provides an example of a defence contractor with substantial civil manufacturing interests that it neglected and ultimately disposed of, on the pretext that it wanted to focus on its core business[8]. In the 1960s Vickers Shipbuilders Group at Barrow, as VSEL was formerly known, comprised both shipbuilding and general engineering interests. Although most of the shipbuilding work was defence related, the engineering division was more diverse and included a substantial amount of civil work that comprised cement machinery, power generation and mining equipment[9]. After the firm closed its cement machinery business in 1970, civil work generally became marginalised, as the company increasingly focussed on marine work. The onset of the Trident submarine programme in the late 1980s and early 1990s merely continued this trend, although the sheer scale of Trident meant that other work got squeezed out. Ultimately by the 1990s VSEL had become one of the most defence dependent prime contractors in the world, with more than 95 per cent military production[10]. Mort and Spinardi[11] suggest that VSEL was 'far from atypical of post World War Two industrial behaviour in the UK', indeed they go so far as to suggest that there is widespread evidence of British manufacturing companies favouring defence work over civil.

Less dramatic but none the less significant cases of other firms that favoured defence work over civil include British Aerospace and Ferranti. Gummett[12] notes that by 1990, after several years of trying to diversify away from the defence sector, British Aerospace's turnover from sales of military aircraft and other defence systems was three times that from civil aircraft. Similarly at Ferranti, despite a big investment in domestic electronics and civil computing, the company withdrew from both fields in the 1960s as it increasingly focussed on defence avionics[13].

EARLY SUCCESS IN CIVIL AVIATION

In the immediate postwar years civil aviation was dominated by American manufacturers. This reflected the continued development of large four-engined airliners in the US in the early 1940s[14], at a time when the development of comparable designs in Britain had been halted by the British government. The leading American airliners of this period were the Lockheed Constellation which first flew in 1943 and the Douglas DC6 which first flew in 1946. They were followed in the early 1950s by improved versions in the form of the Super Constellation, the 'first of the true intercontinental airliners'[15], and the DC7. US dominance in the airliner market was replicated in the civil aero engine market, where Pratt and Whitney and Wright were the leading manufacturers. All the larger American airliners of the 1940s and 1950s were powered by American produced piston engines, principally Pratt and Whitney's R2800 and Wright's R-3350[16]

In Britain, Bristol, the leading producer of civil engines pre-war[17], retained its position in the early postwar years. Its Centaurus and Hercules engines powered most of the British airliners of the immediate postwar period. Though its wartime Merlin engine was poorly suited to the demands of the civil market[18], in the late 1940s Denning Pearson, then general manager responsible for sales and service, persuaded Rolls-Royce's managing director, Ernest Hives that the company should seek to 'major in civil aviation'[19]. Rolls-Royce's first gas turbine engine for this market was the turboprop Dart, which entered service as the world's first commercial gas turbine on 18th April 1953[20]. The design brief called for an engine that drew upon the company's previous experience and practice. Hence the Dart was a relatively simple design using a centrifugal compressor that built on Rolls-Royce's wartime experience with superchargers[21], rather than utilizing the more advanced axial compressor then under development, and it enabled the company to enter the market some four or five years ahead of rival turboprop and turbojet designs and avoid many of the technical problems encountered by competitors.

Table 1

Dart Engine Civil Applications

	Application	*Engines*	*Country of origin*	*Entry into service*	*Quantity*
1.	Vickers Viscount	4	UK	1953	444
2.	Fokker F27	2	Holland	1958	750
3.	Handley Page Herald	2	UK	1961	50
4.	Armstrong-Whitworth Argosy	4	UK	1959	76
5.	Grumman Gulfstream 1	2	US	1959	200
6.	Avro 748	2	UK	1962	400
7.	NAMC YS-11	2	Japan	1965	182
8.	Convair CV 600	2	US	1965	67
	Total				2169

Source: Heathcote, Roy. *The Rolls-Royce Dart – pioneering turboprop,* Historical Series No. 18, Derby: The Rolls-Royce Heritage Trust. 1992.

Powering small/medium range airliners such as the British built Vickers Viscount, the Dart was an outstanding success. The Dart-powered Vickers Viscount sold particularly well in North America[22]. Trans Canada Airlines was one of the first airlines to order the Viscount in 1952, eventually taking some 51 aircraft. Having broken into the North American market, orders from the US duly followed, most notably from Capital Airlines who eventually purchased 60[23]. The success of the first commercial application of the Dart on the Vickers Viscount not only demonstrated the suitability of gas turbines for commercial airline service, it also encouraged other applications (table 1) including the Dart-powered Fokker F27 which became the world's best selling turboprop airliner[24]. The Dart outsold all other commercial turboprop engines. It was Rolls-Royce's best selling commercial engine of the 1950s and 1960s (table 2) with more than 5000 engines delivered over the period 1952-66 and total sales of £155.7m[25], of which 75.5 per cent were exports[26].

Table 2

Sales of Rolls-Royce Commercial Engines 1952-66

	Dart	*RA29 (Avon)*	*Conway*	*Tyne*	*Spey*
	£m	£m	£m	£m	£m
Home Sales	38.2	24.4	51.3	15.3	26.6
N. America	44.3	4.2	24.7	31.7	18.5
Other	73.2	69.3	22.9	8.5	13.8
Export Sales	117.5	73.5	47.6	40.2	32.3
Total	155.7	97.9	98.9	55.5	58.9

Source: Churchill/PRSN 1/29 Report on the commercial business generated by the Dart, Avon, Conway, Tyne and Spey aero engines 1952-66, January 1967, p4.

The success of the Dart in terms of sales to foreign airlines, especially in North America, enabled Rolls-Royce to learn the civil aviation business. In the civil aviation field, as General Electric discovered when it entered the civil market in the 1960s, the airlines had much more demanding requirements in terms of product support and spare parts availability[27]. The US was both the largest civil aviation market and the most developed, hence selling gas turbine engines in North America meant that Rolls-Royce gained first hand experience of the levels of service and support expected in the US. As Gardner[28] notes, the Viscount airliner gave Rolls-Royce experience of several million flying hours as well as:

> the hard-won knowledge of what operators – especially in the USA – required and expected from a major-league supplier in the way of service support, spares and guarantees.

When the leading airlines switched to turbojet powered airliners in the early 1960s it led to a period of volatility in the civil aero engine market. Of the two leading manufacturers of piston engines, Pratt and Whitney and Wright, the former affected a smooth transition to turbojet engines by offering the JT3 engine, a modified version of its successful J57 military engine. Wright retained a strong commitment to piston engine technology during the 1950s. Turbo-compound versions of its R-3350 engine represented the ‘pinnacle’ of piston engine technology[29]. Wright flirted briefly with the new gas turbine technology, producing a licence-built version of the British Armstrong-Siddeley Sapphire turbojet engine[30], but it proved to be too little too late and the engine met with little commercial success leading to Wright’s rapid exit from the industry by the mid-1960s.

As Wright left the commercial aero engine sector so General Electric of the US entered. Having established a strong position in the military engine market, General Electric offered a commercial version of its J79 military turbojet engine, the CJ805. Unfortunately the principal application for this engine, the Convair 880/990 arrived on the market after its main competitors, the Boeing 707 and the Douglas DC8, and only sold in small numbers. As a result General Electric gained only a small share of the commercial jet market during the 1960s[31]. Rolls-Royce fared better when it came to launch a civil turbojet engine. Like its American rivals Rolls-Royce initially relied on a turbojet engine designed and developed for the military market. The RA29 or Avon engine as it was also known, was Rolls-Royce’s first axial turbojet and it found a number of civil applications including later versions of the British Comet and the French Caravelle short range airliner. The Caravelle, introduced in 1958, was the first short range jet airliner. Used extensively by the French national carrier, Air France, it also sold well in the US[32]. Rolls-Royce continued to expand its production of civil engines in the 1960s, helped by Britain’s initial lead in the jet airliner field that saw the introduction of a number of British designs, such as the Hawker-Siddeley Trident and the BAC 1-11, both powered by Rolls-Royce’s Spey turbofan. While the first of these designs, the Hawker-Siddeley Trident, only sold in small numbers, the BAC 1-11 did rather better, with extensive sales to foreign airlines including Braniff, Mohawk and American Airlines in the US. Nor was the Spey engine, confined to British airframes. The Dutch manufacturer, Fokker, installed Spey engines on its short range regional airliner, the F28, as did US manufacturer Grumman for its Gulfstream II and III business jets.

