An Exploration of Supply Chain Management Practices in the Aerospace Industry and in Rolls-Royce

by

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Submitted to the Engineering Systems Division
in Partial Fulfillment of the Requirements for the Degree of

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Abstract

This thesis is a part of the Supply Chain 2020 research project which seeks to study best practices in supply chain management in multiple industries in order to develop a deeper understanding of key principles and practices characterizing the creation of excellent supply chains through a long-term research agenda. This thesis addresses the first phase of the research by concentrating on the aerospace industry and by focusing on Rolls-Royce through a case study. The objective of the thesis is to conduct an exploratory study of the best practices in supply chain management in the aircraft engine manufacturing industry, and how these practices impact the competitive positioning of an engine manufacturer within the industry. The analysis involves a broad review of the current state and future directions of the aerospace industry by tracing the key factors shaping its evolution and by identifying the major strategic forces that would influence its future. Within this general industry context, the thesis analyzes Rolls-Royce's position in the industry as a leading aircraft engine manufacturer and presents a focused study of Rolls-Royce's supply chain management practices..

In particular, the thesis involves a deeper exploration of the aircraft engine manufacturing business segment of Rolls-Royce and strives to understand the company's supply chain management practices, by examining the role of major factors that have proven crucial to effective supply chain management within the company. The thesis also presents more specific case study examples that track the implementation and results of major supply chain management initiatives. Finally, the supply chain design and management practices are analyzed from the perspective of their role in the company's business strategy. This is accomplished by employing a number of business strategy frameworks to understand the key factors that determine the competitiveness of a tier one supplier in the aerospace industry, such as Rolls-Royce, and by examining how those factors have affected Rolls-Royce's supply chain management strategies and practices.

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I would also like to thank John McLauchlin at Rolls-Royce, Henrique Marcondes at Embraer, John Weiss at i2 Technologies and Pete Wiese from CSC Consulting for answering my questions and giving me a clear picture of practices within the industry and the company. Specifically I want to thank Dick Lewis, for his invaluable time spent in giving me a COO's perspective on Rolls-Royce's supply chain operations.

Lastly, but definitely not the least, I would like to thank my wife Devika, my little daughter Ambika, and my daughter's maternal and paternal grandparents, who shared my ups and downs of this arduous academic journey at MIT, and supported me throughout.

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1 Introduction

This chapter describes the purpose and approach of this thesis within the larger context of the objectives of the Supply Chain 2020 (SC2020) research project. It also gives a background description of salient characteristics of the aerospace industry and indicates why it is an interesting industry to study in identifying emerging best practices in supply chain management. Finally, it introduces Rolls-Royce, an important manufacturer of engines in the aerospace industry, which is the subject of a case study to provide a more fine-grained examination of key trends in supply chain management in the aerospace industry.

The following chapters provide a review of the existing literature on the aerospace industry (Chapter 2) and the current state of the industry (Chapter 3). This is followed by an overview of Rolls-Royce as a case-study of a tier-one supplier in the aerospace industry, given in Chapter 4. Specifically, Rolls-Royce's aircraft engine manufacturing business and its specific supply chain practices are studied in Chapter 5. Finally, the supply chain's role in its business strategy is analyzed in Chapter 6, to understand how it supports its business and operational objectives and enables it to survive and gain market share in the competitive environment of a consolidating industry.

1.1 The Supply Chain 2020 Research Project

The Supply Chain 2020 (SC 2020) research project is designed to study supply chains in the aerospace, apparel, automotive, computers manufacturing, communication equipment, consumer packaged goods, pharmaceutical, petroleum and retail industries. This would be done by studying leading companies within these industries, to ascertain what specific supply chain practices are being followed by these companies that make them a leader.

Two question that arise as one thinks about the project are:

- How does one identify which supply chains are excellent?
- How does one ensure what specific part of all supply chain activity is the one of interest, and hence worthy of research?

In the context of SC 2020 project, the companies' recent financial and market success is taken as an indicator of the success of their operational activities. Hence we study the firms which have demonstrated strength in recent financial performance and have been gaining market shares in their respective industries. To answer the second question, we study those activities which are considered by the industry practitioners as creating strategic value, and which they plan to focus on over the long term horizon.

Rolls-Royce is an attractive candidate for research, since it has moved with the industry dynamics since 1980's and has maneuvered itself into a position of strength in late 1990's in a fast maturing and consolidating industry. It has done so primarily by focusing on its suppliers and creating a competitive supply chain which can be a source of learning for other industries and companies. We intend to understand these lessons learned in the SC 2020 research project.

1.1.1 Motivation for the SC 2020 Research Project

The long-term goal of the SC 2020 project is to identify "excellent" supply chain practices in specific industries, and study any patterns or similarities that can be identified. The results of this study can be then applied to different industries, and one can evaluate the applicability and benefits of successful practices of one industry to another. Together with conceptual knowledge and understanding of patterns in such supply chains, a projection can be made as to how a company's supply chain should look in the year 2020 (within the context of a its specific industry), so as to become a leader, or maintain existing leadership position. Hence the SC 2020 research motivation is as follows:

SC 2020 Research Motivation[1]: The Supply Chain 2020 Project intends to identify and analyze the factors that are critical to the success of future supply chains out to the year 2020.

1.1.2 Phase 1 of the SC 2020 Project:

The SC 2020 project is divided into three phases[2]:

1) Current phase: Understanding the current supply chains in the industries under study.
2) Modeling phase: Using this understanding to develop macro-factor scenarios and create a supply chain model.
3) Analysis phase: Finalize the supply chain scenarios and analyze the likely impact of supply chain design in 2020, and the implications for corporate action today.

In the current phase of the project, the project focuses on researching today's excellent supply chains to identify what is important in maintaining a competitive positioning. This includes the business strategies, operating models, goals, and supply chain processes that yield the best results for a company in its industry.

This thesis seeks to study the aerospace industry's supply chain by studying one of the leading companies in the industry i.e. Rolls-Royce. We try to understand its current position in

[1] "Proceedings of the Supply Chain 2020 Project's Industry Advisory Council Kickoff Meeting, May 24, 2004"
[2] Ibid

the industry and the practices that make Rolls-Royce's supply chain a competitive one. The formal research question for the thesis is described below.

1.1.3 Thesis Research Question

The basic research question being addressed in this thesis can be defined as follows: What are the emerging best practices in supply chain management in the aerospace industry and what business strategies, operating models, goals, and processes makes the supply chain management practices of a particular case-study company's supply chain management practices exemplary? While the thesis strives to identify such emerging best practices, it does not take the position that they are necessarily widely prevalent within the industry. Further, the thesis does not necessarily endorse or intend to portray the supply chain management practices of a specific case-study company (e,g. Rolls-Royce) as necessarily being "exemplary" or "best-in-class" but rather as an illustrative example of currently observed practices.

1.1.4 Thesis Roadmap

This thesis includes two studies:

1) Looking at the industry and the sub-industry of aircraft engine manufacturing. The focus would be on the broad industry-wide trends, patterns and emerging practices in supply chain management within the aerospace industry, specifically the engine manufacturers. The purpose would be to identify emerging examples of supply chain excellence within engine manufacturing, and therefore study the factors shaping these developments. The factors affecting the industry are:

- Market demand shifts, customer preferences.
- Shifts in military acquisition policies.

- New technological developments.
- Affect of geo-politics on what products are needed/ demanded.

2) A case study of Rolls-Royce, to focus on the supply chain management practices in its aircraft engines manufacturing businesses. The purpose would be to study what factors were changed in the transformation and the resulting impact on parameters such as:

- Product costs.
- Product quality.
- Service levels.
- Inventory management.
- Aftermarket services.
- Affect on profitability and position in the industry.

This study would bring out the factors that matter most to maintain a strong position in the industry, and hence the 'excellence' of these parameters can be studied.

1.2 Methodology

The research on the question is accomplished through the following steps:

- **Literature review and conceptual understanding:** Extensive review of the MIT's Lean Aerospace Initiative's library of research on aerospace manufacturing and supply chain management practices to study overall industry and its dynamics. Further external literature such as industry reports from consulting and financial companies, credit rating agencies and research institutions would be studied. Other important resources used include consultants working with the industry and views of the industry experts on the aerospace industry. This study would yield an understanding of what issues are relevant to supply chains within the aerospace industry.

- **Study of company documents:** On specific companies, including the case study company, study of existing internal or publicly available documents relevant to their supply chain systems and management processes.
- **Company visits and Interviews:** On-site visits to the case study company and interviews with company personnel, in order to gain an organizational and a conceptual view of its existing supplier network and supply chain management practices and processes from the company's perspective.
- **Results of the study presented using the company as a case study:** Finally, an analysis of the information developed would be integrated for an overall characterization and evaluation of Rolls-Royce's supplier network, supply chain management practices and processes.

1.3 Evolution of the aerospace industry:

The aerospace industry has been changing significantly over the past 20-30 years to shift attention to the cost structure of the aircraft. Specifically, an engine manufacturer such as Rolls-Royce has also changed tremendously over last decade to focus heavily on supply chain and supplier relationships and cultivate it as a strength to reduce costs while increasing functionality, and hence create a source of competitive advantage.

