Technology Strategy and Innovation: The Use of Derivative Strategies in the Aerospace Industry

D.J.Smith and M.F. Rogers*

*Nottingham Trent University, *Civil Aviation University of China*

ABSTRACT

Strategy has become an increasingly important theme within the management of innovation. This is reflected in the increasing amount of attention given to topics such as technology strategy within the innovation literature. However research into technology strategy has tended to focus on technology acquisition rather than technology exploitation.

This paper focuses on one often neglected way in which companies can exploit the technological resources at their disposal, namely through the use of a derivative strategy where new technology is combined with old products or parts of old products in order to develop new products. The paper explores this type of strategy by means of a case study from the commercial jet engine sector of the aerospace industry. The case study provides an opportunity not only to explore the nature of derivative strategies in detail it also highlights the benefits, both direct and indirect, to be gained from this type of strategy as a means of exploiting an organisation's technological resources.

The paper shows how a derivative strategy can contribute to the broader strategic goals of companies in technology based industries through strategies designed to ensure the most effective utilization of the technology base.

Address for Correspondence:

Professor David J. Smith
Nottingham Business School
Nottingham Trent University
Burton Street
Nottingham
NG1 4BU

Tel. 00 44 115 848 4745
Email David.Smith02@ntu.ac.uk

Technology Strategy and Innovation: The Use of Derivative Strategies in the Aerospace Industry

Introduction

The rise, within the field of strategic management, of interest in the resource-based approach to strategy[1], has led to renewed interest in technology as one of the key resources of the firm. This in turn has produced a growing literature on technology strategy[2,3] as firms consider the most appropriate way to utilize their technological resources in the longer term.

The concept of technology strategy is defined by Clarke et al.[4] as,

> *'a strategic approach to the development of a firm's technology.'*

By this they mean that issues to do with a firm's technology should not be left to ad hoc short term decisions, but instead should be a central concern of senior management planning on a long term basis.

According to Clarke et al.[5] the central issue in technology strategy is the acquisition, development and exploitation of technology. Acquisition concerns decisions surrounding both the technologies to invest in and how to invest. Clarke et al.[6] note that where the latter aspect is concerned, firms can vary the degree to which technology acquisition is integrated into the organisation's activities. The degree of integration ranging from developing technology in-house to collaboration, licensing and the acquisition of assets. The need to span an ever-greater range of technologies has made technology acquisition a strategic issue in many technology-based companies according to a study by Granstrand et al.[7]. In their study of technology strategy in UK firms Clarke et al.[8] found evidence of increasing use of external methods of technology acquisition, especially among larger firms. This is true of the pharmaceutical industry where firms are increasingly turning to external sources as conduit for acquiring appropriate technologies, and doing so via a variety of collaborative arrangements[9].

Just as the acquisition of technology is one of the central concerns of technology strategy, so too is the exploitation of technology, but it appears to have received less attention from researchers. Having acquired and developed technological resources, technology strategy recognises that firms face a variety of options when it comes to the most appropriate exploitation of them.

Among the strategic issues surrounding the exploitation of technological resources are the means to be employed and the question of timing. This latter aspect has spawned a modest but influential literature. When it comes to timing, Christensen[10] has highlighted the dilemma faced by innovators. There are those, such as Foster[11] who advocate the benefits of early moves to secure a 'first mover' advantage, while others, such as Teece[12] have noted that in some circumstances a 'follower/imitator' strategy may be more appropriate.

When it comes to the means for exploiting technologies a variety of degrees of integration are available. Much attention in recent years has focussed on external arrangements for exploiting technology. This is especially true of the aerospace industry. External methods such as licencing have long been popular in aerospace, reflecting the huge sunk costs of aerospace programmes and the often complex political issues surrounding market access. More recently the aerospace industry has attracted a variety of collaborative arrangements[13]. Generically termed strategic alliances, they include various forms of joint venture and risk sharing partnership.

While the external means for exploiting technological resources have attracted considerable attention, the internal means have remained somewhat neglected by researchers reflecting the relative lack of developments in this field. The means for exploiting technological resources through internal means is normally confined to innovation in the form of new product development. However as Keeble[14] has pointed out, innovation is not confined to new product development, it can also involve continuing product innovations. Rothwell and Gardiner[15] have explored the latter under the umbrella term of 're-innovation'. Significantly one of the industries they focus on is aerospace.

Having observed[16] that,

> *'most studies of technological innovation have concentrated upon the commercial introduction of a new product,'*

they note that in many industry sectors there are relatively few completely 'new' products reaching the market. This causes them to highlight the importance of 'post launch improvements' which they observe can range from,

> *'design modifications and minor improvements to a complete re-think or a major re-design.'*

Where the latter is concerned Rothwell and Gardiner[17] comment that,

> *'it is sometimes possible to develop a new product, satisfying a new market, by utilizing existing technology or components.'*

They give the example of Black and Decker's development of a heat gun for paint stripping in the retail DIY market. Rothwell and Gardiner's work in highlighting this means of exploiting technological resources is significant. It is interesting that in addition to the Black and Decker example, they also cite examples from the aerospace industry. However they make little mention of another way in which this strategy can work, using new technology instead of existing technology. This is commonly used in aerospace where new products, especially aero engines, are developed by replacing outdated technology with new technology to create a new product that meets new market requirements. The CFM56 engine developed for the commercial market by General Electric and SNECMA, which was based on the 'hot core' of the F101 military engine[18], is a good example[19]. In aerospace this is usually termed a derivative strategy rather than re-innovation and the aim of this paper is to explore the concept of derivative strategy as a means of exploiting the technological resources of the firm as part of a technology strategy. Specifically the paper aims to explore the nature of derivative strategy, identify the potential benefits from this kind of technology strategy and explain why aerospace firms find it an attractive proposition. The paper does this by means of a case study of an aero engine programme. The programme in question is Rolls-Royce's Tay engine, which was undertaken in the 1980s with the very specific intention of transferring technology from the company's large high thrust RB211 engine to one of its older medium sized engines.