Combined sales of the turboprop Dart and the Avon and Spey jet engines helped to give Rolls-Royce a 31 per cent share of the worldwide civil gas turbine market[33] between 1956 and 1964. In the words of chief executive Sir Denning Pearson, Rolls-Royce’s strategy focussed on establishing the company as,

> …a supplier of engines for the smaller and medium sized airline and executive aircraft[34]

Focussing on this market segment proved highly effective in gaining entry to the market for commercial aero engines and positioning Rolls-Royce alongside Pratt and Whitney and General Electric, as one of a small number of manufacturers of both military and civil gas turbine engines. It also avoided direct head-to-head competition with rivals Pratt and Whitney and General Electric who supplied the leading US airliner manufacturers and was a way around the institutional barrier of single sourcing, where airframe manufacturers specified a single make of engine[35]. With American airframe manufacturers like Boeing closely linked to American engine makers like Pratt and Whitney, this made the prospect of market entry particularly difficult for European engine manufacturers like Rolls-Royce.

Having gained a slice of the emerging market for civil gas turbines, Rolls-Royce became part of a well defined strategic group. The Big Three, comprising Rolls-Royce, Pratt and Whitney and General Electric, were the only aero engine manufacturers with the capability to design, develop, manufacture and support both military and civil aero engines[36]. Other strategic groups served the various national military markets, but only the Big Three engine makers had a presence in both the military and civil segments and competed on an international basis.

AMERICAN STRATEGY

Although the introduction of its 707 airliner quickly established Boeing as a manufacturer of commercial jet airliners, it was the arrival of further Boeing designs in the mid-1960s, especially the medium range tri-jet 727 and the twin-jet 737[37], that 'firmly established Boeing's position in the market'[38], dis-lodging Douglas, the former market leader. Boeing's market dominance had significant implications since the company maintained a particularly close relationship with the US engine maker Pratt and Whitney. Hence as the civil aviation market came to be dominated by Boeing during the course of the 1960s, so the civil aero engine market came to be dominated by Pratt and Whitney. Bluestone et al.[39] estimate that between 1966 and

1978 Pratt and Whitney accounted for almost three quarters of all civil aero engine orders.

The implications of Boeing's success in the market for the first generation of commercial jet airliners, and the resulting market dominance of Pratt and Whitney, were well appreciated at Rolls-Royce's Derby headquarters. Market analysis presented to a committee of Rolls-Royce's main board on 27th February 1967 showed that sales of the five existing civil engines then in production, would fall dramatically from £58.9 million in 1969 to £3.5 million in 1975[40]. This massive decline was the result of poor sales prospects for many of the company's existing commercial aero engines. It was anticipated that only the Spey engine[41] would continue selling well into the 1970s and its prospects were limited because of the weak demand for Rolls-Royce powered British airliners in a market increasingly dominated by Boeing. Faced with a predicted sharp decline in its share of the civil market, Rolls-Royce might well have chosen to take the path followed by many defence contractors in the UK, and simply opted out of the civil market. But it did not.

Instead Rolls-Royce retained its commitment to civil aviation. Following its takeover of its only UK rival, Bristol Siddeley Engines Ltd (BSEL) two years earlier, in 1968 Rolls-Royce designated its Bristol site as the 'prime site' for military engine work within the company[42], a move that reflected BSEL's close relationship with the RAF. At the same time Derby, was designated the centre for civil engine work. This move not only marked the increasing divergence between military and civil engine technology, it also demonstrated Rolls-Royce's commitment to civil aviation. It was no coincidence that henceforth civil engine manufacture was to be based at the company's headquarters at Derby.

However if Rolls-Royce was to maintain its position in the civil market, the company's senior management was clear that it had to obtain 'a permanent foothold in the US market'[43], because by the late 1960s US aircraft manufacturers dominated the market for commercial airliners. As Rolls-Royce's chief executive Sir Denning Pearson[44] explained,

> It appeared to us that if we were to stay in the civil engine business which we had built up since the war, we needed to get into a United States – built airframe as first engine choice.

An opportunity to break into the US market began to appear in the late 1960s as the aircraft manufacturers started to plan for a new generation of wide-bodied airliners powered by new high by-pass ratio (HBPR) engines. Both Pratt and Whitney and General Electric received extensive US government funding to design and build demonstrator versions of HBPR engines, as part of the giant C5A military transport programme of the late1960s[45]. Denied such support, Rolls-Royce sought a strategic alliance with General Motors[46] and its Allison engine division for joint development and production of an HBPR engine for this new market, in order to share the anticipated heavy development cost and make it more attractive to the US market. However despite lengthy negotiations this cooperative venture never materialised.

Rolls-Royce lost out in the competition for engines to power the first wide-bodied jet, the Boeing 747, when Pratt and Whitney's JT9D design was selected in 1966. However by 1967 there were three further wide-bodied airliners being proposed, from Lockheed and McDonnell-Douglas in the US and the new European Airbus consortium. The Americans were proposing tri-jet designs while the Europeans had come up with a proposal for a twin jet. For these wide-bodied applications Rolls-Royce's proposed 'advanced technology engine'[47] was to be available in two sizes, the RB207, an engine of 50,000lbs thrust and a smaller 30,000lbs thrust engine designated the RB211. Within the company there was a preference for the smaller engine because it avoided direct competition with Pratt and Whitney's JT9D[48].

The advanced technology engine employed a very ambitious design that was more technologically advanced than either of the engines being developed by its US rivals. It was potentially quieter, more fuel efficient and more reliable. This was possible by virtue of the novel three shaft architecture employed on the advanced technology engine. The three shaft architecture made for a significantly shorter engine which made it more rigid and thence more reliable[49]. Potentially it also made the engine heavier, but Rolls-Royce planned to use a revolutionary wide chord fan[50] made from carbon fibre that was both lighter and more aerodynamically efficient than the solid titanium blades used by its rivals, resulting in a quieter and more fuel efficient engine.

After a long sales campaign the RB211 engine was selected by Lockheed in March 1968 for its L-1011 TriStar wide-bodied airliner. It is hard to over-estimate the significance of the Lockheed contract for the company at this time. Indeed as a later enquiry[51] noted:

> a contract with a US manufacturer had for them become not merely a consummation devoutly to be wished, but a task in which failure would be unthinkable.

Though the larger RB207 was also selected for the European Airbus, when Rolls-Royce found it simply did not have the resources to develop two new engines simultaneously, the American strategy came to the fore and this engine programme was terminated, leaving this particular market segment to General Electric. In the event a combination of financial and contractual difficulties on the RB211 engine, combined with a failure on the part of Rolls-Royce's management to appreciate and provide for the technical problems involved in developing an advanced design, led to the company being taken into public ownership in February 1971, ironically on the very day that the RB211 engine delivered its designed performance under test. Eventually a new contract with Lockheed was negotiated and thanks to favourable exchange rates, the first batch of RB211 engines was delivered at a profit[52].

Although the RB211 achieved both technical and financial success (table 3), and helped to maintain Rolls-Royce's position as a major player in the civil market, the company's new management quickly realised that in the civil aero engine market, Rolls-Royce still had a limited customer base. Plans to extend the customer base remained firmly wedded to the company's American strategy. In this Rolls-Royce was helped by changes in the institutional arrangements surrounding the airliner market. The competitive scramble that surrounded the launch of the first wide-bodied jets led to moves away from single sourcing of engines in favour of multiple sourcing[53].

Table 3

Sales of HBPR engines by the Big Three manufacturers 1972-1982

Engine	*1972*	*1973*	*1974*	*1975*	*1976*	*1977*	*1978*	*1979*	*1980*	*1981*	*1982*
JT9D	147	164	108	144	102	42	91	215	249	158	130
CF6	212	162	209	113	119	124	182	297	336	228	150
RB211	114	163	135	111	39	55	71	74	151	195	128

Source: Rogers, M. Foster. “Global competition in the aero engine industry”, Paper presented at the Prince Bertil Symposium, 7-9 November, Stockholm, Sweden. 1984.

Ironically it was Pratt and Whitney, the company that benefited most from single sourcing in the 1960s that started the trend towards multiple sourcing, when their JT9D engine was selected by North West Airlines and Japan Airlines for the long range version of the McDonnell-Douglas DC10 which had hitherto been powered exclusively by General Electric’s military derived CF6 engine. However it was in the 747 market that multiple sourcing really took off. Boeing was attracted to the idea of competition from engine companies as a way of broadening the customer base for the 747, and specified the General Electric CF6 engine as an alternative to Pratt and Whitney’ s JT9D. CF6 powered 747s became particularly strong in the European market helped by the involvement of France’s Snecma and Germany’s MTU as minority partners in this engine programme, and marking a resurgence of General Electric in the civil engine market.