The aerospace industry is unique because of the high interdependence and close linkages between the manufacturers and suppliers. This relationship forms a key part of how the industry has changed in the past 30 years to focus on cost reduction through better supply chain management. The study of the industry thus offers avenues of analysis and learning to the SC 2020 research project. There have been two distinct phases within the aerospace industry that have seen significant changes in industry dynamics[3]. These phases were:

1) Airline deregulation (1979): The airline deregulation broke the relationship that Boeing had with several airlines. Prior to the deregulation, a small number of major domestic airlines had closely linked, mutually beneficial relationships with the aircraft manufacturers in launching new products, and were able to play competing producers against each other. Deregulation made it difficult for airlines to become launch customers, which allowed entry of companies like GE to enter the market as an entity which had till then not existed in the commercial aerospace industry i.e. the leasing company. The primary impact of this occurrence was that from 1979 onwards, affordability of acquiring and operating an airplane became the key in the industry, and functionality and technology which had been the driving force in the past, took a back seat. Therefore, the focus shifted from making the most technologically and functionally advanced aircraft, to decreasing the costs, increasing quality and consistency of performance for the aircraft and all its components.

2) End of Cold War (1990): The end of the cold war affected the aerospace further. During much of post World War period, domestic aircraft producers could wage price wars with each other on the commercial side, with the knowledge that they could expect steady source of profits from the defense and government procurement. During the post-cold war period, defense budgets shrank and military aircrafts changed significantly, and as was in case of commercial aerospace, the focus shifted from *innovation* to *affordability* of the aircraft. The militaries of the North American and European nations (which are the largest consumers of military aircrafts) sought to

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[3] K.Bozdogan, *Aerospace Industry: an Industry of Industries*, Working Paper, Lean Aerospace Initiative, Center for Technology, Policy and Industrial Development, Massachusetts Institute of Technology, November 2000

have advanced yet affordable aircraft. Hence the focus of the defense aerospace industry became not only to make a better aircraft, but more importantly, how to do it cheaper.

Both of these developments shifted the attention from technology and functionality, to cost structure of the aircraft, its engine, avionics and sub-components. In other words, from "Higher, faster, Further" to "Better, Faster, Cheaper"[4]. The primary driver of this initiative was collaboration between the suppliers and manufacturers in components design and manufacturing. Further, the industry started focusing heavily on Lean Manufacturing principles to continuously drive the costs lower.

1.3.1 Comparison with the Automotive Industry

The industry sought to learn these practices from the automobile industry, which is also a high capital industry with a large supplier base and had been under pressures to improve costs and quality due to pressure from the Japanese manufacturers. However, there are crucial differences with the automotive industry:

Product complexity: While an automobile has 10,000 unique parts, an aircraft may feature over a million unique parts[5]. A car might have a 200 hp engine, while a Boeing 747 has a 75,000 hp engine.

Role of government regulation: Aerospace is a highly regulated industry, and hence the methods available to reduce costs would be limited by security and reliability concerns.

[4] Earll M. Murman, et al. *Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative* (Great Britain, Houndmills: Palgrave, 2002)

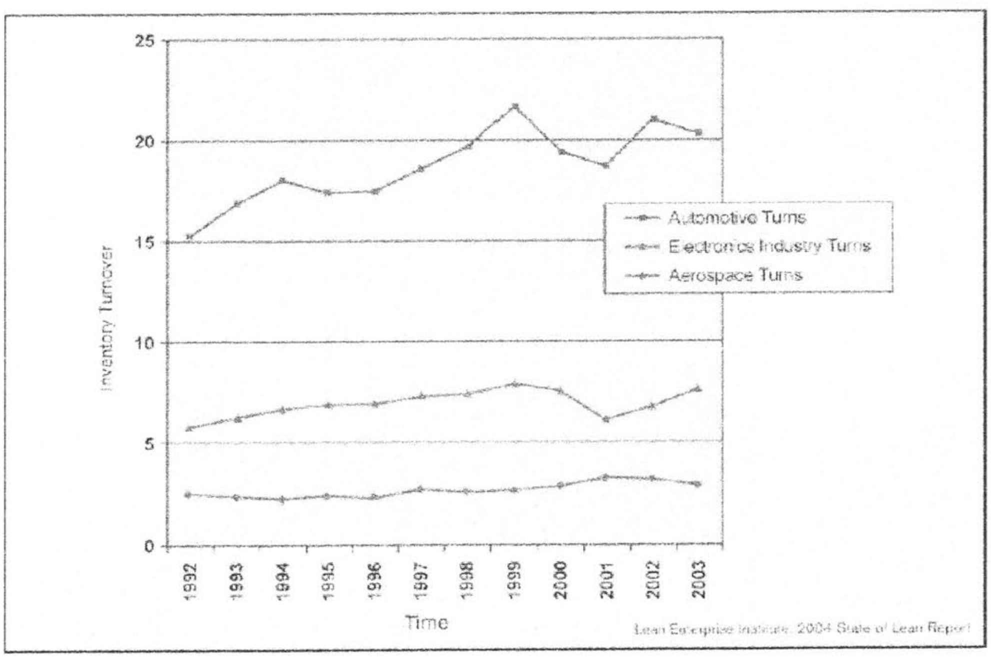
[5] K.Bozdogan, *Aerospace Industry: an Industry of Industries*, Working Paper, Lean Aerospace Initiative, Center for Technology, Policy and Industrial Development, Massachusetts Institute of Technology, November 2000

Product lifecycle: An average automobile may be used for an average for 10 years, while an average aircraft could last up to 50 years. Hence, the role of aftermarket service is far more prominent in the aerospace industry, than the automotive industry.

Production Volumes: While a car is produced in several hundred thousands units, an airplane is produced in a few thousand units. Therefore, automakers get a sharper edge on implementing improvements.

But regardless, aerospace can use the automotive or the electronics industry to benchmark itself on key parameters such as Inventory turns (Figure 1)[6], where it lags these industries.

Figure 1: Comparisons of inventory turns in different industries



Furthermore, the common external forces that impacted both industries are globalization and industry consolidation[7], and the possible tools that both the industries have turned to address the

[6] From Beason, M., Chairman, The Supplier Excellence Alliance, "The SEA Lean Enterprise System", compiled from Lean Enterprise Institute, *"2004 State of Lean Report"*.
[7] A.T. Kearney paper on aerospace Industry, "The Shifting Role of Suppliers", Insight (AT Kearney's knowledge journal), 2003.

resulting issues are also the same i.e. supply chain integration to work more closely with suppliers, and lean manufacturing.

1.3.2 Changes in Industry Dynamics since 1979

The following changes characterize the shifts in industry dynamics since 1979[8]:

Supplier relationships: There has been an increased focus on supplier relationships between manufacturers such as Boeing and Airbus, and their suppliers. Attempts have been made to change from a 'hierarchical and pyramidical' structure to a 'network' structures which encourage greater collaboration. This allows closer relationships between the manufacturers and suppliers, for product development and cost reduction exercises.

Reduction in supplier base: There has been a consolidation in manufacturers and suppliers in the three sectors of aerospace (i.e., military, commercial and small aircraft). The supplier base in the industry has been reduced by 50% during the first half of the 1990s due to component rationalization as well as industry consolidation[9]. Therefore, suppliers now supply complete sub-assemblies, rather than individual components.

Role of government certification: The role of Federal Aviation Authority (FAA) has grown in importance for the purpose of supplier certification. A certified supplier can supply a component that need not be tested for use in an aircraft, while a non-certified supplier's component needs extensive testing.

Increase in technology transfer between the military and commercial aircraft: Since development costs of a new aircraft are high, most companies leverage designs created for

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[8] K.Bozdogan, *Aerospace Industry: an Industry of Industries,* Working Paper, Lean Aerospace Initiative, Center for Technology, Policy and Industrial Development, Massachusetts Institute of Technology, November 2000

[9] Interview with Ian Couldray, Director of Supply Chain at Rolls Royce at Mt. Vernon, OH, December 2004

government programs (with R&D funded by the government) to create platforms for commercial products.

Systems view of the industry: The focus in the industry has changed to look at an aircraft as a system, rather than a collection of individual components. Hence the focus is now on how to make different components of an aircraft work together, and understand the affect of one component of performance on another seemingly unrelated component. The system view of the aircraft includes not only aerospace components, but also the affect of various components and technologies from related industries such as Telecommunication and Transportation (both Passenger transportation and Cargo transportation).

Therefore, the aerospace industry provides an interesting environment to study how the supply chain practices of the industry have reacted to counter the market dynamics and pressures to maintain margins, and how supply chain management has been used to maintain competitive positions of the players within the industry. To begin with, it would be important to understand what is already known about the affect of supply chains of business strategy, and what is already known about supply chains in the aerospace industry. This would be studied in the next chapter by reviewing the existing literature on this subject.

2 Literature Review

The forces and the resulting dynamics of the aerospace industry during the 1980's and early 1990's forced the industry to look for solutions to its problems, by turning to academia and learning from other industries. In that regards, the academic focus on industry's supply chain and operations is relatively new, compared to other industries such as Retailing or Automotive. Therefore, the industry is 10-15 years behind the Automotive industry in terms of acquiring new operational methodologies such as supplier collaboration and lean manufacturing principles[10]. The research available on aerospace industry's practices, therefore, is fairly recent compared to research on the automotive industry.