Rolls-Royce: Aero Engine Manufacturer

Rolls-Royce is one of three companies worldwide with the capability to design, develop, manufacture and market commercial jet engines. Founded in 1904, as a manufacturer of cars the company moved somewhat reluctantly[20] into aero engine manufacture during World War 1. However war time priorities meant that aero engine production soon exceeded that of cars. During World War 2 Rolls-Royce entered the field of turbojet technology when it acquired Frank Whittle's pioneering jet engine from the Rover company[21] . Rolls-Royce was able to use the expertise it had built up during the 1930s in developing compressor technology for supercharging conventional piston engines like the highly successful Merlin[22], to produce a viable jet engine for military use. By the end of World War 2, the company led the world in jet engine technology and the Rolls-Royce Nene engine was the leading turbojet engine of the late 1940s[23]. In the 1950s Rolls-Royce jet engines powered the world's first commercial jet airliner the De Havilland Comet[24]. However during the course of the first phase of the commercial jet engine industry's evolution[25] between 1958 and 1967, the civil jet airliner market came to be dominated by US manufacturers[26], who increased their share of total civil aircraft sales from 40 per cent in 1960 to 85 per cent in 1967[27]. These aircraft were powered in the main by engines built by the American engine maker Pratt and Whitney[28]. Furthermore projections made by Rolls-Royce in 1967 suggested sales of its civil aero engines then in production would decline from £69 million to under £4 million in 1975[29]. Hence when the second phase of the industry's evolution began in the late 1960s[30] with the development of the first wide-bodied jets, Rolls-Royce saw this as an opportunity to remedy the situation by making a concerted effort to break into the American market. Unfortunately it was the development of the high thrust RB211 that led to a financial crisis in 1971, which resulted in the company being taken over by the UK government and the car division being sold off.

Rolls-Royce in the 1970s

Despite early difficulties, the RB211 engine proved to be a technical success powering the Lockheed L1011 airliner, one of three first generation wide bodied jets that helped transform the economics of air travel in the early 1970s[31]. Sales of the RB211 were strong during the 1970s helped by two factors.

The first was the switch from single sourcing, where airliners were built using a single make of engine, to multiple sourcing where airliners were offered a choice of engines built by different manufacturers. This change accompanied the introduction of the first generation of wide-bodied airliners in the early 1970s. Hithertoo nationalism had been a feature of most sourcing decisions. Thus airliners built by the American manufacturer Boeing during the 1960s[32] were fitted with engines produced by the American engine manufacturer Pratt and Whitney. However when Britain pulled out of the European Airbus consortium in 1969, it opened the way to General Electric of the US with its CF6 engine supplanting Britain's Rolls-Royce[33] as engine supplier on the Airbus programme. The move away from nationalism to a more commercial environment suited the airlines as it gave them more choice and meant that competition between engine manufacturers resulted in lower prices. This change of policy also helped Rolls-Royce enormously. During the 1970s Rolls-Royce developed both up-rated and de-rated versions of its RB211 engine, in order to extend the number of airliner applications it could offer beyond the Lockheed L1011[34].

The second factor was the oil crisis of the late 1970s. A dramatic rise in the cost of aviation fuel meant airlines were increasingly interested in installing the most efficient engines. From 1975 until 1981 when Pratt and Whitney introduced a new fuel efficient version of its JT9 engine, Rolls-Royce's 524 version of the RB211 engine was the most fuel efficient engine available for the Boeing 747 jumbo jet. As a result British Airways and several other airlines ordered 747s fitted with Rolls-Royce engines.

Rolls-Royce in the 1980s

Rolls-Royce's success in recovering from the financial crisis of the early 1970s, masked a number of underlying difficulties that began to surface as the new decade opened and the commercial jet engine industry entered what Bonacorssi and Giuri[35] identify as the third phase of the industry's evolution beginning in the early 1980s.

The first of these difficulties was a deteriorating financial position[36]. In 1980 the company started to make substantial losses, caused in large part by a decision not to hedge the foreign exchange risk associated with its foreign currency transactions[37]. This policy had brought significant profits in the late 1970s, but as Britain became an oil exporting nation in the early 1980s, and the in-coming government instituted a high interest rate policy, the company was caught out by the rapid appreciation of the UK pound. In 1981 Rolls-Royce made a loss of £93m and this worsened to £115m[38] two years later, almost all attributable to the foreign exchange risk associated with its American contracts[39].

The second of these difficulties focussed on adverse competitive conditions at the beginning of the decade. The combination of de-regulation in the US and a worldwide recession[40] made life very difficult in the civil aviation business. Orders for new airliners fell sharply. From a level of 700 to 800 new jet airliners per year in the late 1970s, orders fell to 223 in 1982, and in that year Rolls-Royce sold a total of 30 of its RB211 engines[41]. To add to the company's woes, Lockheed its principal customer for the RB211 announced that it was exiting civil aviation work by ceasing production of its L1011 wide-bodied jet, with the last L1011 being completed in 1983[42]. By 1985 Rolls-Royce had just 11 per cent of the commercial jet aero engine market compared to General Electric's 32 per cent and Pratt and Whitney's 51 per cent.

The third problem area surrounded the introduction of new Federal Aircraft Regulations (FAR): Part 36, Stage 3 noise regulations, designed to curtail aircraft noise, and due to come into effect in 1986[43], which meant that Rolls-Royce's existing medium-sized engines of 10,000 – 20,000lbs thrust, the Spey and the Conway, which had been designed at a time when noise issues were not a priority, would be obsolete.

This would not only affect sales of airliners fitted with Rolls-Royce engines, but other aircraft as well including the highly successful Gulfstream business jet.

****

Insert Table 1

****

Finally Rolls-Royce faced the prospect that since most of the airliners which utilized its medium sized jet engines had, or soon would, cease production. Table 1 shows that by 1980 most of the first generation European airliners introduced in the 1960s, had ceased or were about to cease production. Since almost all of these airliners, including the French built Caravelle, were Rolls-Royce powered, the company was facing a bleak position in terms of sales of all but its large engines.

Just how bleak this picture was is illustrated by figures from Rolls-Royce itself. The company estimated that in 1980 it was producing engines for just four types of commercial airliner[44]. This compares with General Electric which offered engines for nine types and Pratt and Whitney which offered engines for ten[45]. With such a narrow product range inevitably Rolls-Royce's long term prospects in the commercial jet engine market were poor.

New Engines

By the early 1980s Rolls-Royce was not the only company worried about the consequences of new noise regulations. The American business jet manufacturer Gulfstream, was extremely concerned. The company's Gulfstream III business jet powered by two Rolls-Royce Spey engines was proving very successful[46]. Table 2 shows that sales to American customers were building up steadily in the early 1980s and these were matched by a similar level of sales to foreign customers. Despite this Gulfstream faced problems over noise, not only the prospect of new much tougher FAR Stage 3 noise regulations due to come into force in 1986[47], but complaints from local committees around airfields across the US where Gulfstream III aircraft were operating. Gulfstream also faced the prospect of increasing competition from new competitor aircraft then under development, especially the French built Dassault Falcon 900 and the Canadian Canadair Challenger CL601. These new aircraft were direct competitors in the *'heavy iron'* [48] niche of the business jet market that Gulfstream had previously had to itself. Faced with these problems, Gulfstream looked initially at using a 'hushkit' for its Spey engines. The design favoured was a 'translating ejector' – a retractable form of noise suppressor. Unfortunately the design proved expensive to develop, added considerable additional weight that resulted in reduced fuel consumption. As a result Gulfstream decided not to proceed with this option.