These new institutional arrangements provided scope for Rolls-Royce too to broaden its customer base. In 1972 work began on an up-rated and optimised version of the RB211. Formerly launched in 1974 as a 50,000lbs thrust engine for the long range version of the Lockheed L1011, the 524 engine used the same sized fan as the RB211 but with a re-designed core[54]. However the 524 was powerful enough to power the 747 and in 1975 Boeing began offering the 524 as an engine option. The 524 had the advantage of being more fuel efficient than either of its US-made rivals and in the following year Rolls-Royce made a major breakthrough when British Airways ordered six 524 powered 747-200s[55]. Entering service in 1977, the 524 did particularly well in the rapidly growing Asian market where Cathay Pacific, Qantas, All Nippon Airways and Air New Zealand ordered 747s powered by Rolls-Royce’s

524 engine[56]. As a result the company's share of the HBPR engine market, which as table 3 shows had dipped in the second half of the 1970s following the initial success of the RB211, rose steadily in the early 1980s. By 1981 Rolls-Royce had a 31 per cent share of the HBPR market, outselling Pratt and Whitney's JT9D in that year.

In the late 1970s Rolls-Royce took its American strategy a step further when it put forward a new engine for Boeing's proposed 757 twin-jet, then being developed as a replacement for the best selling 727. Described as a 'cropped fan' design, the new engine comprised the core of the RB211 but with the fan scaled down from 85.5 inches to 73.2 inches, giving a power rating of 37,000lbs[57]. In 1978 the new engine was designated the launch engine on the Boeing 757, the first time that Boeing had ever launched a new airliner with anything other than a Pratt and Whitney engine. Rolls-Royce's 12.7 per cent market share at this time was well behind both Pratt and Whitney with a massive 62.7 per cent and General Electric with 24.6 per cent[58], the latter having recovered from the very poor performance of its first commercial turbojet engine the CJ805, through the success of its military-derived CF6 engine that powered the McDonnell-Douglas DC10 and the Airbus A300. Though in third place behind its US rivals, nonetheless Rolls-Royce's market share at this time was considerably healthier than earlier in the decade and, as a vindication of the American strategy, its engines now powered three different American airliners.

FULL LINE STRATEGY

The 535 engine entered service in 1982, but within months, the impact of a second oil crisis on fuel prices and severe financial problems for US airlines caused by competition following the de-regulation of the airline industry, brought a sharp drop in the demand for airliners, especially the new Boeing 757[59]. Worse still was Lockheed's decision in 1982 to exit the civil airliner market by ceasing production of its L-1011 Tri-Star airliner[60], when outstanding orders had been completed in 1984. These events exposed shortcomings in Rolls-Royce's product strategy, particularly its relentless pursuit of the US market.

Hence the early 1980s proved a testing time for Rolls-Royce. Having made a small loss in 1981, profitability declined sharply in 1982, as the company recorded a loss of £91m[61]. This reflected, 'a sharp reduction in workload in 1982'. The following year things were worse. Rolls-Royce's new chairman, Sir William Duncan, noted[62]:

> It is obvious we are still emerging from the worst recession in airline history, and that 1983 was another very difficult year throughout the aerospace business, including Rolls-Royce.

Sales of large commercial engines by Rolls-Royce fell from 150 in 1982 to a mere 60 in 1983. The situation in terms of new orders was even worse with orders for large commercial engines totalling a mere 30. This was at a point where Rolls-Royce had geared up to manufacture 300 large commercial engines per year. Not until the following year did Rolls-Royce see any sign of improvement when the second half of the year brought a steady growth of workload for the civil business[63].

The sharp decline in orders in the early 1980s forced Rolls-Royce's senior management into a change of strategy. Despite its success in developing derivatives of the RB211, even by the mid-1980s Rolls-Royce had a total of only five civil airframe applications[64], four of which were American. By comparison Rolls-Royce's US rivals Pratt and Whitney and General Electric offered ten and nine applications respectively[65]. It was now apparent that in pursuing its American strategy Rolls-Royce had failed to foresee the success of Airbus[66]. While Lockheed and McDonnell-Douglas had engaged in a fierce struggle with their near identical three-engine designs, Airbus had entered the market in the mid-1970s with a twin-engine wide-bodied design. Although sales had been slow at first, the increasing reliability of gas turbine engines combined with a second oil crisis in the early 1980s, demonstrated the superiority of twin-engine designs in the wide-bodied sector. Airbus's share of new orders for commercial airliners which in 1975 stood at 8 per cent rose to 31 per cent in 1990[67] achieved largely at the expense of McDonnell-Douglas and Lockheed. Rolls-Royce's pre-occupation with its American strategy allowed the US engine manufacturer General Electric to build a near monopoly of Airbus applications.

Consequently from the mid-1980s onwards Rolls-Royce attempted to re-position itself within the global aero engine market. To get on equal terms with its US rivals and raise its overall share of the civil aero engine market, it adopted a 'full line'[68] or 'generalist'[69] strategy designed to broaden its product portfolio. The logic behind this full line strategy was that having more airframe applications would lead to more sales and thence a higher market share. Offering a product portfolio comprising engines for all segments of the market also provided scope for extending the application of gas turbine technology, thereby spreading the very high R & D cost associated with maintaining the technology base, across the maximum number of engines. For Rolls-Royce this was particularly attractive since unlike its two US rivals, it was not part of a large diversified industrial conglomerate and therefore its access to resources was more limited.

In order to implement the full line strategy Rolls-Royce resorted to a series of strategic alliances with other engine manufacturers, including a number of smaller manufacturers of military engines with ambitions for involvement in the civil engine market. In a seven year period between 1983 and 1990, Rolls-Royce concluded no fewer than four collaborative agreements for new civil engines (table 4). The first of these was a joint venture with Pratt and Whitney to develop a new engine of 25,000lbs thrust. The joint venture company was called International Aero Engines AG (IAE) and was established in December 1983. The initiative behind the formation of IAE was to satisfy the growing demand for new, fuel efficient, environmentally-friendly, easy to maintain turbofan engines in the 10 tonne class. Such engines were needed to power a new generation of narrow-bodied airliners like the Airbus A320.

IAE effectively brought together two design teams. One, comprising Rolls-Royce and a Japanese group, Japan Aero Engine Company (JAEC) were developing a slightly smaller engine the RJ500[70]. The other comprised Pratt and Whitney and minority European partners MTU of Germany and Fiat of Italy who had previously collaborated on the PW2037 engine.

Table 4

Civil Joint Ventures involving Rolls-Royce

Joint Venture Company	*International Aero Engines AG*	*General Electric Rolls-Royce*	*Williams Rolls Inc*	*BMW Rolls-Royce GmbH*
Type	Joint venture	Risk &Revenue Sharing Partnership	Joint venture	Joint venture
Partners	Rolls-Royce (30%) Pratt & Whitney (30%) MTU (12.1%) Fiat (8%) JAE (19.9%)	General Electric (85%/75%) Rolls-Royce (15%/25%	Rolls-Royce (15%) Williams International (85%)	Rolls-Royce (49.9%) BMW (51.1%)
Product	V25000	CF6-80C 535-E4	FJ44	BR700
Date	1983	1984	1989	1990
Thrust (lbs)	25,000-33,000 lb.	40,000lbs & 60,000lbs	2,300 lb.	15,000-21,000 lb.
Airframe	A320, A321, MD90	A310 & B757	Cessna Citation, SJ30, Raytheon Premier 1	Gulfstream V, Global Express, Boeing 717
Market	Small Commercial Airliners	Large & medium twin jet airliners	Small Business Jets	Large Business Jets, Regional Jets

For Rolls-Royce, IAE and the V2500 engine filled a gap in its product portfolio between the largest version of its Tay engine of 18,000lbs thrust and the smallest engine in the RB211 family the 535 engine developing 37,000lbs thrust. This was a sector in which General Electric had begun to enjoy success with its military derived CFM56 engine, which was the product of a joint venture with the French engine maker Snecma. Despite initial technical problems with the V2500, IAE firmly established itself within its market sector. The V2500 went into service in 1989 and during the course of the 1990s output rose steadily so that by 1998 IAE's output was running at 300 engines per year[71]. By 2002 IAE had achieved a 70 per cent share of the Airbus A320 market[72]. With the V2500 powering the A319, A320 and A321 versions of the narrow-bodied Airbus as well as the McDonnell-Douglas MD 80 and MD90, the joint venture enabled Rolls-Royce to significantly increase the number of its civil airframe applications.