The research on role of operations and supply chains on business strategy, however, is a well researched topic. The idea of supply chain as being a core part of strategy was discussed by Porter (1985) where he suggested that competitive advantage depends on not only the firm's value chain but also how it fits in its overall value system. Porter (1996) proposed that pure operational excellence is not a strategy. He defined sustainable advantage as one coming from doing activities that are different from competition, or doing them in a way that is hard to replicate, and ensuring that these activities are designed to support a specific business that the firm has chosen to compete in. A firm should choose what business it would compete in, and therefore also choose what businesses it would not compete in, and then design its activities in a way (as mentioned above) so that its unique set and design of activities gives it a sustainable

[10] Interview with John Weiss, VP, i2 Technologies, March 2004

advantage. On similar lines, Hammer (2004) proposed that a firm can build sustainable competitive advantage by excelling at operational activities, and doing them better than competition. Thus Porter focuses on choosing the right business and then designing a set of activities that is hard to copy (proposing that competitive value of individual activities cannot be separated from the whole), while Hammer focuses on performing these activities better than competition, to get a sustained advantage.

The competition among the aerospace industry players would be analyzed in this perspective in Chapter 6, evaluating the costs and non-cost factors that are required for maintaining competitiveness in the industry.

On the subject of designing a set of activities to support a business strategy or an operational objective, Fisher (1997) proposed that the design of the supply chain (and the activities therein) should follow from the nature of customer demand for a company's products. Therefore, if the company has functional products with consistent demand (for example Wal-Mart in the grocery business), then the company should focus on serving the customers with an efficient supply chain to get most margins out of the business. On the other hand, if the products are innovative and have shorter lifecycle with unpredictable demand (for example Hewlett-Packard in laser printer business), then the company should focus on a responsive supply chain. On similar lines, Simchi-Levi (2000) explained the use of 'pull', 'push' and push-pull' strategies and that the correct choice of strategy follows from the nature of product and customer demand. This model is used in this thesis to analyze and understand the prevalence of a pull based production system in the highly cyclical aerospace industry.

The research on aerospace industry, due to reasons mentioned in the beginning of the chapter, is limited. The foremost body of knowledge about the industry comes from the Lean

Aerospace Initiative (LAI) at Massachusetts Institute of Technology (MIT). The subject of lean manufacturing was introduced to a wide audience by Womack et al. (1990) and Womack et al (1996) at MIT after their study of the Toyota Production System. However, the principles that are applicable to the Automotive industry are very relevant for the aerospace industry due to similarities discussed in Chapter 1. The principles of lean manufacturing emphasize the process of reducing waste, with the goal of creating value for the organization. Murman et al. (2002) at LAI have researched the issues facing this 'flagship' industry of the US and many other nations, and have suggested methods and processes specifically to guide companies in the aerospace industry in their journey towards developing lean enterprises. The book dives deeply into different segments of the aerospace industry (i.e., commercial, defense and regional/ corporate jet market) and traces the evolution of the aerospace industry to understand the forces at play in the industry, as well as changes in the global geopolitical environment and government regulations to understand the industry's evolution and current state in a historical perspective. By presenting a comprehensive analysis of the industry, its operations and supply chain, the LAI has greatly influenced the recent attempts by the industry in past 8-10 years to adopt principles such as supplier collaboration and lean manufacturing.

LAI has demonstrated the applicability of lean principles to the aerospace industry through multiple success stories of aircraft programs such as C-130J transport aircraft, F/A-22 Raptor fighter aircraft and RAH-66 helicopter, and many other examples.

The LAI research has been reinforced by theses written at MIT. Gostic (1998) used Allied Signal, Boeing, Lockheed Martin and Pratt & Whitney as case studies to study supply chain management in the aerospace industry, and Goh (2003) studies the Maintenance, Repair and Overhaul (MRO) activities in the industry. These theses are similar in their quest for understanding this industry (Gostic, 1998) and the profitable MRO services (Goh, 2003). This thesis builds on these perspectives and studies Rolls-Royce as a case study in today's perspective of the aerospace industry.

The understanding of current state of the aerospace industry and the operational and supply chain practices comes from various industry experts, white-papers written by consultants advising the industry, and reports from trade bodies such as the Aerospace Industries Association (AIA) and the US International Trade Commission, which measures the competitiveness of the various segments of the industry (aircrafts, engines and equipment) in different geographies. The current and future trends in the industry are documented by journals, for example *'Aviation Week & Space Technology'* and *'Insight'*, as well as by other magazines, such as 'The Economist' and 'The Engineer'. Further, investment-oriented analysis is presented by financial institutions and credit rating agencies such as Standard and Poor's. These analyses and trends are used to understand the industry and the position of Rolls-Royce within the industry.

Finally, the supply chain at Rolls-Royce has been studied in Rolls-Royce's internal improvement initiatives, and one of its success stories has been documented in a video film *"Supplier Operating Model and AE 3007 Engine Flowline."* This film is a good source of seeing some of the Rolls-Royce's supply chain principles in practice, and has been used in this thesis to understand their progress in how far the company has come in its planned journey towards lean manufacturing.

3 The Aerospace Industry

This chapter defines the global aerospace industry by its components, and provides its historical revenues, employee strength and profitability. It also covers the primary aerospace products and customers, the underlying trends and industry drivers and the supply chain structure within the industry. It then examines the Engines sector of the industry (which is the focus of this paper), and introduces the primary products and companies within the sector, and traces the historical and future growth of this sector.

3.1 Definition of the Industry

The aerospace and defense industry has three main sectors. These are "systems & aerostructures", "engines" and "equipment". The industry also has three product segments which are "aircraft", "missiles" and "space".[11]

3.2 The Global Aerospace Industry

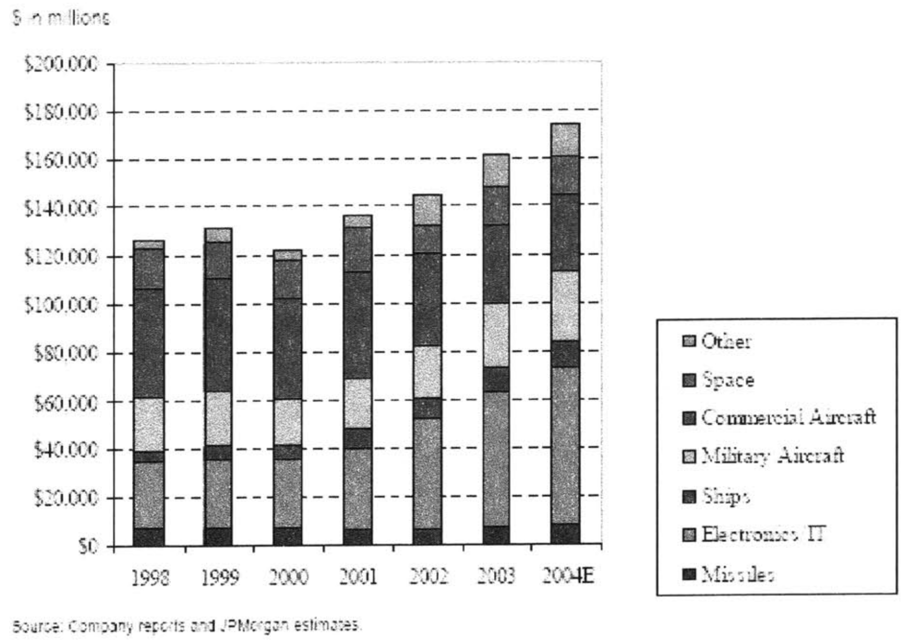
The U.S. aerospace industry is the global leader in both revenues and employment. In 2002, total consolidated revenues were in excess of $153 billion and 714,000 employees.[12] The European aerospace industry was second largest with 74.6 billion Euros in consolidated revenues and 408,000 employees.[13]

[11] The European Association of Aerospace Industries (AECMA) Fact and Figures Report 2002 p.10
[12] Aviation Industry Association Revenues and Employment Summary 1988-2002
[13] The European Association of Aerospace Industries (AECMA) Fact and Figures Report 2002

Though many other nations manufacture final products such as jet aircraft and rockets, none have large commercial aircraft products, defined as passenger transport aircraft with capacity of one hundred passengers or more (for the purpose of this paper). The aircraft final product segment made up 52.2% and 46% of revenues in the U.S. and Europe, respectively.[14] Within the aircraft segment, large commercial aircraft revenues were 54.4% of the European revenues versus 34.4% of the U.S. revenues. In the same year, the military aircraft segment sales in the U.S. were the strongest component with $37.9 billion or 47.4% of total revenues. [15]

Approximately 45% of all defense spending around the world is related to aerospace systems[16]. Consolidated revenues of primary companies in the defense market, as represented in Figure 2[17], shows a trend of growth.

Figure 2: Consolidated revenues of primary aerospace companies by year



[14] The European Association of Aerospace Industries (AECMA) Fact and Figures Report 2002, Aviation Industry Association Revenues and Employment Summary 1988-2002.
[15] Aviation Industry Association 1988-2002
[16] JP Morgan Aerospace and Defense report, September 2004
[17] From JP Morgan Aerospace and Defense report, September 2004, compiled from Company Reports and JP Morgan estimates.

3.2.1 Changes in the Industry through 1990's

At the end of the 1980s the military component of the aircraft segment was nearly double the commercial segment in terms of revenues. The following five years saw the civil segment grow in consecutive years to reach the revenue level of the military segment by 1992. The revenue trend for the U.S. civil aircraft segment has been a steadily positive one since the mid 1990s. The military segment saw very modest growth relative to the commercial segment in the same period. Both segments reduced their employee base drastically, as can be seen in Table 1.