****

Insert Table 2

****

The problems with the Spey had long been recognised. The Spey engine was developed in the late 1950s and ran for the first time in December 1960. It had been designed and built in a hurry as a 'crash programme', following a *'diktat'*[49] by Britain's state-owned airline BEA in 1959, that the planned De Havilland Trident airliner, for which BEA was the prime customer, be reduced in range and size (from 120 seats to 87). This meant that the Rolls-Royce Medway engine of 14,000 lbs thrust, that De Havilland planned to use, was too big. As a result Rolls-Royce had to very rapidly develop a new smaller engine, the 10,000lbs thrust Spey, at short notice. Having pioneered the fanjet or turbofan principle on its larger Conway engine[50], Rolls-Royce again opted for a similar design for the Spey. The architecture of the turbofan creates a flow of air that bypasses the engine core. This flow of air not only improves the efficiency of the engine it also reduces engine noise. Unfortunately Rolls-Royce at the time failed to appreciate just how effective this could be. The bypass ratio, which governs the proportion of air on a turbofan design that bypasses the engine core, was set at a lowly 0.64 on the original Spey[51] design. This meant that the fuel consumption of the Spey was poor, but this was not regarded as critical since the Trident was intended for short haul operations where fuel economy is much less important. Unfortunately the low bypass ratio also meant that the Spey was a notoriously noisey engine. At the time, in 1960, jet airliners were still something of a novelty, with relatively few in operation (jet services only started in 1958).

Consequently aircraft noise was not the major environmental issue it had become by the end of the decade.

The RB401 engine

Rolls-Royce's Bristol Engine Division had since 1974 been developing a new and more efficient small turbofan engine. Developed by what had been Bristol Siddeley engines until taken over by Rolls-Royce in 1966, the RB401 was an internally funded engine project in the 5,000 lbs thrust class designed for the developing market for medium-sized business jets. First run at the end of 1977, the RB401 was an advanced design with a high bypass ratio that incorporated a number of features from its much larger cousin the RB211[52]. Designed as a replacement for the Viper engine, the low parts count and excellent performance figures meant that the RB401 should have been attractive in the business jet sector of the commercial jet engine market. Unfortunately this sector is extremely fragmented[53] and it is not uncommon for engine companies to be unable to find a launch customer who can provide an economically viable launch. This proved to be the case with the RB401, and by 1980 no applications had been secured.

Hence when the American business jet manufacturer, Gulfstream, seeking a new engine that would meet the new FAR stage 3 noise requirements due to come into force in 1986, proposed a revised and up-rated version of their large, long range, Spey-powered Gulfstream III business jet, to be called the Gulfsream IV, the Bristol team were keen to put forward their engine. Gulfstream had a long association with Rolls-Royce. The first executive aircraft built by Grumman, the Gulfstream I, which first flew in 1958, was powered by two Rolls-Royce Dart turboprop engines. All the later versions of the Gulfstream used Rolls-Royce engines. Although the RB401 was significantly less powerful than the Spey, Gulfstream was sufficiently impressed with the performance and the noise level to commit to the new engine. To achieve the required amount of power the preliminary specification of the new up-rated Gulfstream IV, was a 4 engined design using the Rolls-Royce RB401[54]. The use of the RB401 meant that compared to its predecessor, the Gulfstream IV would meet the new noise requirements with ease. Gulfstream even began to explore a new smaller capacity 2 engined design , the Gulfstream V using two RB401 engines, and aimed at a different sector of the fragmented business jet market.

Seeing the RB401 as the solution to its problems, Gulfstream, which had split off from its parent company Grumman and was now led by Allen Paulson, raised the necessary finance for development work on the Gulfstream IV from a consortium of banks. Design work on the 4-engined, RB401 powered Gulfstream IV began in 1981. As well as having new engines the Gulfstream IV design incorporated a number of other technological improvements including a super critical wing, extensive use of composites and state-of-the art electronic instrumentation.

However when Allen Paulson and his colleagues at Gulfstream learnt in December 1982, only one week before the official launch of the 4 engined Gulfstream IV, that Rolls-Royce were planning another more powerful engine that was also capable of meeting their requirements but with two engines rather than four, they cancelled the project with immediate effect. The other engine that Rolls-Royce was planning was the Hi-flow Spey or as it was eventually known, the Tay engine.

The Tay engine

The studies which led to the launch of this other more powerful engine, began with the search by the Dutch aircraft manufacturer, Fokker, for a quieter powerplant as a way of overcoming the problems it faced with its Spey powered short haul F28 regional airliner[55]. Work on the 'Hi-flow Spey'[56] as the engine was initially known, began at East Kilbride[53], Rolls-Royce's plant in Scotland in 1981. Opened in the early 1950s to make engines for the Korean War[58], historically the plant dealt only with military engines. However internal reorganisation and rationalisation undertaken by the company at the start of the 1980s as part of a major cost cutting drive[59] had resulted in Derby becoming the focus for work on large high thrust engines like the RB211, with production of older commercial engines, like the Spey, being transferred to East Kilbride. In spite of the rationalisation, East Kilbride at the time retained a 600 strong design team[60]. Able to offer an integrated service that included design, development and product support as well as production, the East Kilbride plant had close links with customers such as the Dutch aerospace firm Fokker. Staff were aware that the company was looking to upgrade the successful F28 airliner to meet new market requirements in terms of fuel economy and noise.

There had been earlier attempts to develop a quieter Spey engine. The Spey like the Conway, the world's first fanjet or turbofan was basically a turbojet which bypassed only a small fraction of the inlet flow. According to Gunston[61] the Spey was developed,

> *'just at the time that Rolls-Royce was recognising that its choice of bypass ratio was much too timid'.*

Consequently earlier work on the Spey had focussed on simply fitting a larger fan to the front of the engine in order to raise the bypass ratio and make it quieter. In the mid-1970s, work on the Spey 606[62], a new version of the Spey with a larger fan to give an increased bypass ratio of 1.96, reached the detailed engineering design stage. However the airframe application intended for this engine, the BAC One Eleven 700, never materialised because of the nationalisation of the British Aircraft Corporation to create what became British Aerospace.