Rolls-Royce's second collaborative venture during the 1980s was formed in February 1984 when the company concluded an agreement with General Electric whereby it would take a 15 per cent stake in the latter's CF6-80 engine programme in return for General Electric taking a similar stake in Rolls-Royce's 535E4 programme (table 4). The arrangement with General Electric was not a joint venture but a risk and revenue sharing partnership where each partner simply took a stake in one of the other partners' engine programmes. The agreement gave Rolls-Royce access to the market for very large engines of 60,000lbs thrust being developed for the second generation of wide-bodied jets such as the Airbus A310, while giving General Electric access to the market for second generation narrow-bodied jets such as the Boeing 757. The agreement was widely welcomed in the British press. Sir William Duncan, Rolls-Royce's new chairman, portrayed the agreement with General Electric as another move in the company's strategy of broadening its product portfolio. In the company's annual report[73] he noted:

> As a result of these two new collaborative ventures, Rolls-Royce will be competing in all the main sectors of the gas turbine market for commercial aero engines.

He went on to stress that it was financial pressures at this time which had forced the company to resort to collaborating, noting that collaboration had the effect of:

> ….reducing the heavy financial burden associated with the launch of new engine projects.

He reiterated Rolls-Royce's strategy particularly in relation to the company's use of a full line strategy to maintain its technology base in evidence to the Trade and Industry Committee of the House of Commons in June 1984[74]

> If we had not sought to collaborate with Pratt and Whitney in the V2500, and General Electric in the large thrust CF6-80C, one could not have seen us being able to sustain our previous level of research and development.

However there were those who placed a different interpretation on Rolls-Royce's agreement with General Electric. Rogers[75] in an analysis of the aero engine market at this time pointed out that collaboration with General Electric meant that the company was abandoning any hopes it might have of competing in the market for ultra high power engines of 60,000lbs thrust or more. Since Rolls-Royce's role in the CF6-80C engine was at best a minor one, the company was effectively leaving this market sector to its arch rivals, Pratt and Whitney and General Electric. The sector involved the most sophisticated engines employing the most advanced technology, so Rolls-Royce was effectively ceding technological leadership to its rivals.

However on 5th November 1984, Sir William Duncan, the architect of the General Electric agreement, died suddenly[76]. His successor as chairman, Sir Francis Tombs, was less enthusiastic about this particular collaborative agreement. During 1985 it became clear that an upgraded and more powerful version of Rolls-Royce's own 524 engine could be developed as a competitor to the CF6-80C for long range versions of Boeing's new 767 airliner as well as McDonnell-Douglas's proposed MD11. This, combined with an upturn in the civil engine market and a rapid improvement in Rolls-Royce's profitability led to the agreement with General Electric being terminated in November 1986[77].

The two further collaborative ventures that Rolls-Royce entered at this time fared rather better. In 1989, Rolls-Royce embarked on a joint venture with Williams International Inc. of the US, a manufacturer of small gas turbine engines. Williams International had developed a range of small gas turbines to power cruise missiles in the 1970s and by the 1980s was keen to use the expertise it had built up to enter the market for engines to power small business jets. The joint venture brought together

Rolls-Royce’s expertise in manufacturing components such as turbine discs and turbine blades and its worldwide product support capability with Williams International’s expertise and experience in small gas turbines. The main application for the 1,900lbs thrust FJ44 engine proved to be Cessna’s best selling CitationJet, and by 1999 the Williams-Rolls joint venture had produced more than 1,000 engines. In terms of Rolls-Royce’s full line strategy, the Williams-Rolls joint venture enabled the company to extend its product range in the small engine sector of the market.

The other joint venture was an Anglo-German collaboration with car manufacturer BMW, established in May 1990 to develop a new engine in the 15,000-20,000lbs thrust market sector to power a new generation of regional airliners and large ‘heavy iron’ business jets, as well as re-engining old aircraft[78]. For BMW the joint venture represented a return to aero engine manufacturing after a gap of almost 30 years, the company having been one of the pioneers of the jet engine during World War II. Sir Ralph Robins made clear Rolls-Royce’s perspective in evidence to the House of Commons Trade and Industry Committee in 1993[79] when he noted that Rolls-Royce:

> had no money left to do another engine, but we knew that we had the capability of penetrating that market because it is a market in which we have been very successful in the past.

The joint venture developed the BR700 engine which came in two versions the BR710 for large business jets and the BR715 for regional airliners. Entering service in 1996, by 1999 the joint venture’s order book had risen to 1,000 engines with turnover in that year amounting to £727m.

In volume terms, this joint venture, along with Rolls-Royce’s other cooperative ventures of the 1980s, IAE and Williams-Rolls Inc, played a major part in increasing the aero engine manufacturer’s penetration of the civil aero engine market. This is reflected in table 5 which shows the pattern of Rolls-Royce’s engine deliveries, in particular the sharp rise in deliveries of civil engines relative to military engines from the mid 1990s onwards.

Table 5

Rolls-Royce Engine Deliveries 1994-2001

Year	*Military*	*Civil*	*Total*
1995	120	405	525
1996	214	424	638
1997	161	625	786
1998	164	911	1,075
1999	181	1,080	1,261
2000	194	1,091	1,285
2001	179	1,362	1,541

Source: Rolls-Royce. Annual Report 1999, London: Rolls-Royce plc. 2000; Rolls-Royce. Annual Report 2001, London: Rolls-Royce plc. 2002.

While Rolls-Royce was forced to rely on collaborative agreements to extend its product portfolio in the 1980s, in the 1990s it relied on a unique modular design of engine to extend its product portfolio at the top end of the power range. By the mid-1980s the G and H versions of Rolls-Royce's 524 engine were delivering 60,000lbs thrust[80], but as the airliner manufacturers began to develop proposals for a second generation of wide-bodied airliners, it became clear that engines more powerful than Rolls-Royce's largest version of the 524 would be needed. Among the proposed airliners coming forward were the McDonnell-Douglas MD11, the Airbus A330/340 and the Boeing 767-X. To meet the requirements of these new airliners Rolls-Royce proposed an up-rated version of the 524, the 524L, but it quickly became apparent that this new market niche would in time stretch well beyond even this thrust level. In the face of growing requirements for greater power outputs the reaction of Rolls-Royce's competitors varied. General Electric opted for an entirely new design, the GE90, while Pratt and Whitney went for a more powerful derivative of its current large engine the PW4000. Rolls-Royce revised its proposed 524 engine and judging the revised engine to be a step change made this clear by designating the new engine as the Trent when it was launched in 1988, in order to signify that although it was a three shaft modular design incorporating a number of features of the 524, it was in fact a new engine. As such it was designed to form the basis of a family of new engines.

By 1990 the family included three engines all based on a common Trent core. By fitting a different size of fan to a common core, Rolls-Royce was able to offer three different sizes of engine each with a different power output and targeted at a different airframe application. As table 6 shows the Trent 600 with a 95 inch fan and 65,000-68,000lbs thrust would power the MD11, the Trent 700 with a 97.5 inch fan and 67,000-71,000lbs thrust would power the A330 while the Trent 800 with a 110 inch fan would power the 767-X.

Table 6

The Trent Engine programme

Engine	**Trent 500**	**Trent 600**	**Trent 700**	**Trent 800**	**Trent 900**	**Trent 1000**
Thrust lbs	53,000-56,000	65,000-68,000	67,000-71,000	92,000-95,000	80,000	58,000-70,000
Fan size	97.5in.	95in.	97.5in	110in.	116in.	112in.
Bypass ratio	8.5:1	8:1	5.5:1	6.5:1	8:1	10:1
Entry into service	2002	With-drawn	1995	1996	2006	2008
Application	A340	MD11	A330	B777	A380	B787

Source: Walters, Brian. "Rolls' biggest fan", *Air International*, 56, No.2 (1999): 115-118; Wastnage, Justin. "Airbus briefs suppliers on A350", *Flight International*, 28 September – 4 October, (2004): 6.

Rolls-Royce was able to meet the different power requirements of these aircraft by virtue of the Trent's modular three shaft design configuration. This had been a feature of the initial proposal for the RB211 put forward by Rolls-Royce's designer Adrian Lombard in the 1960s[81]. The use of three shafts gave the designers much greater scope for varying performance characteristics of the engine. In particular it facilitated the use of a common core[82] with the power output varied by the size of fan used. The use of the same basic design for the core meant that Rolls-Royce could develop new engines more quickly and more cheaply[83].