Table 1 – Composition of aerospace industry 1989 and 1999- Increase in Civil Aerospace relative to Defense, and decrease in employee base[18] (All dollar figures are given in millions of current dollars)

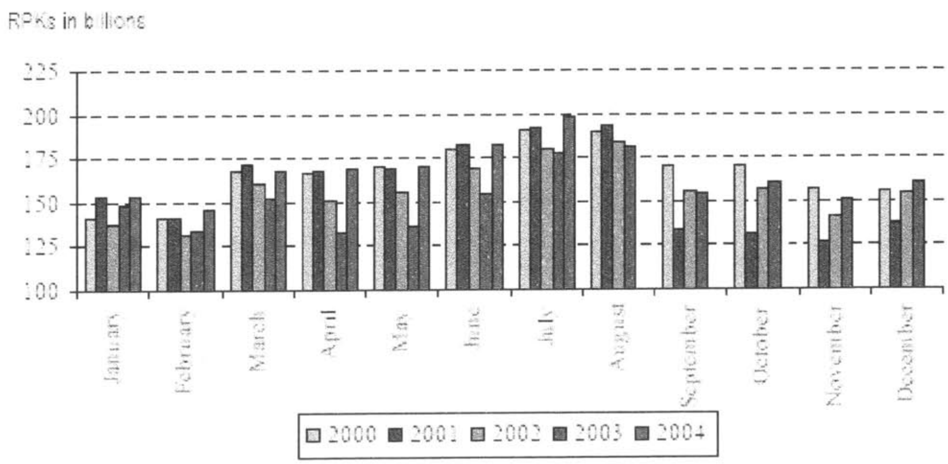
NAICS Code[19]	**Industry Group**	**1989**		**1999**	
		Value of Shipments	**Employment (in thousands)**	**Value of Shipments**	**Employment (in thousands)**
336411 (SIC 3721)	Aircraft mfg.	43,338.9	277.5	73,961.0	200.2
336412 (SIC 3724)	Aircraft engine & engine parts mfg.	21,565.8	132.0	24,290.6	83.2
336413 (SIC 3728)	Other aircraft & auxiliary equipment mfg.	19,074.9	192.9	22,429.5	132.6
336411, 336412, 336413 (SIC 372)	**Aircraft and parts (Subtotal)**	**83,979.6**	**602.4**	**120,681.1**	**416.0**
336414, 336415, 336419 (SIC 376)	**Guided missiles, space vehicles & parts (Subtotal)**	**29,497.7**	**221.0**	**18,981.4**	**73.9**
3364 (SIC 372, 376)	**AEROSPACE PRODUCTS & PARTS MFG. – TOTAL**	**113,477.3**	**823.4**	**139,662.4**	**489.9**

[18] **SOURCES:** From documents from the LAI repository, compiled by U.S. Department of Commerce, Census Bureau, 1992 Census of Manufactures, MC92-I-37B(P), Issued December 1994, Table 1

[19] The aerospace industry is defined by the U.S. Census Bureau by using the North American Industry Classification System (NAICS) Code 3364 industry group. Before the 1997 Census of Manufactures, the aerospace industry was defined by the Census Bureau by using the Standard Industrial Classification (SIC) system, consisting of two major industry sectors: SIC 372 (Aircraft and parts) and SIC 376 (Guided missiles, space vehicles and parts).

The effects of global economic weakness along with the terrorist attacks of September 11, 2001 were manifested by a $9 billion, or 18%, drop in revenues from 2001 to 2002 (as shown in Figure 3[20] for global Revenue Passenger KM, RPK). This affected airlines, aircraft manufacturers and engine manufacturers. For example, after September 11, 2001, the demand for engines at Rolls-Royce dropped from 1000 to 600 engines.[21]

Figure 3: Worldwide Revenue Passenger KM (RPK) 2000-2004



Source: Composite of data from Air Transport Association, Association of European Airlines, and the following Asian carriers: Cathay Pacific, SIA, JAL, ANA, EVA, China Airlines, Thai Airways and Korean Air

The U.S. space segment, both military and non-military, had sales of $20.6 billion in 2003. The satellite manufacturing industry had revenues of $14.9 billion and the rocket manufacturing and launch operations generated $5.7 billion. The orders from governments, universities and the military generated 83% of satellite manufacturing revenues, which drove the rest of the industry.

[20] From JP Morgan Aerospace and Defense report, September 2004

[21] Interview with Richard B. Lewis II, formerly COO of Rolls Royce, April 2004

3.2.2 Revenues in the Industry

The revenues have been discouraging for the overall industry. In recent years, the U.S. aerospace & defense sector has seen revenue growth that has been below GDP growth. In 1988, aerospace sales as percent of GDP were 2.2%. This figure climbed to 2.3% in years 1991 and 1992 but then started to decline steadily until recently settling at 1.5% in year 2002.[22] Also, a study of the division of revenues of the top 50 global defense companies shows that the portion of revenues derived from military-related sales make from low of 2.3% to a high of 100% of total sales[23]. Hence, many companies in the industry are exposed to the commercial as well as the military segment in significant amounts. The research and development efforts in the industry have almost always originated in the military segment and then migrated to the commercial segment. Chapter 4 as well as Chapter 5 will further explore this phenomenon.

3.2.3 Profitability of the Industry

The recent profit picture has been disappointing for the overall industry with all segments experiencing significant declines in 2003, as shown in Figure 4[24]. The large commercial aircraft segment had an average operating margin of 7.5% between 2000 and 2003 with a 2003 margin of 5.9%. The same period saw the business and regional jet segment's average operating margins at 12%. The jet engines sub-segment had a 13.4% average operating margin and the rocket launch & satellite making segment had a negative 0.7% average margin over the same period of time.

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[22] Aviation Industry Association Report 1988-2002
[23] From S&P Aerospace and Defense Industry Report October 2004, compiled from Company Reports
[24] Ibid

Figure 4: Aerospace industry segment's profit margins

AEROSPACE & DEFENSE INDUSTRY SEGMENT OPERATING PROFIT MARGINS
(In percent)

	2000	2001	2002	2003	4-YEAR AVERAGE
Large commercial aircraft	7.9	7.8	8.5	5.9	7.5
Business & regional aircraft	14.8	7.9	13.3	12.0	12.0
Maintenance, repair & overhaul	14.6	12.8	5.4	5.9	9.7
Jet engines	14.8	14.2	12.8	11.8	13.4
Military weapons	8.1	8.4	8.6	7.4	8.1
Rocket launch & satellite making	0.5	0.3	2.2	(5.9)	(0.7)

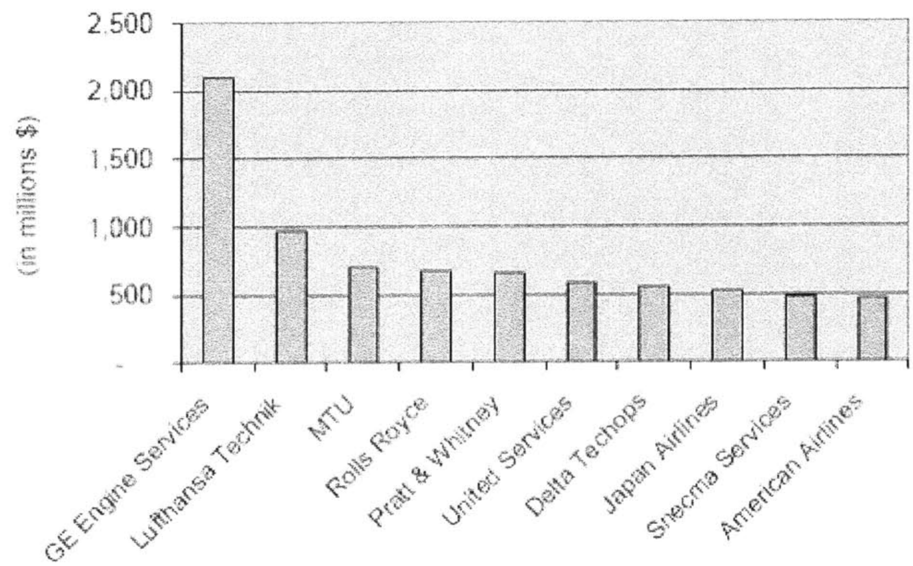
Source: Company reports.

3.2.4 Maintenance, Repair and Overhaul (MRO) market

The after-market maintenance and the engine overhaul supply chains are similar to new products manufacturing supply chains, but different in terms of their financial impact. They are highly profitable business for manufacturers in all tiers of the supply chain. The global MRO market had revenues of $36 billion in 2003 and the global engine market had revenues in excess of $31 billion.[25] Most of the MRO activities are performed in vertically integrated organizations such as national and large scale airlines that operate their own MRO facilities. Aircraft and engine manufacturers also have MRO facilities that service airlines globally. The primary service providers' revenues and in MRO activities is shown in Figure 5[26], which show Rolls-Royce as the fourth largest player.