When Gulfstream cancelled their proposed 4 engined Gulfstream IV, Rolls-Royce was forced to move very quickly. The company's head of civil engines at the time, Ralph Robins, hurriedly negotiated a deal with Gulfstream whereby they would use Rolls-Royce's alternative engine design on a two engined version of the proposed Gulfstream IV. The terms of the deal, covering price, performance and delivery were famously sketched on a table napkin and agreed over dinner by Ralph Robins and Allen Paulson in December 1982[63]. The Tay, as the new engine was now known, was officially launched in March 1983 with an order from Gulfstream for 200 engines together with a cash deposit. Allen Paulson said that he expected Gulfstream to buy more than 300 engines over a 10 year period. Some months later in November 1983 Fokker ordered 100 engines for its new F100 regional jet and further orders soon followed (see table 3).

****

Insert Table 3

****

Development of the Tay proved remarkably rapid. The project was helped by the fact that Ralph Robins, who had secured the deal with Gulfstream, was appointed Rolls-Royce's Managing Director in 1984. Not only was he familiar with the project and one of its most enthusiastic supporters, he was now in a position to act as 'godfather' to the project ensuring that the various hurdles the project faced were successfully negotiated. This was important. The Thatcher government had won a second term in 1983 and indicated that it wanted to see Rolls-Royce privatised in the near future. As a result short term financial performance was a high priority for the company. The business case for the Tay showed that although total expenditure on the project was comparatively modest at almost £100million, the greatest outlay was likely to occur in the run up to privatisation. Cashflow was unlikely to be positive until the end of the decade. Under these circumstances the project had some important internal hurdles to clear within the company, that could easily have led to cancellation.

As it turned out development of the Tay proved remarkably trouble free. Design studies were completed in August 1983. The Tay engine ran for the first time a year later in August 1984. By June 1985 Rolls-Royce had six engines on test. In the same year the project faced major uncertainty as the American car maker Chrysler bought Gulfstream for $637million[64]. However the uncertainty soon subsided when Allen Paulson was retained as president and chief executive. The first Gulfstream IV was rolled out in September 1985 and the first flight took place on 19th September 1985. The Tay engine was certificated in 1986 and entered service on schedule on the Gulfstream IV in spring 1987. By this time Rolls-Royce had a more powerful version of the Tay running and it entered service on the Fokker F100 in April 1988.

The Tay proved to be one of Rolls-Royce's most successful and most profitable engines. Sales were better than initially forecast. As table 4 indicates, the introduction of the Tay engine resulted in the company regaining its share of this important market segment. In October 2002, shortly before Ralph Robins, by now nearly 70, retired as Chairman of Rolls-Royce, Gulfstream took delivery of its 1000th Tay engine for the

Gulfstream IV. Nor was success confined to the 'heavy iron' business jet market. Table 3 shows that the engine enjoyed considerable success in the regional airliner market, with deliveries of the Fokker F100 and its sister airliner the slightly smaller F70, reaching more than 300 by the late 1990s. In addition the Tay successfully opened up a market niche that was not part of the original business plan when the engine was first launched, namely the market for re-engining airliners being converted to freighters. The company's biggest success in this market came in 1990 when Rolls-Royce successfully negotiated the sale of 280 Tay engines as part of a $600 million contract to re-engine the entire Boeing 727-100 fleet of United Parcel Service (UPS) to enable it to meet new more stringent noise regulations[65].

****

Insert Table 4

****

Derivative Strategy: the application of advanced technology

Unlike the earlier Hi-flow Spey project that was ultimately stillborn, the Tay engine project involved much more than simply fitting a bigger fan. The aim was to take the well proved and reliable high pressure 'hot core' of the Spey engine and combine it with elements of the advanced technology developed as part of the RB211 programme. In this the Tay differed from other similar derivative engines produced by Rolls-Royce at this time such as the 524 and 535 engines. These were derivative engines, but they were developed as up-rated and de-rated versions of the RB211. That Rolls-Royce was able to develop two new engines in this way was testimony to the RB211 concept which proved to be a truly robust design[66].

The Tay was different in that the intention was not so much to make it more or less powerful (in fact it was considerably more powerful), but to apply the technology of another more modern engine programme, in order that it could meet the more demanding requirements of the market.

Unfortunately the 'hot core' of the original Spey engine as used in the Trident and BAC One Eleven airliners did not have a very good record in terms of reliability. However a later version of the engine, the Mk 555 developed for the Fokker F28 airliner, was much more reliable and the 'hot core' of this version of the Spey formed the basis of the Tay. To this 'hot core', or high pressure (HP) section which forms the heart of a modern turbofan engine, was added a new fan and associated booster stages at the front of the engine, a new low pressure (LP) turbine at the rear of the engine, needed to power the new fan, a new combustion system and a new larger bypass duct. In each case the opportunity was taken to employ the latest RB211 derived advanced technology in each of these modules.

The most obvious case of this was the new fan. Early single stage fans, such as that employed on the Spey used high aspect ratio blades made from forged titanium. The blades themselves were long and thin. The width of the fan blade was restricted by the need for low weight in order to avoid containment problems in the event of damage to the fan. While a narrow blade was lighter it was subject to vibration. To eliminate this it was necessary to brace the blades at approximately mid-length by means of a 'snubber', a reinforcing ring designed to support the blades. The snubber contributed nothing to the fan's primary function and had an adverse effect on efficiency because it gave rise to pressure losses that reduced the flow capacity of the fan[67].

In place of this type of arrangement, the Tay utilized a 'wide chord' fan derived from the 535E4 version of the RB211. Rolls-Royce's attachment to the idea of a wide chord fan went back to the 1960s when the company developed a wide chord fan constructed of carbon fibre composite for the original RB211[68]. Unfortunately while the fan proved more efficient, it presented problems of blade integrity which at the time could not be resolved. However, while the company was forced to revert to a titanium fan using snubbers for the RB211, it stuck with the idea of a wide chord fan and in the early 1980s developed a hollow titanium wide chord fan that was both light and strong. The first engine to benefit from this development in fan technology was the 535E4 engine which first flew in August 1983 and went into revenue earning service on the Boeing 757 in October 1984[69].

A key feature of the wide chord fan was that the wider blades were more rigid. This eliminated the need for a snubber, which in turn improved the aerodynamics of the fan. A wide blade could use a more efficient airfoil profile[70]. It also meant that the fan needed fewer blades and the 535E4 engine had 22 blades compared to 33 on the earlier 535C version. The result was a significant increase in fan efficiency from 88 per cent to 92 per cent. The end result was less weight, less noise and less fuel consumed. The noise and efficiency benefits were particularly important, since the introduction of the wide chord fan came in the wake of the second oil crisis and just before the introduction of tighter noise regulations.