As a design principle, modularity was not new. In the 1980s Rolls-Royce's 'cropped fan' engine, the 535, had used the same principle by fitting a smaller fan to create a de-rated version of the RB211. However the core was not designed at the outset for up-rating or de-rating. The Trent engine programme from the outset used modularity, something that Rolls-Royce's unique three shaft layout directly facilitated. As table 6 shows by 2002 the Trent had evolved into five different engines[84] ranging in size from 53,000lbs to 95,000lbs thrust, achieved in large part by fitting a different size of fan to a common core.

The first two Trent engines were developed in the early 1990s. The Trent 700 which entered service in 1995 with Cathay Pacific, was a particularly significant development as it was Rolls-Royce's first Airbus application using an engine not built by a joint venture. The Trent 800 which entered service a year later in 1996 found a market on Boeing's 777, as the 767-X was ultimately designated, and by 1999 had 40 per cent of this market niche[85].

These first two engines in the Trent family were followed by the less powerful Trent 500 which was the sole powerplant for extended range versions of the Airbus A340. This was followed by the launch of a fourth engine, the Trent 900 in 2001, for the Airbus A380. For this application Rolls-Royce's rivals were forced to combine their efforts by resorting to a joint venture called Engine Alliance, which developed the GP7200 engine, which combined the core of General Electric's GE90 engine with the fan of Pratt and Whitney's PW4000 engine. Finally in 2004 Rolls-Royce launched the latest Trent engine, the Trent 1000, which became the launch engine on Boeing's 787 'Dreamliner'.

Further steps towards implementing the full line strategy occurred through acquisitions that took place in the 1990s (table 7). The acquisition of the American engine firm Allison in 1995 added a small turbofan engine, the 10,000lbs thrust AE3007, to the company's product portfolio just at the point when the market for small regional jets was taking off, while the acquisition of BMW's share of the BMW Rolls-Royce joint venture in 1999 strengthened Rolls-Royce's position in the market for large corporate jets. Taking stock of both acquisitions the Financial Times[86] noted:

> The acquisition of Allison in the US in 1995, and the joint venture development with BMW, the German car maker, of a new mid-sized jet engine range during the 1990s, has allowed it to carve out a significant, and rising share of the fast-growing market for regional and corporate jets.

The significance of Rolls-Royce's efforts at broadening its product portfolio can be seen in improvements in the company's share of the worldwide civil aero engine market. In 1993, with the Trent still under development, Rolls-Royce's market share stood at 21 per cent[87] almost double what it had been a decade earlier. However it still trailed its two American rivals. Pratt and Whitney had seen its market share decline steadily from 60 per cent in the early 1980s to 30 per cent by 1992[88]. General Electric had recorded an increase in market share over the course of the 1980s, helped in particular by the runaway success of its military-derived CFM56 engine, the product of its joint venture with France's Snecma, and the sole powerplant for the Boeing 737 the world's best selling airliner. Such was the success of this joint venture that by 1992 General Electric had eclipsed Pratt and Whitney as the market leader in the civil aero engine market.

Table 7

Acquisitions by Rolls-Royce 1989-1999

Date	*Company*	*Origin*	*Activity*	*Purchase Price*
1989	Northern Engineering Industries plc	UK	Industrial Power	£306m
1995	Allison Engine Company	US	Aero engines	£320m
1999	BMW Rolls-Royce GmbH	Germany	Aero engines	£289m
1999	Vickers plc	UK	Marine power	£676m
1999	Cooper Energy Services	US	Energy Services	£152m

Source: Rolls-Royce Annual Reports

A decade later in 2003, with three different Trent engines in service and gaining the full benefit of its earlier alliances and acquisitions, Rolls-Royce had a much broader product portfolio, comprising engines for more than 30 different aircraft applications[89] and this was reflected in its overall market share which had consistently averaged 30 per cent over the previous three years[90]. While General Electric had retained its position as market leader, Pratt and Whitney's market share had declined further over the course of the 1990s, resulting in the elevation of Rolls-Royce to the position of the world's second largest manufacturer of civil aero engines. Furthermore Rolls-Royce had been particularly successful in the market for engines to power wide-bodied airliners, the biggest and most profitable market segment, where it had secured a 50 per cent market share[91], and was the only one of the Big Three engine manufacturers to have secured a stake in all the main applications to have appeared on the market since 1990 without recourse to a joint venture.

DIVERSIFICATION STRATEGY

The final steps in Rolls-Royce's path to defence diversification took place in the 1990s. Three acquisitions, one in 1989 and two in 1999 (table 7) aimed to reduce Rolls-Royce's dependence not just on defence but on aerospace in general. As the Financial Times[92] noted at the time of the first of these acquisitions:

> The deal with NEI appears to be the first step in a long process of fundamental change that will turn the aero engine maker into a broader industrial company.

The acquisitions formed part of a strategy designed both to reduce the company's dependence on the highly cyclical aerospace market and provide additional applications for Rolls-Royce's gas turbine technology, in the same way that its pursuit of a broader product portfolio through a full line strategy aimed to spread the cost of maintaining the company's gas turbine technology base.

In the case of Northern Engineering Industries (NEI) it was hoped that the acquisition provided scope for offering complete power generation packages combining Rolls-Royce's gas turbine technology with NEI's steam generation capability, especially in combined cycle gas turbine (CCGT) plants that were expected to be more widely used following electricity market re-structuring both in the UK and the US and Asia.

Despite early success, Rolls-Royce proved to be too small a player in a market dominated by international groups such as Siemens and Westinghouse. Consequently in July 1996 the company announced that it was to sell its large steam power engineering business. The Financial Times[93] noted:

> Seven years after the event, the folly of Rolls-Royce's acquisition of NEI, the power generating group, is plain. Initial hopes that there would be synergy between Rolls' gas turbines, which are derived from aero engines, and NEI's steam business proved a mirage.

The Parsons steam power generating business was sold to Siemens in 1997 and the Reyrolle Switchgear business was sold to VA Tech of Austria the following year.

Table 8

Changes in the Composition of Rolls-Royce Turnover

	1997		*2005*	
	£m	*%*	*£m*	*%*
Civil Aerospace	1,848	49.0	3,510	53.2
Military Aerospace	1,164	30.9	1,413	21.4
Marine	275	7.3	1,097	16.6
Energy	483	12.8	505	7.6
Other	-	-	78	1.2
Total	3,770	100.0	6,603	100.0

Source: Rolls-Royce. Annual Report 1997, London: Rolls-Royce plc. 1998; Rolls-Royce. Annual Report 2005, London: Rolls-Royce plc. 2006.

Ten years after the acquisition of NEI, Rolls-Royce made by far its biggest acquisition with the purchase of Vickers for £636million. The attraction of Vickers was its marine propulsion business where it was a world leader in the manufacture of water jets which were increasingly being used instead of propellers. This was a field in which Rolls-Royce already had expertise having supplied gas turbine and nuclear powerplants to the navy for many years. Vickers had itself recently undergone extensive re-structuring having sold off its automotive interests and bought the Norwegian maritime equipment company Ulstein Holdings. The re-structuring meant that Vickers was now a major player in the maritime propulsion market. The Rolls-Royce and Vickers maritime businesses complemented each other, enabling Rolls-Royce to offer a wide range of competitive products, services and brands. As the company's annual report[94] noted:

> The acquisition of the Vickers marine business in 1999 and our continuing investment in our products are transforming the scope and scale of our marine business.

The final acquisition was Rolls-Royce's purchase of Cooper Energy Service from Cooper Cameron Inc of Ohio. This enhanced Rolls-Royce's position in the market for gas turbines used for gas compression, oil pumping and power generation. The acquisition served to strengthen the company's position in the oil and gas field complementing its existing work in the power generation.

The overall effect of these acquisitions was to reduce Rolls-Royce's defence dependency still further. Table 8 shows that whereas military aerospace comprised almost 31 per cent of turnover in 1997 with Marine and Energy contributing 20.1 per cent, by 2005 military aerospace had declined to 21.4 per cent while Marine and Energy work exceeded it as a proportion of turnover having risen to 24.2 per cent. Overall, military aerospace now comprised barely one fifth of total turnover, very different from the company's one time dependence on military work.

CONCLUSION

By the start of the twenty-first century Rolls-Royce was a very different business to 60 years earlier. Not only had the goal advocated in the 1940s by a young Denning Pearson, that the company should break into civil aviation[95], been achieved, but Rolls-Royce was now the world's second largest aero engine manufacturer after General Electric, as well as being a long established member of the leading strategic group in the industry, and a diversified business to the point where the defence market constituted little more than a fifth of total turnover.