[25] S&P Aerospace and Defense Industry Report October 2004, p.6
[26] From S&P Aerospace and Defense Industry Report October 2004, compiled from *Aerostrategy*

Figure 5: MRO market share for engine overhauls for various service providers



Source: Aerostrategy

3.2.5 Avionics

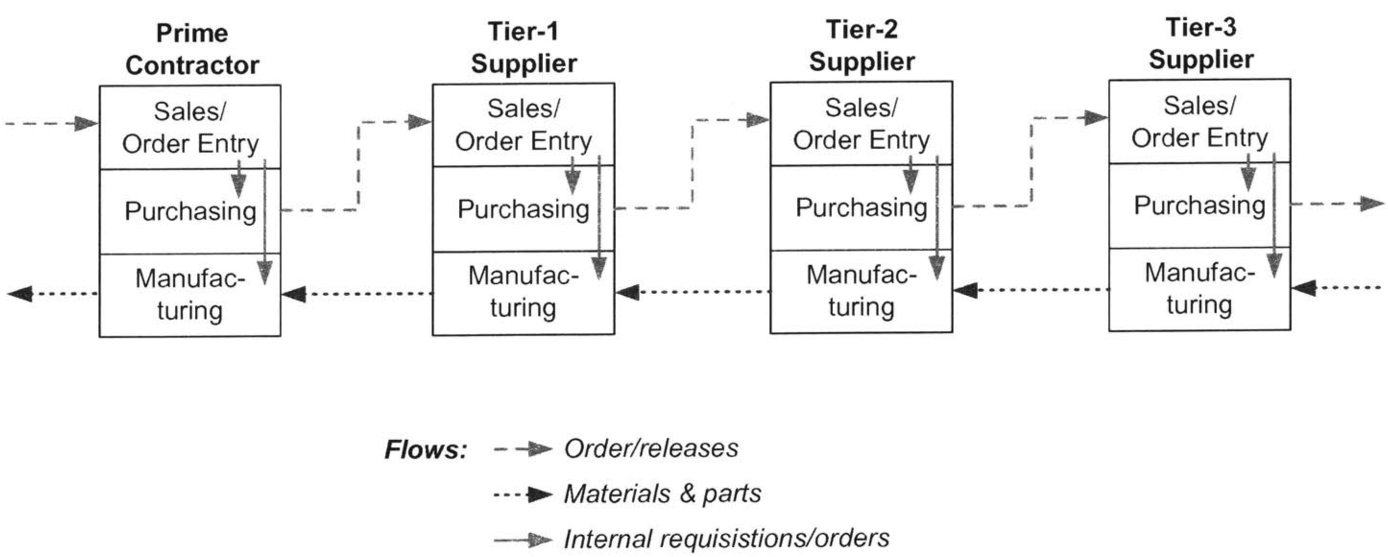
Lastly, the increase of the use of technology in aircraft cockpits enabled the avionics portion of the "equipment" industry segment to reach $10.2 Billion in revenues for the year 2003.

3.3 Supply Chain Structure of the Industry

The Aerospace industry is dominated by a few large companies. These include players such as Boeing and Airbus. These large players are supported by a vast supplier base globally, including fairly large and sophisticated engine and avionics manufacturers. These include suppliers such as General Electric Aircraft Engines (GEAE), Rolls-Royce, Honeywell and Pratt & Whitney. They are referred to as tier-one suppliers, and play a significant role in the aerospace industry.

Tier 1 suppliers are further supplied by a large base of tier 2 and tier 3 suppliers, which serve multiple industries (such as industrial manufacturing or automotive). These tier 2 and 3 suppliers supply all tier 1 suppliers, which share this common supply base, as is shown in Figure 6[27]. The tier 2 suppliers include companies such as L-3Communications, Harris or Parker-Hannifin. These are followed by tier 3 suppliers which include suppliers of machined components such as castings and raw materials suppliers for metals and rubber. Except for the first level of the supply chain who do not trade among themselves (aircraft manufacturers such as Boeing and Airbus), companies actively buy from and sell to each other. Hence, for example, Honeywell and Rolls-Royce are competitors and might collaborate and trade between themselves too. Therefore, the industry is symbolized by collaborative programs and equity cross holdings between aircraft manufacturers (Boeing and Airbus) and its tier 1 suppliers. At tier 2, 3 and 4 levels, there is a large and diversified manufacturing base which is shared by the consuming supply chain tier above it.

Figure 6: Supply Chain Structure in the Aerospace Industry



[27] Presentation by John F. Eash, The Boeing Company, from the LAI document repository

3.4 Supply Chain Challenges and Opportunities

As mentioned in Chapter 1, the biggest challenge facing the industry is a maturing market, slowing growth and industry consolidation. Since growth is slowing and each level of the supply chain is consolidating, it puts pressure on each layer to become efficient and cost effective to survive and gain market share from its rivals. This defines the opportunity for operational improvements at each layer of the supply chain because the survival of each company depends on whether it can deliver a better quality product at a lower cost, and on time to its customer base.

3.5 Engines Segment of the Industry

The "engine" segment of the industry can be broken down into three categories: turbofan, turboprop and turboshaft[28] . The turbofan segment constitutes the lion's share of the total engine demand. Turbofans are used in most of the commercial and military aircraft. Turboprops are used mostly in business and regional aviation as well as in the military (single engine trainers and military transport). Turboshafts are primarily used in helicopters and some vertical takeoff/ landing aircraft. The main manufacturers of aircraft engines are General Electric Aircraft Engines (GEAE), Rolls-Royce, Honeywell (Allied Signals) and Pratt & Whitney (P&W), Snecma, Turbomeca and Williams. These players have remained in their leading positions since past few decades and are expected to remain so in 2014.

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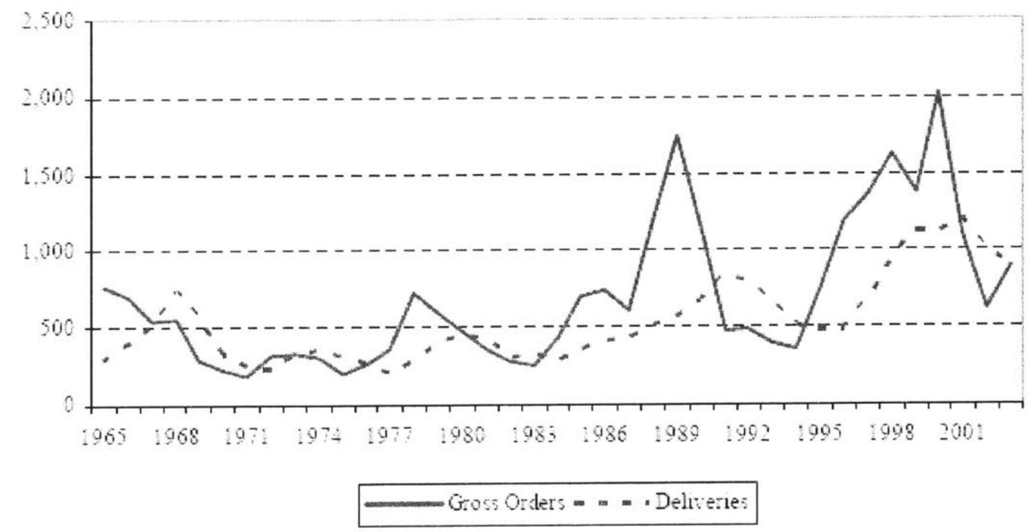
[28] Franus, David; *Aviation Week & Space Technology* Jan 17, 2005 pp. 117.

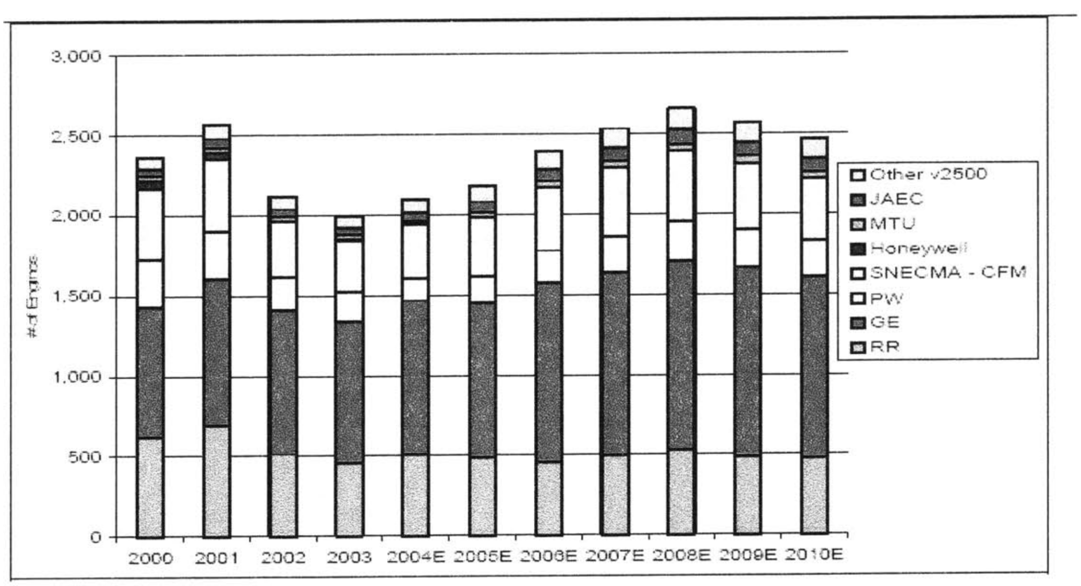
Figure 7: Orders and deliveries for commercial aircrafts (1965-2001): A cyclical business



Source: SpeedNews.

Engine manufacturing is a cyclical business, which derives its demand from the delivery orders for aircrafts (Figure 7[29]). The forecast for selected manufacturers is shown in Figure 8[30].