First fitted to the 535E4 engine, as an innovation the wide chord fan had important implications for Rolls-Royce's product portfolio. The fan is one of the pivotal engine sub-systems on a turbofan engine[71]. On a high bypass ratio engine the fan provides as much as 75 per cent of the thrust of the engine. Hence improvements in fan efficiency have important implications for engine economics. The wide chord fan represented what Henderson and Clark[72] term a modular innovation. This type of innovation according to Henderson and Clark[73] is,

> *'an innovation that changes a core design concept without changing the product's architecture'.*

Since it doesn't change the architecture, the scope for retrospective applications should be considerable. This is exactly what Rolls-Royce proceeded to do with the innovative wide chord blade design,

> *'diffused back into the RB211 family to improve further the fuel and thrust ratings.'*[74]

As figure 1 shows the wide chord fan technology was duly applied to the more powerful 524 engine that powered the Boeing 747 and the collaborative V2500 engine that powered the Airbus A320. However one of the first applications after the 535E4 was the Tay engine.

****

Insert Figure 1

****

The fan on the Tay employed a solid titanium fan blade, rather than a hollow one, but it was nonetheless a wide chord design and it provided significant improvements in thrust, fuel economy and noise reduction.

Nor was the wide chord fan design the only example of RB211 advanced technology utilized on the Tay. The opportunity was taken to significantly increase the bypass ratio. By the early 1980s Rolls-Royce, along with other engine manufacturers had a better grasp of the design features of turbofan engine architecture, helped by their experiences in developing the first generation of high bypass engines like the RB211. As Gunston[75] notes,

> *'the advent of the giant wide-bodied airliners made it self-evident that their quiet fuel efficient technology would have to percolate down to smaller airliners'.*

Thus the fan used on the Tay was bigger than that on the Spey, being some 44 inches in diameter, and this made it possible to configure the engine with the bypass ratio raised from 0.64 on the Spey to 3.0[76]. With a much bigger proportion of the flow of air into the engine now bypassing the core, this made the engine both quieter and more efficient.

The bypass duct through which the air was fed represented another area where new technology was applied. Rolls-Royce was one of the first aerospace companies to see the potential of carbon fibre technology. Although its first application of this technology, the carbon fibre fan, proved unsuccessful, the company continued to be, 'interested in the use of carbon fibre for aero engines'[77]. The Tay was the first commercial aero engine to utilize a carbon fibre bypass duct[78]. Using this material brought benefits in terms of reduced weight and greater strength.

Other major engine sub-systems benefited from the application of advanced technology developed for Rolls-Royce's large high thrust engines. On the Tay a new combustion chamber was developed incorporating porous Transply material that reduced the amount of cooling air required resulting in improved engine efficiency[79]. Similarly a new three stage low pressure (LP) turbine was used with improved aerodynamics designed for high efficiency and low noise generation[80].

Discussion

Essentially the development of the Tay engine provides an example of the application of advances in technology to an existing well established product, in order to create a new product. That the resulting product genuinely was new, and not just a modest incremental improvement, can be gauged from the fact that the Tay engine was fitted to new aircraft such as the Gulfstream IV business jet and the Fokker 100 airliner. As an example of technology strategy the Tay case illustrates one way, amongst many, in which an organisation's technology and technological resources can be exploited. In the process it also shows that derivative strategies, which are commonly used on aerospace programmes, are not confined to up-rating or de-rating an aircraft or an engine, as in the case of Rolls-Royce's 524 and 535 engines or for that matter producing a commercial version of a military engine as General Electric did with the CF34 version of its T34 military jet engine, in order to create a product 'family'[81] by virtue of a 'robust design'.

As a case the Tay engine sheds light on the potential benefits to be derived from derivative strategies. When compared with the alternative technology strategy of developing an entirely new engine, the derivative approach, as exemplified by the Tay provides a number of benefits. For an engine manufacturer, such as Rolls-Royce, the benefit of utilizing an existing engine 'hot core' is that it significantly reduces the cost of developing a new engine[82] and getting it into production. Since the 'hot core' is the part of the engine that, in terms of temperature and pressure[83], operates under the most extreme conditions, it is inevitably the most difficult element in an engine's design[84] and very expensive to develop, test and certificate. On a new engine developed on a 'clean sheet' basis, development costs typically exceed $1 billion[85]. The Tay in contrast cost only £100 million to develop. Some measure of the impact of this cost saving may be gauged by the fact that by the 1990s the Tay was acknowledged to be Rolls-Royce's most profitable engine programme[86].

Secondly the development of a new engine 'hot core' is a lengthy process. Again this is because this section of the engine operates under such demanding conditions. Inevitably it takes a long time to design, develop and certificate. The development of a new 'hot core' can easily mean that it takes six to ten years to get a new engine into production, even longer than for the development of a new airframe[87]. In contrast the development of the Tay, using an existing reliable and well proven 'hot core' took four years. Given the gap that had appeared in Rolls-Royce's product portfolio by the early 1980s when the company could supply engines for just four civil airframe applications[88], reducing the lead time taken to get the new engine into service was an important consideration.

Finally using an existing core reduces can provide important benefits for an engine manufacturers' customers, especially when the engine is a relatively small one and used on aircraft such as regional jets which are used for short routes and therefore subject to extensive maintenance. Parts on the 'hot core' of the engine, such as high pressure (HP) turbine blades, represent one of the major costs to an operator in terms of the purchases of spares[89]. Hence using an existing 'hot core' means that airlines have much less need to re-train maintenance staff or invest in additional spares inventory.

However as well as these direct benefits from a technology strategy based on applying new technology to an existing and established product to create a new product, there are further indirect benefits that have important implications in terms of corporate strategy and the strategic management of an enterprise.

Firstly, Rolls-Royce's long term strategy has in recent years been to achieve a 30 per cent share of the total commercial jet engine market[90]. In the 1970s and 1980s the company's market share was at best about 10 per cent. The logic behind the pursuit of a substantially bigger market share as a strategic goal is that the commercial jet engine market has traditionally been dominated by three firms, the 'Big Three' of Pratt and Whitney, General Electric and Rolls-Royce, and that to remain competitive it is necessary to maintain a substantial slice of the market. In an oligopoly comprising three firms, a market share of less than 30 per cent makes it difficult to remain competitive because the market leader will inevitably have a much bigger market share. Not only does this mean a gap between the firm in question and the market leader, in terms of volume of production, it in the commercial jet engine market it also means a gap in terms of the installed engine base. Since sales of commercial jet engine spares are a function of the size of a company's installed engine base, and spares are typically the most profitable part of the aero engine business, this puts any firm with a small share of the market for new engines at a serious disadvantage. In order to maximise market share engine companies need to be represented in as many sectors of the commercial jet engine market as possible, because airlines tend to stick with existing engine suppliers[91]. Hence a technology strategy that helps an engine manufacturer extend its product portfolio rapidly and economically, as was the case with the derivative strategy employed for the Tay engine, has important indirect benefits in terms of long term strategy.