Over the 60 year period four distinct competitive strategies can be identified. Each reflects a particular point in the evolution of the civil aero engine industry. Thus when gas turbine engines were in their infancy Rolls-Royce pursued a focus strategy designed to gain market entry, and so position Rolls-Royce within the civil aero engine market. This strategy involved a focus on a specific market segment, namely gas turbine engines to power short/medium range and commuter airliners. As a strategy it built in part at least on the company's long standing expertise in supercharger technology. It proved successful not only in winning a substantial share of the developing gas turbine market, but in enabling Rolls-Royce to learn the civil aviation business and by the 1960s the company was part of a group of engine makers who made up the Big Three, the leading strategic group within the industry, whose other members included Pratt and Whitney and General Electric.

However Rolls-Royce's early success proved comparatively short-lived. Boeing's success in dominating the market for civil jet airliners meant that by the late 1960s the US engine maker Pratt and Whitney dominated the civil aero engine market. Rolls-Royce's position, both as a civil engine manufacturer and a member of the Big Three strategic group was severely threatened. To defend its position, Rolls-Royce pursued its American strategy. This was an ambitious strategy designed to break into the market for US-built airliners, by achieving competitive advantage over Rolls-Royce's American rivals through offering a sophisticated advanced technology engine, the RB211. In the short term it was to prove disasterous, leading to the collapse of the company and it being taken into public ownership. In the longer term the strategy did succeed in winning Rolls-Royce a share of the market for engines powering US-built airliners, thereby retaining its position in the Big Three strategic group. However market changes, in particular the success of wide-bodied twin-jet airliners like the

Airbus A300, eventually forced Rolls-Royce to question the wisdom of focussing almost exclusively on the US market. As a result in the 1980s Rolls-Royce changed direction and introduced a new strategy.

Like earlier strategies, the purpose of this new full line strategy was to enable the company to influence its position in the market. Unlike its earlier American strategy the aim was offensive rather than defensive. It was an offensive strategy that aimed to increase the company's market share by offering engines for the widest possible range of airframe applications, thereby strengthening the company's position within the Big Three strategic group. Implemented through joint ventures in the 1980s and through the modular design of the Trent family of engines and acquisitions in the 1990s, it proved highly effective in broadening the product portfolio and led to significantly increased market share.

Although not aimed directly at positioning the company within the aerospace industry, Rolls-Royce's recent strategy of diversification too was concerned with positioning. By trying to reduce Rolls-Royce's exposure to the highly cyclical nature of aerospace, this strategy aimed to position the company as a diversified industrial group similar to its rivals Pratt and Whitney and General Electric.

Hence the strategies pursued by Rolls-Royce over the last 60 years have in common a concern for the company's market position, in particular, a desire to strengthen the company's structural position within the industry, in order to gain competitive advantage. This has generally meant Rolls-Royce being positioned as a member of the leading strategic group in the industry. This in turn reflects the importance of strategic groups in the aero engine industry, where firms in the Big Three group are sharply differentiated from firms in other strategic groups, such as the military engine manufacturers or the small engine manufacturers. This differentiation rests on their strategic assets and the basis upon which they compete, for the Big Three firms are the only engine manufacturers with the capability to design, develop, manufacture and support both military and civil engines.

However as Grimm et al.[96] note, 'a firm's positioning in an industry is only one half of the competitive puzzle'. The resource-based view of strategy, which traces its origins to Penrose[97], emphasises that a firm's resources and the capabilities associated with them are crucial to competitive advantage. This has been a feature of Rolls-Royce's more recent strategies. In particular its full line strategy, aimed not just to position the company in a particular strategic group, it also aimed to enhance the company's capability, especially its technological capability. With advanced technology an increasingly vital feature of competing in the largest and most profitable sector of the civil aero engine market, namely the sector for ultra high thrust engines to power the latest wide-bodied airliners, maintaining technological leadership is critical to gaining and maintaining competitive advantage in the aero engine industry. Technological leadership demands that an aero engine manufacturer maintains an advanced technology base, with resources capable of generating a stream of new technologies that can be incorporated into new engines to deliver improved performance. To do this requires a company to maximise applications for the technology so that the high cost of maintaining an advanced technology base can be spread across a large number of products. Rolls-Royce's full line strategy, and for that matter its diversification strategy, stands as an example of this type of 'resource-based' strategy[98]. Its 30 per cent share of the civil aero engine market worldwide in 2003 combined with its 50 per cent share of the market for engine to power wide-bodied airliners, indicates Rolls-Royce's success in pursuing this type of strategy[99].

Resource-based strategy also provides an explanation of why Rolls-Royce has not resorted to defence dependency. To have forsaken the civil aviation market would have meant conceding technological leadership in the industry, something that apart perhaps for a brief period in the mid-1980s, Rolls-Royce has always been unwilling to countenance.

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REFERENCES

Aris, Stephen. *Close to the Sun: How Airbus challenged America's domination of the skies*, London: Aurum Press, 2002.

Birch, Doug. "International Thrust: IAE V2500 – derivative engineering at its best", *Air International* 54, No.6 (1998): 367-399.

Bluestone, Barry, Jordan, Peter and Sullivan, Mark. *Aircraft Industry Dynamics: An Analysis of Competition, Capital and Labour*, Boston, MA: Auburn House Publishing. 1981.

Bonaccorsi, Andrea and Giuri, Paola. "When shake-out doesn't occur: The evolution of the turboprop engine industry", *Research Policy*, 29, (2000): 847-870.

Bonaccorsi, Andrea and Giuri, Paola. "The long-term evolution of vertically-integrated industries", *International Journal of Industrial Organisation*, 19, (2001): 1053-1083.

Constant, Edward W. *The Origins of the Turbojet Revolution*, Baltimore, MD: John Hopkins University Press.

Coopey, Richard. "Industrial policy in the white heat of scientific revolution." In *The Wilson Governments 1964-1970* edited by Richard Coopey, Steven Fielding and Nick Tiratsoo. London: Pinter: 102-122.

Cownie, John R. "Success Through Perseverance: the Rolls-Royce RB211 engine, *Putnam Aeronautical Review*, 4, December 1989, 230-9.

Department of Trade and Industry. *Rolls-Royce Limited, Investigation under Section 165(a)(i) of the Companies Act 1948, Report by R.A. MacCrindle QC and P. Godfrey FCA*, London: HMSO, 1973.

Doganis, Rigas. *Flying Off Course: The Economics of International Airlines*, London: Routledge, 3rd edn. 2002.

Dunne, J. Paul. "The Changing Military Industry Complex in the UK", *Defence Economics*, 4, (1993): 91-111.

Edgerton, David. *Warfare State: Britain, 1920-1970*, Cambridge: Cambridge University Press. 2006.

Evans, Harold. *Vickers: Against the Odds 1956-1977*, London: Hodder and Stoughton, 1978.

Freedman, Lawrence. "The case of Westland and the bias to Europe" *International Affairs*, 63, No. 1, (1986): 1-19.

Gardner, Charles. *British Aircraft Corporation: A History*, London: B.T.Batsford. 1981.

Gardner, Robert. *From Bouncing Bombs to Concorde*, Stroud: Sutton, 2006.

Garvin, Robert V. *Starting Something Big: The Commercial Emergence of GE Aircraft Engines*, Reston, VA: American Institute of Aeronautics and Astronautics, 1998.

Gilchrist, Peter. *Modern Civil Aircraft 4: Boeing 747*, 3rd edition, Shepperton: Ian Allen, 1999.

Grant, Robert M. *Contemporary Strategy Analysis*, 5th edition, Oxford: Blackwell.

Grimm, Curtis M., Hun Lee, Ken G. Smith. *Strategy as Action: Competitive Dynamics and Competitive Advantage*, New York: Oxford University Press.

Gummett, Philip. "Civil and Military Aircraft in the UK", *History and Technology*, 9, (1992): 203-222.

Gunston, Bill. *Rolls-Royce Aero Engines*, Sparkford: Patrick Stephens, 1989.

Gunston, Bill. *World Encyclopaedia of Aero Engines*, 3rd edition, Sparkford: Patrick Stephens, 1995.

Hanlon, Paul. *Global Airlines: Competition in a Transnational Industry*, Oxford: Butterworth-Heinemann, 2nd edition. 1999.

Hartley, Keith. "Aerospace: The Political Economy of an Industry", In *The Structure of European Industry*, edited by Henry W. de Jong, 3rd edition, Dordrecht: Kluwer.