Figure 8: Aircraft engines delivery forecast (in units) 2000-2010 estimates



E = Morgan Stanley Research estimates

Source: Company data, Morgan Stanley Research

[29] From S&P Aerospace and Defense Industry Report October 2004, compiled from *Speednews*
[30] From Morgan Stanley Research Report on Rolls-Royce, December 2004, compiled from Company Data

Its overall demand pattern has been as follows[31]: Starting in 1995 with about 6750 engines, production rose to a peak of 7750 in 2001, before declining again to 6750 in 2004. The production is forecasted to rise to 9500 in next few years, followed by a slump in 2011. Customers would require fewer additions each year until the old inventory becomes old and needs replacement. During 2005-14 a total of 56,000 turbofan engines worth $175 billion are forecast for production (led by GEAE, P&W, Rolls-Royce and Snecma). The number of turboprop engines in the same period is 9500, worth $8.3 billion (led by Pratt & Whitney and Rolls-Royce). The number of turboshaft engines forecasted is 21,500 (led by GEAE), worth $11.1 billion.

All segments- light business and regional jets, single aisle and widebody heavy jet transport, military light and heavy jets are expected to grow during the 2005-2014 period. Factors affecting business and jet transport engines is the introduction of new aircraft like A-380, as well as continued growth in developing world (new planes) and developed world (replacement of fleet). The factor affecting the military turbine engine production is the replacement of old aircraft with newer generation fighters like F/A-22, F-35 Joint Strike Fighter and Rafale. The light attack aircraft and jet trainers find new markets in European, Middle Eastern and Asian nations, and the demand is expected to double in from 2005 (125 engines) to 2013 (240 engines).

Similarly, the segments for turboprop engines are also expected to grow. Although the turbofan use has diminished the market for turboprop engines, the civil applications in business and regional are remaining profitable niches. In the military, turboprops have remained in demand for single engine trainers and multi-engine transports. Multi-engine transports like Boeing C-130 and Airbus A400M give a big boost to the production requirements for turboprops.

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[31] Franus, David; *Aviation Week & Space Technology* Jan 17, 2005 pp. 117.

For the turboshaft segment, the biggest customer remains to be the U.S. Army, with demand for combat and cargo/ transport helicopters. The demand comes from reengining of existing fleet and new military programs like rotorcraft aircraft (Bell/ Boeing V-22), and the future Improved Turbine Engine program (ITEP), which would be used for Army's need for a high-elevation and the next generation medium lift transport helicopter.

4 Rolls-Royce's Businesses and its Position in the Aerospace Industry

This chapter considers Rolls-Royce's business divisions in terms of revenue and profitability. That is the basis for continuing to explore how Rolls-Royce's aerospace business divisions fit within the aerospace industry as a whole.

4.1 Rolls-Royce's Revenues and Profitability

Rolls-Royce Group Plc. is the second largest aircraft-engines company in the world, behind General Electric Aircraft Engines (GEAE), with annual revenues of $10.1 billion and employs 36,100 people, 20,400 in aerospace in 48 different countries[32]. Its corporate headquarters are in Derby, UK, while North American office is in Indianapolis, IN.

The company focuses on four markets i.e. Civil Aerospace, Military Aerospace, Marine engines and Energy. The average return on capital employed for the group was 11.6%[33], which was higher than 2002 (10.5%), but the cyclical civil aerospace market has been declining since 2001. The group revenues over time and share of revenues by division are described in Table 2[34]:

Table 2: Rolls-Royce group revenues by business segments 1999-2003

	2003	2002	2001	2000	1999
Group Revenue ($ millions)	10,161	10,418	11,390	10,555	8,341
Civil Aerospace	48%	47%	54%	54%	55%
Military Aerospace	25%	24%	22%	24%	25%
Marine	16%	17%	13%	13%	8%
Energy	10%	11%	10%	8%	10%

[32] *Engine strategy pays off for Rolls-Royce,* The Engineer, London: Feb 20, 2004. p. P.20
[33] Aviation Week and Space Technology, Jan 2004
[34] From Rolls-Royce Annual Report 2004

4.1.1 Profitability of the Business Units

The profitability (EBIT) of each division is shown in Table 3[35]:

Table 3: Rolls-Royce group profitability by business segments 2002-2003

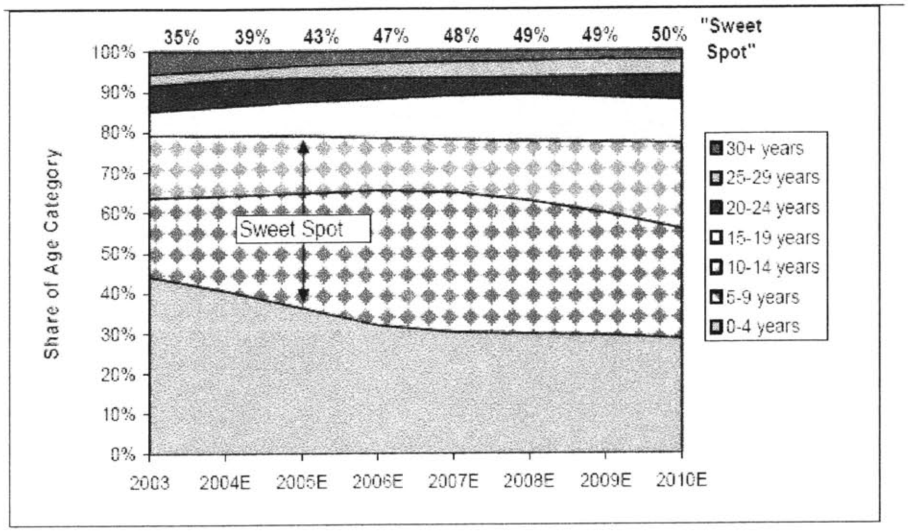
	2003		2002	
	Revenue	Profitability	Revenue	Profitability
Group	10,161	6.7%	10,418	6.5%
Civil Aerospace	4,849	4.9%	4,930	5.5%
Military Aerospace	2,516	10.5%	2,477	13.3%
Marine	1,669	7.7%	1,771	8.3%
Energy	1,051	5.1%	1,150	-6.4%

As is obvious from the table above, Military and Marine business have the highest profit margins, while largest segment i.e. civil aerospace has the most margin pressures. These profitability measures paint a weak picture against GEAE, the leader in the aerospace market with EBIT margins of 17% in civil segment and 23% in military segment[36]. This could be because GEAE has a 70% share of its civil aerospace revenues coming from aftermarket services (with 30% profit margins), as opposed to 50% for Rolls-Royce. In military segment, GEAE has a larger base of military aircraft and hence they can utilize their R&D and asset base more profitably.

Besides the products, Aftermarket service revenues constitute 50% of revenues in each division, and hence Maintenance, Repair and Overhaul (MRO) contracts are strategic focus for revenue and profit growth. This revenue is directly proportional to the number of engines in the service and their age. Engines which are 5-9 years old provide the most aftermarket service revenues, as can be seen in Figure 9[37].

[35] From Rolls-Royce Annual Report 2004
[36] Morgan Stanley Research on Rolls-Royce, Dec 2004
[37] From Morgan Stanley Research Report on Rolls-Royce, December 2004, compiled from Company data and Morgan Stanley Research

Figure 9: Rolls-Royce fleet age composition 2003-10 estimates

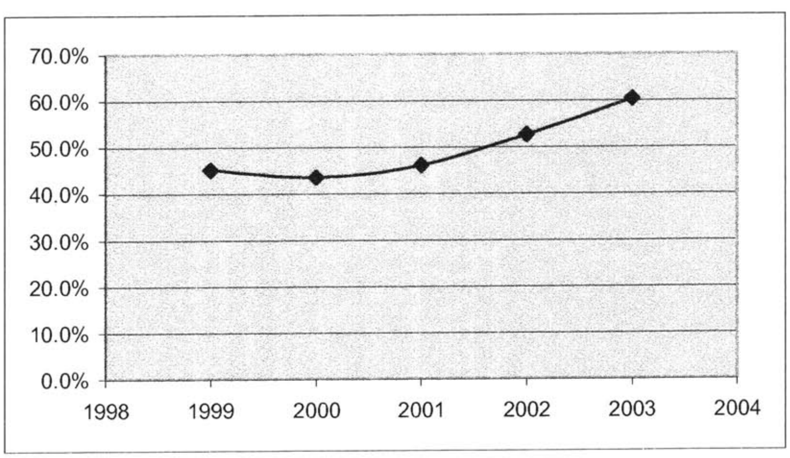


E = Morgan Stanley Research estimates

Source: Company data, Morgan Stanley Research

In 2003, these aftermarket services yielded \$5.1 billion in sales (excluding joint ventures), out of a group sales of \$10.1 billion. Including joint ventures, the services revenue was \$6.1 billion. On average, each unit sale of a gas turbine yields aftermarket services and product sales amounting to twice the price of the original unit, and hence Rolls-Royce sees its installed base as a source of stable and guaranteed revenue[38]. Figure 10[39] shows the growth in service revenues.