The second aspect is to do with technology itself, especially the maintenance of a competitive technology base. In the aerospace industry, technology is critical for competitive advantage and this means that firms have to spend vast sums on R & D in order to maintain a competitive technology base. Given this huge investment which is an essential requirement, especially in the aero engine sector, in order for firms to keep up and remain competitive, aero engine manufacturers have increasingly to look to ways of making the best use of their technology base. This means taking every opportunity to put the technology derived from the technology base to work. In Rolls-Royce's case this amounts to a deliberate policy. Described at one time as a policy of 'economy in technology'[92] and more recently as a policy of 'create once and use many times'[93], it amounts to applying the technology developed for one engine programme to as many other engine programmes as possible in order to gain economies of scope.

Both of these strategic considerations meant that Rolls-Royce was anxious to extend its product portfolio to the point where it was represented in all the market segments that made up the commercial jet engine market. This formed the basis of the company' s competitive strategy. Such a strategy is described as a 'full line strategy'[94 95], implying that aero engine manufacturers aim to offer a product portfolio that covers all sectors of the commercial jet engine market. Thus the derivative strategy employed to develop the Tay engine, as well as providing direct benefits also contributed indirect benefits. These were particularly important in terms of the company's competitive strategy, the cornerstone of which was the maintenance of a competitive technology base.

Conclusion

The case study of the Tay engine provides valuable insights into the use of derivative strategies in the aerospace industry. As far as the nature of derivative strategy is concerned, the Tay case shows that such a strategy can involve more than developing up-rated or de-rated versions of an existing product. Similarly it shows that it can involve more than the use of an existing design or existing components in the development of a new product. The case clearly shows that a derivative strategy can be a way of exploiting new technology, in this case Rolls-Royce's wide chord fan technology, by applying it to components or modules of an existing product in order to develop, a new product. When used in this way, a derivative strategy represents one form of technology strategy, in that it is a means of exploiting the technological resources of an organisation.

The Tay case, occurring as it did at a crucial point in Rolls-Royce's recovery and return to a position of strength within the Big Three group of aero engine manufacturers, brings into sharp relief the benefits of a derivative strategy. However one of the advantages of a case study of an engine programme begun 20 years ago is that one can set what occurred against the backdrop of developments across the engine sector of the aerospace industry. Doing this shows that the direct benefits of the use of a derivative strategy, in terms of a shorter lead time and lower development costs, were not the only benefits that accrued. In fact the use of a derivative strategy contributed significant indirect benefits. In the main these have taken the form of economies of scope through spreading the cost of maintaining a competitive technology base. Given the importance of competing through technology for aero engine manufacturers, especially those who compete in the large engine sector where performance in terms of fuel efficiency is critical to success, this is clearly a valuable contribution.

When the direct and indirect benefits are taken together, it becomes perhaps a little clearer why derivative strategies are popular and widely used, as a form of technology strategy, in all sectors of the aerospace industry.

References

1. R. M. Grant, 'The resource-based theory of competitive advantage: implications for strategy formulation', **California Management Review**, 33 (3), 1991, pp. 114-135.

2. M. Dodgson, 'Technology Learning, Technology Strategy and Competitive Pressures', **British Journal of Management**, 2 (3), 1991, pp. 133-149.

3. M. Dodgson, **The Management of Technological Innovation: An International and Strategic Approach**, (Oxford, Oxford University Press, 2000).

4. K. Clarke, D. Ford, M. Saren and R. Thomas, (1995) 'Technology Strategy in UK Firms', **Technology Analysis and Strategic Management**, 7 (2), 1995, pp. 169-190.

5. **Ibid**., p. 171.

6. **Ibid**., p. 171.

7. O. Granstrand, C. Oskarsson, N. Sjoberg and S. Sjolander, (1990) 'Business Strategies for New Technologies', in: E. Deiaco, E. Homell, and G. Vickery, (Eds) **Technology and Investment: Crucial Issues for the 1990s**, (London, Pinter, 1990).

8. Clarke, Ford, Saren and Thomas, **op. cit**., Ref. 4, p. 188.

9. D.J. Bower, 'New Technology Supply Networks in the Global Pharmaceutical Industry', **International Business Review**, 2 (1), 1993, pp. 83-95.

10. C.M. Christensen, **The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail** (Boston, Harvard Business School Press, 1997).

11. R.N. Foster, **The Attacker's Advantage** (London, Pan Books, 1986).

12. D.J. Teece, 'Profiting from technological innovation: implications for integration, collaboration, licensing and public policy', **Research Policy**, 15, 1986, p. p285-305.

13. P. Dussauge and B. Garrette, **Cooperative Strategy: Competing Successfully through Strategic Alliances**, (Chichester, Wiley, 1999).

14. D. Keeble, 'Small firms, innovation and regional development', **Regional Studies** 31, 1997, pp. 281-293.

15. R. Rothwell and P. Gardiner, 'The Strategic Management of Innovation', **R & D Management**, 19 (2), 1989, pp. 147-160.

16. **Ibid**., p. 147.

17. **Ibid**., p. 152.

18. K. Hayward, **International Collaboration in Civil Aerospace**, London, Pinter, 1986).

19. Dussauge and Garrette, **op. cit**., Ref 13.

20. P. Pugh, **The Magic of a Name: Part One, The First 40 years**, (Cambridge, Icon Books, 2000), p. 62.

21. J. Golley, **The Genesis of the Jet: Frank Whittle and the Invention of the Jet Engine**, Shrewsbury, Airlife Publishing, 1996), p. 205.

22. S. Hooker, **Not much of an Engineer**, (Shrewsbury, Airlife Publishing, 1984), p. 31.

23. V.P. Dawson, 'The American Turbojet Industry and British Competition: The Mediating Role of Government Research', in: W.M. Leary (Ed), **From Airships to Airbus: The History of Civil and Commercial Aviation, Volume 1, Infrastructure and Environment**, (Washington, Smithsonian Institution Press, 1995), . 137.

24. M.F. Rogers, **Global Competition in the Aero Engine Industry**, Paper presented at the Prince Bertil Symposium, 7-9 November 1984, Stockholm, Sweden.