Harvey, Giles. "Progress with the high-thrust Trent turbofan", *The Rolls-Royce Magazine*, No. 46, (1990): 2-5.

Harvey-Bailey, Alec. *Hives- The Quiet Tiger*, Historical Series No. 7, Paulsbury, Northants: Sir Henry Royce Foundation. 1985.

Hayward, Keith. *Government and British civil aerospace: A case study of post-war technology policy* , Manchester: Manchester University Press. 1983.

Hayward, Keith. *International Collaboration in Civil Aerospace*, London: Pinter. 1986.

Hayward, Keith. *The British Aircraft Industry*, Manchester: Manchester University Press. 1989.

Hayward, Keith. *The World Aerospace Industry: Collaboration and Competition*, London: Duckworth. 1994.

Heathcote, Roy. *The Rolls-Royce Dart – pioneering turboprop*, Historical Series No. 18, Derby: The Rolls-Royce Heritage Trust. 1992.

Hendy, John. *Innovating for Failure: Government Policy and the Early British Computer Industry*, Cambridge, MA: MIT Press, 1989.

Heppenheimer, T.A. *Turbulent Skies: The History of Commercial Aviation*, New York: John Wiley and Sons. 1995.

Hooker, Stanley. *Not Much of an Engineer,* Shrewsbury: Airlife Publishing. 1984.

Irving, Clive. *Wide-Body: The making of the Boeing 747*, London: Coronet Books, 1993.

Isaac, Debra. "What went wrong with Westland", *Management Today*, March (1986a): 72-75.

Isaac, Debra. "Rebirth at Rolls-Royce", *Management Today*, July (1986b): 44-51.

Kay, Anthony. L. *German Jet Engine and Gas Turbine Development 1930-1945*, Shrewsbury: Airlife Publishing, 2002.

Krook, Dan. "Great where others are too big", *The Rolls-Royce Magazine*, No. 11, December – February (1981): 14-17.

Lawrence, Philip K. and Thornton, David W. *Deep Stall: The Turbulent Story of Boeing Commercial Airplanes*, Aldershot: Ashgate. 2005.

Lloyd, Ian. "Five nation V2500 enters service", *The Rolls-Royce Magazine*, No. 41, June (1989): 14-18.

Lovering, John. "The Development of the Aerospace Industry in Bristol 1910-1984", Project Working Paper No. 5, ESRC Inner City in Context Research Programme, School of Advanced Urban Studies/Department of Geography, University of Bristol. 1984.

Lyth, Peter. J. "The history of commercial air transport: A progress report 1953-93", *Journal of Transport History*, 14, No. 2 (1993): 166-180.

Mecham, Michael. "BMW, Rolls-Royce Partnership Concentrates on the Small Engine Market", *Aviation Week and Space Technology*, 25th May (1992): pp70-72.

Millar, Ronald. and Sawers, David. *The Technical Development of Modern Aviation*, London: Routledge and Kegan Paul. 1968.

Mort, Maggie and Spinardi, Graham. "Defence and the Decline of UK Mechanical Engineering: The Case of Vickers at Barrow", *Business History*, 46, No.1 (2004): 1-22.

Mowery, David C. *Alliance Politics and Economics: Multinational Joint Ventures in Commercial Aircraft*, Cambridge, MA: Ballinger. 1987.

Nahum, Andrew. "Two Stroke or Turbine? The Aeronautical Research Committee and British Aero Engine Development in World War II", *Technology and Culture*, 38, No. 2 (1997): 312-354.

Nelms, Douglas. "The little engine with a big future", *The Rolls-Royce Magazine*, No. 50, September (1991): 7-10.

Newman, Nicholas. "How Westland Whirled", *Management Today*, April (1982): 67-74 and 116-118.

Norris, Guy. "Reverse Thrust: Engine makers to stake their prospects on new programmes as hopes of 2003 recovery recede", *Flight International* 3-9 December (2002): 47-56.

Norris, Guy. "Trent to lead 7E7 after landing ANA", *Flight International* 19-25 October (2004): 5.

Owen, Geoffrey. *From Empire to Europe: The Decline and Revival of British Industry since the Second World War*, London: Harper Collins. 1999.

Pattillo, Donald M. *Pushing the Envelope: The American Aircraft Industry,* Ann Arbor, MI: University of Michigan Press, 1998.

Penrose, Edith T. *The Theory of the Growth of the Firm*, Oxford: Oxford University Press. 1959.

Phillips, Almarin, Phillips, A. Paul, and Phillips, Thomas R., *Bizjets: Technology and Market Structure in the Corporate Jet Aircraft Industry*, Kluwer, Dordrecht. 1996.

Pugh, Peter. *The Magic of a Name: The First 40 Years*, Cambridge: Icon Books. 1999.

Pugh, Peter. *The Magic of a Name: The Power Behind the Jets 1945-1987*, Cambridge: Icon Books. 2001.

Reed, Arthur. *Britain's Aircraft Industry: What went right? What went wrong?* London: J.M.Dent & Sons Ltd. 1973.

Ritchie, Sebastian. *Industry and Air Power: The Expansion of British Aircraft Production 1935-1941*, London: Frank Cass, 1997.

Rogers, M. Foster. "Global competition in the aero engine industry", Paper presented at the Prince Bertil Symposium, 7-9 November, Stockholm, Sweden. 1984.

Rolls-Royce. "Dart Turboprop passes its 40th birthday", *The Rolls-Royce Magazine,* No. 30, September (1986b): 8-9.

Rolls-Royce. *1904-2004 a century of innovation*, London: Rolls-Royce Group plc.

Rowe, Brian H. “Aircraft engine industry”, In *National Interests in an Age of Global Technology*, edited by Thomas H. Lee and Proctor P. Reid. Washington: National Academy of Engineering. 1991: 93-97.

Smith, David. J. “Strategic alliances and competitive strategies in the European aerospace industry: the case of BMW Rolls-Royce GmbH”, *European Business Review*, 15, No. 4 (2003): 262-276.

Smith, David .J. and Rogers, M. Foster. “Technology Strategy and Innovation: The Use of Derivative Strategies in the Aerospace Industry”, *Technology Analysis and Strategic Management*, 16, No. 4 (2004): 509-527.

Sutton, John. *Technology and Market Structure: Theory and History*, Cambridge, MA: MIT Press. 1998.

Taylor, Trevor and Hayward, Keith, *The UK Defence Industrial Base: Development and Future Policy Options*, London: Brassey’s, 1989.

Tweedale, Geoffrey. “Industry and de-industrialization in the 1970s”. In Richard Coopey and Nicholas Woodward (eds.) *Britain in the 1970s: The troubled decade*, New York: St Martin’s Press, 1996: 251-272.

United Kingdom. House of Commons. *House of Commons papers*, HC 347, Memorandum from Sir David Huddie and Sir Denning Pearson. 1972.

UK Parliament. *Report of the Committee of Enquiry into the Aircraft Industry*, (Plowden Report) Cmnd 2853, London. 1965.

UK Parliament. *Trade and Industry Committee*, London. 1984.

UK Parliament. Trade and Industry Committee, Third Report. *British Aerospace Industry*, Volume 1, Cmd 563, London, 1993.

Uttley, Matthew R.H. *Westland and the British Helicopter Industry 1945- 1960: Licensed Production v. Indigenous Innovation*, London: Frank Cass. 2001.

Walters, Brian. “Rolls’ biggest fan”, *Air International*, 56, No.2 (1999): 115-118.

Wastnage, Justin. “Airbus briefs suppliers on A350”, *Flight International,* 28 September – 4 October, (2004): 6.

Watson, Jim. “Selection environments, flexibility and the success of the gas turbine”, *Research Policy*, 33, (2004): 1065-1080.

Wilson, John. *Ferranti: A History – Building a Family Business 1882-1975*, Lancaster: Carnegie. 2003.