Figure 10: Rolls-Royce aftermarket services as a percentage of total revenues



[38] Interview with Richard B. Lewis II, formerly COO of Rolls-Royce, April 2004

[39] From Rolls-Royce Annual Report 2004

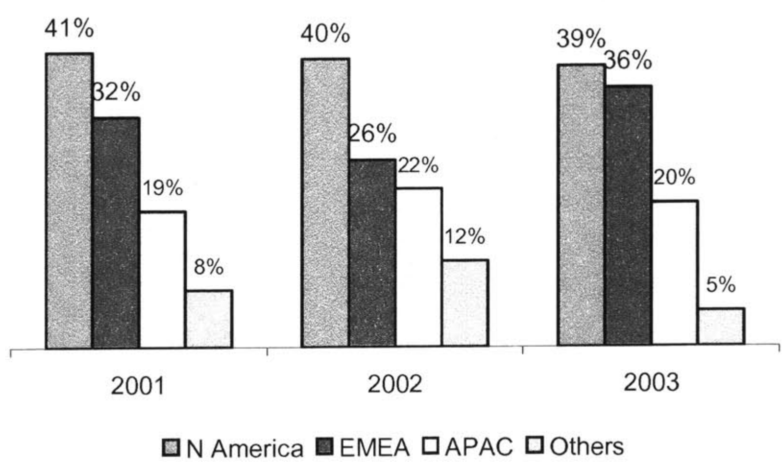
At the end of 2003, Rolls-Royce had 54,000 gas turbines installed, aggregating all three markets. This has grown a 100% since 1993, when it had 27,000 units installed, showing the recent growth and penetration of Rolls-Royce into its traditional markets.

It serves its four markets with the same core technology i.e. 5-80 MW gas turbines technology that can be used as a powerplant in a civil or military aircraft, ship or energy system. In our focus on the aerospace industry, we would study Rolls-Royce's core product segment, i.e. aircraft engines in this paper. But since the underlying technology is the same in all products, the learning can be applied to other divisions as well.

4.1.2 Geographical Distribution of Revenues

Rolls-Royce increasingly sells in global markets, as shown in Figure 11. In 1993, its UK sales were $1.7 billion, while in 2003, they were $1.81 billion[40]. Its non-UK sales grew from $4.5 billion in 1993 to $8.4 billion in 2003. Its manufacturing facilities for aircraft manufacturing are concentrated in US and Western Europe, while Marine manufacturing is dispersed in Eastern Europe and East Asia as well.

Figure 11: Rolls-Royce revenue by geographies



[40] Rolls-Royce data

4.2 Rolls-Royce's Business Strategy

Rolls-Royce defines its strategy as follows[41]:

- Address four global markets.
- Invest in technology, capability and infrastructure.
- Develop a competitive portfolio of products and services.
- Grow market share and installed base.
- Capture substantial aftermarket service opportunities.

The priorities as defined by the Rolls-Royce group are[42]:

Focused investment in technology: Rolls-Royce sees its market for new products slowing down, and its technology acquisition, as well as supporting new product development, would increasingly focus on the development of derivative products, unit cost reduction, improvement of in-service operation and extending the scope of value services.

Operational Excellence: Over time, Rolls-Royce has focused on getting more productive by constantly focusing on its supply chain restructuring, improvement of manufacturing processes, lead-time reduction and rationalization of facilities. Improvement initiatives have been launched to focus upon operating and product unit costs.

Development of aftermarket services: Rolls-Royce offers long term service contract called TotalCare in the civil sector and Mission Ready Management Solutions (MRMS) in the military sector. These contracts, besides providing Maintenance, Repair and Overhaul (MRO) facilities, also offer engine health monitoring and predictive maintenance.

[41] Rolls-Royce Annual Report 2004
[42] John Rose, CEO, address to the shareholders in 2004 Annual Report

4.3 Business Units

The company has four business units i.e Civil Aerospace, Military Aerospace, Marine engines and Energy.

4.3.1 Civil Aerospace

Rolls-Royce has established itself as the number two civil aero engine manufacturer in the world (after GEAE) with a 30% market share over past 3 years (in terms of number of engines in service)[43]. It is a world leader in the widebody aircraft category, with a world leading 50% market share. It offers engines with a wide power spectrum from 2,000 lb thrust to 100,000 lb thrust. It has an installed engine base of 10,450 at the end of 2003, and continues to grow. The engine deliveries in this segment tripled from mid 1990's to 2001, followed by a severe recession after 2001. Rolls-Royce expects the engine deliveries to gradually recover 2005 onwards. Its strategy for this segment is to drive down costs, while increasing aftermarket service revenues.

Table 4[44] provides a picture of the division's recent history:

Table 4: Rolls-Royce Civil Aerospace division performance history 1999-2003

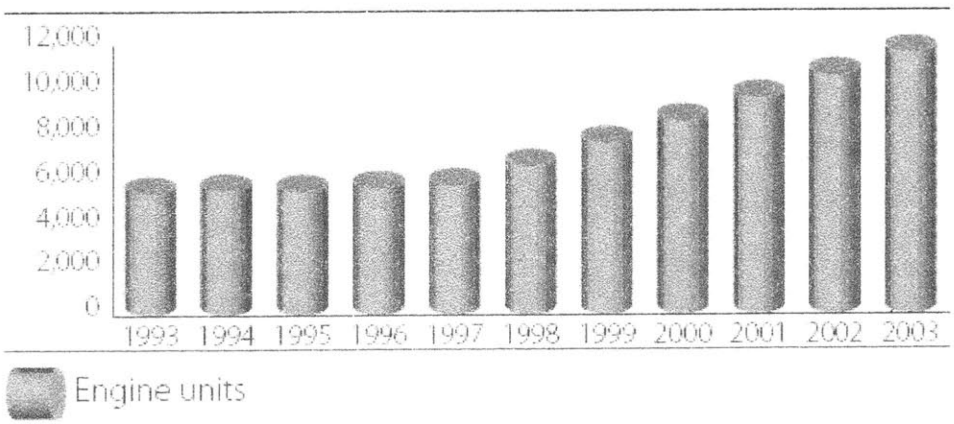
	2003	2002	2001	2000	1999
Revenue in $ millions	4,849	4,930	6,197	5,670	4,579
Engine deliveries	746	856	1,362	1,091	1,080
Employees	19,800	21,100	23,900	24,600	25,700
Installed engine base	10,450	9,910	9,212	8,322	7,447

As is obvious from the table above, the new engine deliveries are slowing down, and hence Rolls-Royce is focusing on aftermarket services, which form 53% of sales in this segment. In that context, the installed engine base is a very important metric, and is tracked in the Figure

[43] From Rolls-Royce Annual Report 2004
[44] Ibid

12[45]. Rolls-Royce expects $28.5 billion of future revenues over next 25 years from this installed base of 10,450 engines. These services' coverage has increased from covering 20% engines in 1993 to over 60% in 2003.

Figure 12: Rolls-Royce's installed civil jet engine fleet



Source: Public data provided by Rolls- Royce

Products and Customers: Over 30 civil aircraft types are powered by Rolls-Royce engines. Most airlines fly aircrafts powered by Rolls-Royce engines, such as Boeing 747 (RB211) and Airbus A320 (V2500). It offers Trent 500 on Airbus A340-500, and Trent 900 is offered on Airbus A380. Among the regional and business jets, it offers successful products such as BR700 series (used in aircrafts like Boeing 717) and AE3007, used in regional jets like Embraer.

4.3.2 Military Aerospace

Rolls-Royce is number one manufacturer of military engines in Europe (in terms of engines in service) and number two in the world (after GEAE), with 24,000 engines currently in service[46]. In addition, the defense aerospace has also delivered 11,000 commercial helicopter engines, and is the world's largest helicopter engine manufacturer. Its strategy in this sector is to

[45] From Rolls-Royce Annual Report 2004
[46] Ibid

get certified on new military programs, improve efficiency and cost reduction and expand aftermarket services. Table 5[47] presents the divisions history over past years:

Table 5: Rolls-Royce Military Aerospace division performance history 1999-2003

	2003	2002	2001	2000	1999
Revenue in $ millions	2,516	2,477	2,520	2,525	2,048
Engine deliveries	510	505	472	555	511
Employees	4,900	5,100	6,700	7,200	7,900

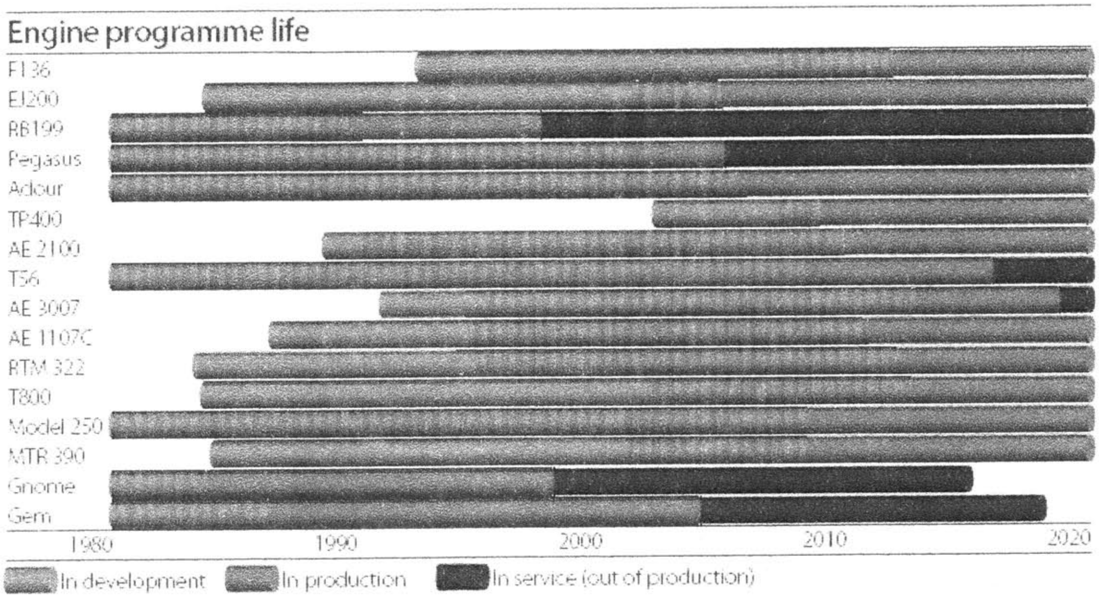
In 2003, aftermarket services represent 56% of sales, new engine deliveries represent 28% of sales and R&D services to government accounts for 16% of sales. In a trend similar to civil sector, the driver of revenues is the aftermarket services.