25. A. Bonaccorsi, and P. Giuri, 'Industry life cycle and the evolution of an industry network', **LEM Working Paper Series**, No. 4, December 2000, Sant' Anna School of Advanced Studies, Pisa, Italy.

26. V.P. Dawson, **op. cit**., Ref. 23.

27. Financial Times, 7th April 1987.

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

29. Financial Times, **op. cit**., Ref 27.

30. Bonaccorsi and Giuri, **op. cit**., Ref. 25, p. 18.

31. R. Doganis, R. (2002) **Flying Off Course: The Economics of International Airlines**, 3rd edition, London, Routledge, 2002).

32. One notable exception was the purchase, by Britain's BOAC in the early 1960s, of Boeing 707 airliners powered by Rolls-Royce Conway engines.

33. A. Reed, **Britain's Aircraft Industry: What went right? What went wrong?** (London, J.M. Dent and Sons Ltd, 1973), p. 122.

34. K. Hayward, **The British Aircraft Industry**, (Manchester, Manchester University Press, 1989).

35. Bonaccorsi and Giuri, **op. cit**., Ref. 25, p. 20.

36. K. Kaivanto, 'Post Concorde Developments in the UK Civil Aerospace Industry', **Warwick Business School Research Papers**, No. 206, 1996, University of Warwick, Coventry.

37. K. Hayward, **Government and Civil Aerospace: a case study in postwar technology policy**, (Manchester, Manchester University Press, 1983), p203.

38. Kavianto, **op. cit**., Ref. 36, p. 9.

39. Hayward, **op. cit**., Ref. 34, p. 159.

40. P. Pugh, **The Magic of a Name: Part Two, The Power behind the Jets 1945-1987**, (Cambridge, Icon Books, 2001), p. 297.

41. **Ibid**., p. 304.

42. Heppenheimer, **op. cit**., Ref. 28, p. 254.

43. K. Goddard, **The Rolls-Royce Tay Engine and the BAC One-Eleven**, Historical Series No. 30, (Derby, Rolls-Royce Heritage Trust, 2000).

44. Rolls-Royce **Annual Report 1996**, (London, Rolls-Royce plc, 1997), p. 8.

45. Hayward, **op. cit**., Ref. 34, p. 162.

46. T.C. Treadwell, **Ironworks: The Story of Grumman and its Aircraft**, Stroud, Tempus Publishing, 2000).

47. Goddard, **op. cit**., Ref. 43, p. 15.

48. A. Phillips, A.M. Phillips and T.R. Phillips, **Bizjets: Technology and Market Structure in the Corporate Jet Aircraft Industry**, (Dordrecht, Kluwer, 1994).

49. Hayward, **op. cit**., Ref. 37, p. 34.

50. Heppenheimer, **op. cit**., Ref. 28, p. 188.

51. B. Gunston, **World Encyclopaedia of Aero Engines**, 3rd edition, (Sparkford, Patrick Stephens, 1995).

52. B. Gunston, **Rolls-Royce Aero Engines**, (Sparkford, Patrick Stephens, 1989).

53. Interview with John Ashmole, Moor Lane site, Derby, 8th April 1983.

54. Phillips, Phillips and Phillips, **op. cit**., Ref. 48, p111.

55. Interview with John Ashmole, Moor Lane site, Derby, 8th April 1983.

56. Goddard, **op. cit**., Ref. 43, p14.

57. Goddard, **op. cit**., Ref. 43, p6.

58. R. Botham, E. Simpson and V. Whyte, **Scottish Aerospace: An Actual or an Embryonic Cluster?** (Glasgow, Training and Employment Research Unit, University of Glasgow, 2001).

59. Pugh, **op. cit**., Ref. 40, p300.

60. Botham, Simpson and Whyte, **op. cit**., Ref. 58, p20.

61. Gunston, **op. cit**., Ref. 52, p214.

62. Goddard, **op. cit**., Ref. 43, p14.

63. Rolls-Royce, News release: Rolls-Royce Celebrates 1000 Tay Engines for Gulfstream, 2nd October 2002.

64. Phillips, Phillips and Phillips, **op. cit**., Ref. 48, p. 113.

65. P. Pugh, **The Magic of a Name: Part Three, A Family of Engines 1987-2002**, (Cambridge, Icon Books, 2002), p69.

66. R. Rothwell and P. Gardiner, 'Robustness and Product Design Families', in: M. Oakley (Ed) **Design Management**, (Oxford, Blackwell, 1990), p. 282.

67. A. Prencipe, 'Exploiting and Nurturing In-House Technological Capabilities: Lessons from the Aerospace Industry', **International Journal of Innovation Management**, 5 (3), 2001, p. 310.

68. G. Spinardi, 'Industrial Exploitation of Carbon Fibre in the UK, USA and Japan', **Technology Analysis and Strategic Management**, 14 (4), 2002, p. 385.

69. Gunston, **op. cit**., Ref. 52, p. 212.

70. Prencipe, **op cit**., Ref. 67, p. 310.

71. Prencipe, **op cit**., Ref. 67, p. 309.

72. R. Henderson, and K. Clark, 'Architectural Innovation: the Re-configuration of Existing Product Technologies and the Failure of Established Firms', **Administrative Science Quarterly**, 35, 1990, pp. 9-30.

73. **Ibid.**, p. 12.

74. Rothwell, and Gardiner, **op. cit**., Ref. 15, p. 156.

75. Gunston, **op cit**., Ref. 52, p. 214.

76. Gunston, **op cit**., Ref. 52, p. 152.

77. Spinardi, **op cit**., Ref. 61, p. 385.

78. I. Kinnear, 'Tay certificated and soon to enter service', **Rolls-Royce Magazine**, 30, September 1986, p. 22.

79. J. Ashmole, 'Developing the Tay turbofan', **Rolls-Royce Magazine**, 19, December 1983, p. 21.

80. Kinnear, **op. cit**., Ref. 78, p. 22.

81. Rothwell and Gardiner, **op. cit**., Ref. 15, p. 157.

82. Kinnear, **op. cit**., Ref. 78, p. 22.

83. Ashmole, **op. cit**., Ref. 79, p. 18.

84. Hayward, **op. cit**., Ref. 18, p. 132.

85. Hayward, **op. cit**., Ref. 18, p. 126.

86. C. Forestier-Walker, and G. Hewitt, G. **Aerospace, Defence and Motors: Engineering Review**, January 1997, (London, Charterhouse Tilney Securities Ltd), p. 17.

87. House of Commons (1993) **Third Report of the Trade and Industry Committee: British Aerospace Industry**, 1, (London, HMSO, 1993), p. 15.