Notes

1. Coopey, "Industrial policy in the white heat of the scientific revolution", 102; Edgerton, *Warfare State*, 265.
2. Dunne, "The Changing Military Industry Complex in the UK", 94.
3. Owen, *From Empire to Europe*, 311.
4. Rolls-Royce, *Annual Report 2005*, 14.
5. Uttley, *Westland and the British Helicopter Industry 1945- 1960*, 2.
6. Newman, "How Westland Whirled", 68.
7. Isaac, "What went wrong with Westland", 73.
8. Mort and Spinardi, "Defence and the Decline of UK Mechanical Engineering", 2.
9. Evans, *Vickers*, , 91.
10. Mort and Spinardi, "Defence and the Decline of UK Mechanical Engineering", 10.
11. Ibid., 17.
12. Gummett, "Civil and Military Aircraft in the UK", 206.
13. Hendy, *Innovating for Failure*; Wilson, *Ferranti*.
14. Millar and Sawers, *The Technical Development of Modern Aviatio*n, 134.
15. Pattillo, *Pushing the Envelope: The American Aircraft Industry*, 162.
16. Millar and Sawers, *The Technical Development of Modern Aviatio*n, 142.
17. Harvey-Bailey, *Hives - The Quiet Tiger*, 22; Millar and Sawers, *The Technical Development of Modern Aviatio*n, 143.
18. Millar and Sawers, *The Technical Development of Modern Aviatio*n, 143.
19. http://www.rolls-royce.com/people/; Pugh, Peter. *The Magic of a Name: The First 40 Years*, 262; Department of Trade and Industry, *Rolls-Royce Limited*, 4.
20. Heathcote, *The Rolls-Royce Dart*, 44.
21. Interview with Foster Rogers, 26th October 2004. The Rolls-Royce Merlin engine employed a supercharger to deliver improved performance. Superchargers utilize a centrifugal a compressor to compress the air going into a piston engine and this was the same type of compressor used on the Dart.
22. Churchill/PRSN 1/5 Copies of Papers submitted to the Rolls-Royce Board Committee of 27 February 1967.

23. Gardner, *From Bouncing Bombs to Concorde*, 86; Heathcote, *The Rolls-Royce Dart*, 46.
24. Lyth, “The history of commercial air transport”, 175
25. Churchill/PRSN, 1/29 Report, January 1967, on the commercial business generated by the Dart, Avon, Conway, Tyne and Spey aero engines 1952-65, updated November 1971, 4.
26. Ibid., 2.
27. Garvin, *Starting Something Big*, 17.
28. Gardner, *British Aircraft Corporation*, 71.
29. Pattillo, *Pushing the Envelope*, 158.
30. Gunston, *World Encyclopaedia of Aero Engines, 186.*
31. Bluestone, *Aircraft Industry Dynamics*, 63; Mowery, *Alliance Politics and Economics*, 1987, 39.
32. UK Parliament, *Plowden Report*, 12.
33. Ibid., 15.
34. Churchill/PRSN, 1/27 Memorandum of the Benefits of the RB211 Engine Order for the US Trijet and the British Economy, 30th January 1968, para. 2.4.
35. Bonaccorsi and Giuri, “The long-term evolution of vertically-integrated industries”, 1053-1083.
36. Taylor and Hayward, *The UK Defence Industrial Base: Development and Future Policy Options*, 17.
37. Lawrence and Thornton, *Deep Stall: The Turbulent Story of Boeing Commercial Airplanes*, 47.
38. Sutton, *Technology and Market Structure*, 446.
39. Bluestone, *Aircraft Industry Dynamics*, 60.
40. Churchill/PRSN 1/5 Copies of Papers submitted to the Rolls-Royce Board Committee of 27 February 1967: Business Analysis of Existing Projects.
41. Churchill/PRSN 1/29 Report, January 1967, on the commercial business generated by the Dart, Avon, Conway, Tyne and Spey aero engines 1952-65, updated November 1971, 5.
42. Lovering, “The Development of the Aerospace Industry in Bristol 1910-1984”, 20.
43. Churchill/PRSN 1/27 Memorandum on the case of the RB211-50, 2nd January 1970.

44. United Kingdom, *House of Commons papers*, 471.
45. Cownie, “Success Through Perseverance”, 231-2; Gilchrist, *Modern Civil Aircraft*, 8.
46. Churchill/PRSN 1/5 Copies of Papers submitted to the Rolls-Royce Board Committee of 27 February 1967, 1.
47. Churchill/PRSN 1/1 Copies of Board of Directors’ meeting minutes of Rolls-Royce.
48. Churchill/PRSN 1/31 Report on the export sales opportunity of the RB211, July 1967, 2.
49. Interview with Foster Rogers, 26th October 2004. Large HBPR engines are prone to flexing causing excessive wear of internal components such the outer edges of turbine blades. This reduces engine performance, hence a shorter being more rigid is more reliable.
50. Hitherto large HBPR engines used solid titanium blades with a narrow chord, which necessitated the use of a snubber to hold the blades in place. A wide chord fan eliminated the need for a snubber thereby improving aerodynamic efficiency.
51. Department of Trade and Industry, *Rolls-Royce Limited*, 359.
52. Hayward, *The British Aircraft Industry*,139.
53. Bonaccorsi and Giuri, “The long-term evolution of vertically-integrated industries”,1059.
54. Hooker, *Not Much of an Engineer*, 197.
55. Gunston, *Rolls-Royce Aero Engines*, 177.
56. Rolls-Royce. “Prospectus”, *Financial Times*, 30th April 1987, 14.
57. Gunston, *Rolls-Royce Aero Engines*, 210.
58. Bluestone, *Aircraft Industry Dynamics*, 62.
59. Lawrence and Thornton, *Deep Stall*, 78.
60. Rogers, “Global competition in the aero engine industry”, 11.
61. Rolls-Royce, *Annual Report 1982*, London: Rolls-Royce plc, 1.
62. Lambert, Richard and Makinson, John. “Rolls faces up to reality”, *Financial Times*, 4th February 1984, p16.
63. Rolls-Royce. *Annual Report 1984*, London: Rolls-Royce plc. 1985, 2.
64. Aris, *Close to the Sun*, 185.
65. Hayward, *The British Aircraft Industry*, 162.

66. Tweedale, "Industry and de-industrialization in the 1970s", 262.
67. Hartley, "Aerospace: The Political Economy of an Industry", 324.
68. Rowe, *National Interests in an Age of Global Technology*, 95.
69. Bonaccorsi and Giuri, "When shake-out doesn't occur: The evolution of the turboprop engine industry", 863.
70. Hayward, *International Collaboration in Civil Aerospace*, 142.
71. Birch, "International Thrust: IAE V2500 – derivative engineering at its best ", 369.
72. Norris, "Reverse Thrust, 47-56.
73. Rolls-Royce. *Annual Report 1983*, London: Rolls-Royce plc. 1984, p2.
74. UK Parliament. *Trade and Industry Committee*, 25.
75. Rogers, "Global competition in the aero engine industry", 14.
76. Pugh, *The Magic of a Name*, 314.
77. Rolls-Royce. *Annual Report 1986*, London: Rolls-Royce plc. 1987, 3.
78. Fisher, Andrew and Betts, Paul. "Rolls-Royce in BMW joint venture", *Financial Times*, 4th May 1990, 22.
79. UK Parliament, *British Aerospace Industry*, 25.
80. Walters, "Rolls' biggest fan", 116.
81. Department of Trade and Industry, *Rolls-Royce Limited*, 115; Irving, *Wide-Body*, 372.
82. Since the core operates under the most demanding conditions it is the most costly part of an engine to develop.
83. Interview with Foster Rogers, 26th October 2004. The modular design inherent in a three shaft configuration meant new technologies could be added to existing products. For example the 524G-T engine employs technology from the later Trent engine.
84. The Trent 600 engine was abandoned when the market failed to materialize.
85. Walters, "Rolls' biggest fan", 118.
86. Done, Kevin. "Engines revved up to impress unnerved investors", *Financial Times*, 29th January 2000, p4.
87. UK Parliament. *British Aerospace Industry, 15.*
88. Hayward, *The World Aerospace Industry*, 102.
89. Rolls-Royce. *Annual Report 2004*, London: Rolls-Royce plc. 2005, p18

90. Rolls-Royce. *Annual Report 2003*, London: Rolls-Royce plc. 2004, p8
91. Prebble, Lewis. "Technology Acquisition and Application – a services perspective" Paper presented at Aero Engine Expo 2005, London, 6th October 2005.
92. Garnett, Nick, "Rolls-Royce to buy NEI in deal worth £300m", *Financial Times,* 11th April 1989, p1.
93. Financial Times. "Rolls Steam Bath", *Financial Times*, 20th July 1996, p20.
94. Rolls-Royce. *Annual Report 2001*, London: Rolls-Royce plc. 2002, p7.
95. Pugh, Peter. *The Magic of a Name: The First 40 Years,* 262.
96. Grimm et al., *Strategy as Action,* 68.
97. Penrose, *The Theory of the Growth of the Firm*, 5.
98. Grant, *Contemporary Strategy Analysis,*132.
99. Rolls-Royce. *Annual Report 2003*, London: Rolls-Royce plc. 2004, p18.

Defence contractors and the growth of civil work_v1.2/5th November 2006