88. Rolls-Royce, **op. cit**., Ref. 44, p. 8.

89. Ashmole, **op. cit**., Ref. 79, p. 19.

90. Rolls-Royce, **Annual Report 2001**, (London, Rolls-Royce plc, 2002), p. 7.

91. M. Brown, 'Engine Trouble', **Management Today**, December 1994, pp. 50-54.

92. P.C. Ruffles, 'Reducing the Cost of Aero Engine Research and Development', **Aerospace**, November 1986, p. 15.

93. Rolls-Royce **Annual Report 2000**, (London, Rolls-Royce plc, 2001).

94. B.H. Rowe, ‘Aircraft Engine Industry’, in: T.H. Lee and P. R. Reid, (Eds), **National Interests in an Age of Global Technology**, (Washington, National Academy of Engineering, 1991), p. 95.

95. D.C. Mowery, **Alliance politics and economics: Multinational joint ventures in commercial aircraft,** (Cambridge, Mass., Ballinger, 1987), p. 2.

Table 1

World Commercial Jet Transport Deliveries 1958-85

Aircraft	*Deliveries*		*Orders*	
Boeing 707	957	(last delivery 1979)		
Boeing 727	1831	(last delivery 1984)		
Boeing 737	1139		246	
Boeing 747	617		40	
Boeing 757	49		13	
Boeing 767	121		72	
MDD DC8	556	(last delivery 1972		
MDD DC9	976	(last delivery 1985)		
MDD MD80	237		157	
MDD DC10	369		8	
Lockheed L1011	249	(last delivery 1984)		
Convair 880/990	102	(last delivery 1970)		
US sub-total	7203	83.7%	371	61.9%
DH Comet	112	(last delivery 1967)		
Aerospatiale Caravelle	279	(last delivery 1973)		
HS Trident	117	(last delivery 1978)		
BAC VC10	54	(last delivery 1970)		
BAC 1-11	232	(last delivery 1987)		
BAe 146	30		23	
Fokker F28	222	(last delivery 1987)	15	
Fokker F100	-		38	
Mercure	10	(last delivery 1975)		
VFW 614	10	(last delivery 1980)		
Airbus A300	253		17	
Airbus A310	71		46	
Airbus A320	-		90	
Europe sub-total	1404	16.3%	229	38.1%
Total	8607		600	

Source: Hayward (1986: p23)

Table 2

Deliveries of Gulfstream GIII Aircraft to US customers

Year	*US deliveries*
1980	10
1981	20
1982	22
1983	22
1984	25
1985	12
1986	8
1987	1
1988	2
Total	122

Source: Phillips, Phillips and Phillips (1994)

Table 3

Sales and Deliveries of Fokker Airliners 1984-96

	Sales		*Deliveries*	
Year	*F100*	*F70*	*F100*	*F70*
1984	8			
1985	26			
1986	36			
1987	0			
1988	3		8	
1989	93		27	
1990	33		25	
1991	10		53	
1992	18		46	
1993	30	8	67	1
1994	11	17	33	26
1995	10	16	15	13
1996	0	6	4	6
	278	47	278	40

Source: European Commission (1997) *The European Aerospace Industry*, Brussels.

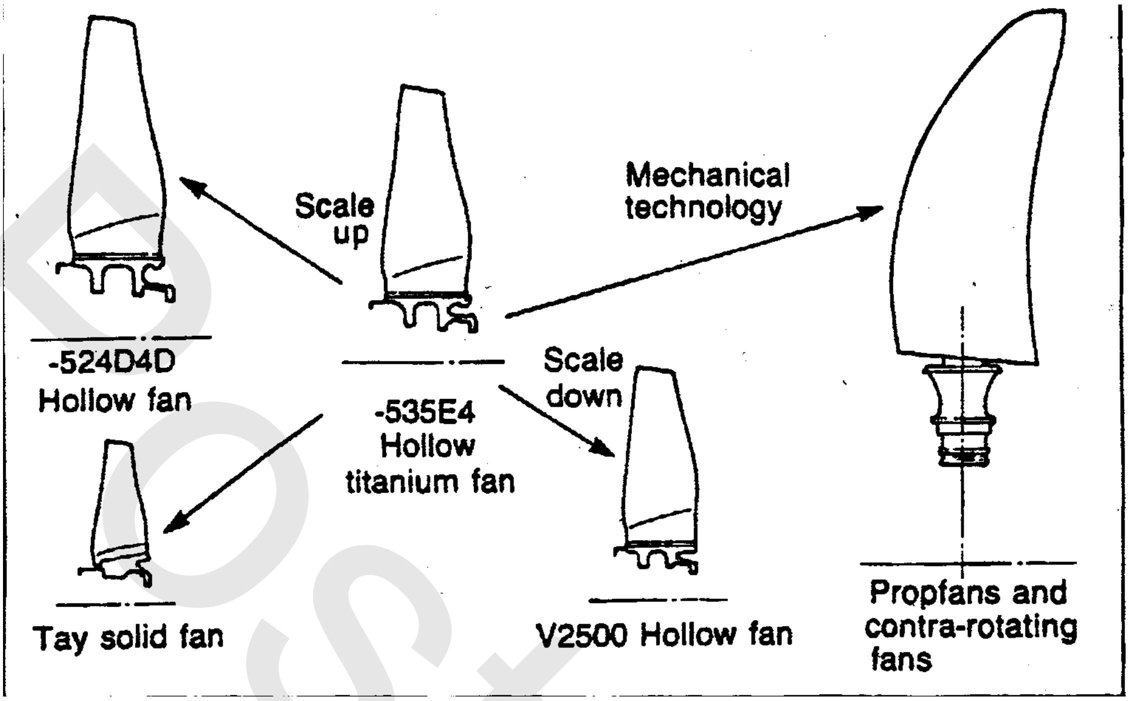
Table 4

Jet Engine Market Share: 10,000lbs – 20,000lbs segment (Engine Deliveries)

Year	*CFM-International*	*Pratt & Whitney*	*Rolls-Royce*	*Total*
1981	-	611	40	651
1982	-	378	40	418
1983	-	236	60	296
1984	22	229	34	285
1985	160	194	30	384
1986	260	234	38	532
1987	266	248	36	550
1988	324	262	38	624
1989	288	234	50	572
1990	356	284	90	730
1991	448	270	126	844
1992	460	194	124	778
1993	324	70	112	506
1994	252	44	56	352
1995	142	28	78	248

Source: European Commission (1996) European Aerospace Industry, Brussels.

Figure 1
Applications of Wide Chord Fan Technology



Source: Ruffles (1986)