Products and Customers: Rolls-Royce offers a broad portfolio of product programmes in key market sectors i.e. light attack aircraft, transport, trainers, light helicopters and surveillance. Figure 13 displays the current engines, and their product life till the year 2020.[48]

US Department of Defense (DoD) is the largest government customers, and Rolls-Royce supplies 25% of all engines purchase by the DoD. Rolls-Royce participates in the Joint Strike Fighter (JSF) program with F136 and F136 turbofan engines. It also participates in V-22 Osprey program, and has been successfully tested with production beginning in 2008. Further, Rolls-Royce has a strong position in Unmanned Aerial Vehicles (UAV) such as the US Global Hawk and Firescout program.

[47] From Rolls-Royce Annual Report 2004
[48] Ibid

Figure 13: Stages of lifecycle of Rolls-Royce's various military engines



Source: Rolls-Royce Annual report 2004

In Europe, the TP400 turboprop engine is certified on Airbus A400M transport plane, and RTM 322 and MTR 390 turboshaft engines are selected for helicopters by Spain and Greece. In Asia, Rolls-Royce sees demand for its Adour engine in Hawk jet trainers purchased by India and UK.

Rolls-Royce's customers are increasingly focusing on purchasing capability rather than just equipment, which translates into service revenues through MRMS contracts, and "Power by the Hour" contracts. Its MRMS revenues have been $500 million since it was launched two years ago.

4.3.3 Marine

Rolls-Royce is a world leader in Marine propulsion systems[49]. It acquired Vickers plc to achieve this position in 1999. It sells gas turbines in the 3-40 MW range, and the products such

[49] Rolls-Royce Annual Report 2004

as MT30 (most powerful marine engine in the world, used by UK and US navy) have 80% commonality with Trent 800 aircraft engine. Other smaller engines like NT5 and AG 9140/50 are derived from industrial gas turbine designs. Its strategy for this segment is to leverage its civil aerospace engines to offer large marine gas turbines, and establish product leadership. It is also focusing on operational efficiencies and increasing the aftermarket services.

The divisions' revenues and employees have varied over the years (Table 6)[50]:

Table 6: Rolls-Royce Marine Aerospace division performance history 1999-2003

	2003	2002	2001	2000	1999
Revenue in $ millions	**1,669**	**1,771**	**1,489**	**1,352**	**693**
Employees	6,400	6,500	6,500	6,500	6,700

It has manufacturing bases in N. America, UK and Scandinavia, and low cost bases in Poland, Korea and China. The revenue is balanced between naval and commercial sales (32.5% each), with the rest 35% coming from aftermarket services. Rolls-Royce' equipment is operated on 15,000 commercial vessels, 800 offshore support vessels and 2,000 warships.

Products and Customers: The commercial markets are offshore oil and gas, fast passenger ships, cargo and liquefied gas carriers. The military customers are world's navies, primarily US, Japanese and European navies. Rolls-Royce is the design authority for UK's nuclear submarine fleet.

4.3.4 Energy

Rolls-Royce is the worldwide leader in its oil and gas applications, both onshore and offshore[51]. It uses this position to offer power generation solutions. The business uses gas turbine

[50] From Rolls-Royce Annual Report 2004
[51] Ibid

technology at its heart, and leverages the industrial version of aero-engine cores, such as the industrial Trent. It also utilizes cross-selling opportunities with the marine business.

While the current oil and gas market is strong, worldwide power generation business is depressed. Rolls-Royce expects that gas turbine technology would be preferred by customers when the market recovers, and has developed the industrial Trent based platform to compete in this market. The strategy for this segment is to maintain its leadership position in oil and gas, build a strong power generation business, grow the aftermarket service revenues and improve manufacturing costs. Rolls-Royce intends to leverage its common technology for serving multiple markets. The division's recent history is shown in Table 7[52]:

Table 7: Rolls-Royce Energy Aerospace division performance history 1999-2003

	2003	2002	2001	2000	1999
Revenue in $ millions	1,051	1,150	1,094	857	868
Engine deliveries	54	68	72	79	77
Employees	4,000	4,500	4,900	5,400	9,200

Products and Customers: The global energy demand is expected to double in size by the year 2020[53]. The primary growth is expected to come from developing countries, with Rolls-Royce's most significant projects being in Qatar (Dolphin Energy Ltd.) and China (West-East China Gas Pipeline). Rolls-Royce would use its RB211 gas turbine in both the projects, and the industrial Trent powered gas compressors for underwater pipeline between Qatar and UAE. It also intends to sell innovative aftermarket services to increase the revenues in this segment.

The next chapter would dive deeply into Rolls-Royce's commercial and military aerospace segments, and explore the business practices within these divisions.

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[52] From Rolls-Royce Annual Report 2004
[53] US Department of Energy.

5 Rolls-Royce's Position as Aircraft Engines Manufacturer and its Supply Chain

This chapter describes the overall position of Rolls-Royce in the aircraft engine manufacturing industry and in its specific product segments. It details the structure of the company's supply chain within the aerospace-related divisions, location of facilities and the performance metrics that the supply chain is designed to focuses on. It uses this structure to explore the supplier facing business processes, internal business processes, and customer facing business processes of the supply chain.

Finally, the chapter studies the application of the business processes through key supply chain initiatives at the company, and details a case study where the supply chain of a product was improved using these key initiatives.

5.1 Market Share in Aircraft Engines

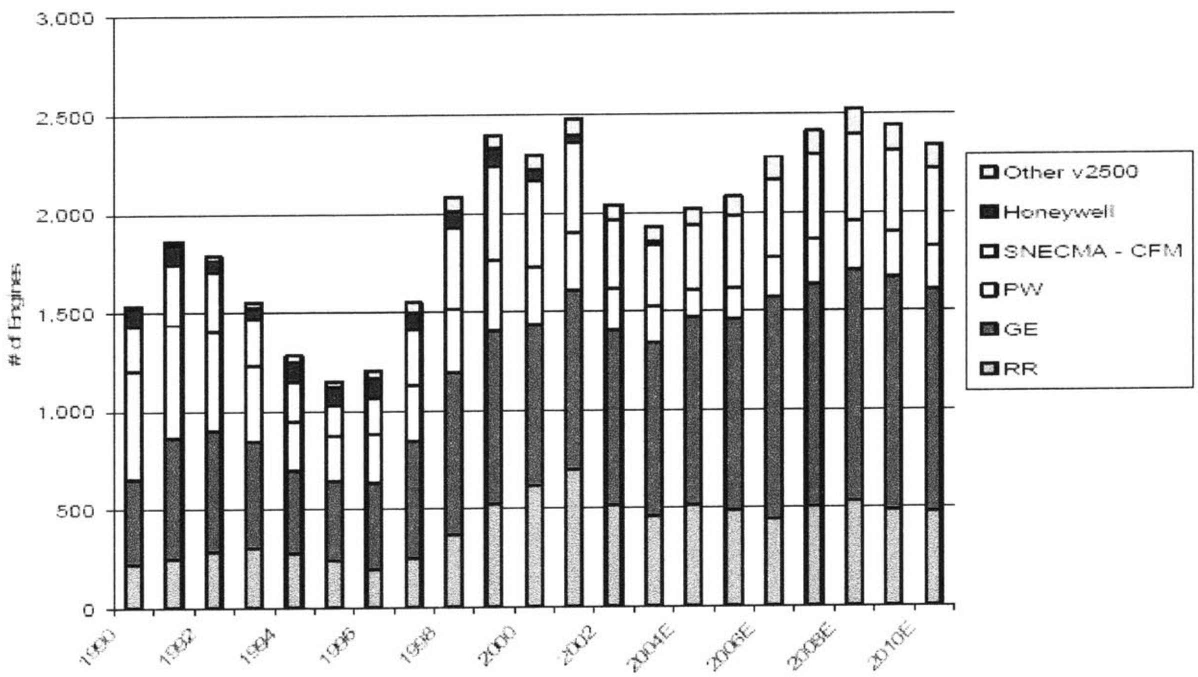
Rolls-Royce's market share can be seen from two perspectives i.e. by unit volumes and by revenues.

5.1.1 Market share by engine unit volumes

Rolls-Royce is the second largest aircraft-engine manufacturer in the world, behind General Electric Aircraft Engines (GEAE). Its competitive position over time for Single Aisle

(SA) aircraft engines, Wide Body (WB) aircraft engines and regional/ corporate jet engines against other primary manufacturers is shown in Figure 14.[54]

Figure 14: Total aircraft engine deliveries by major manufacturers 1990-2010 estimates



Rolls-Royce has come back strongly in late 1990's to regain market share, and is expected to retain it in near future. Table 8[55] describes estimates for market shares in the industry.

Table 8: Rolls-Royce's market share in engines (units) 2000-2010 estimates

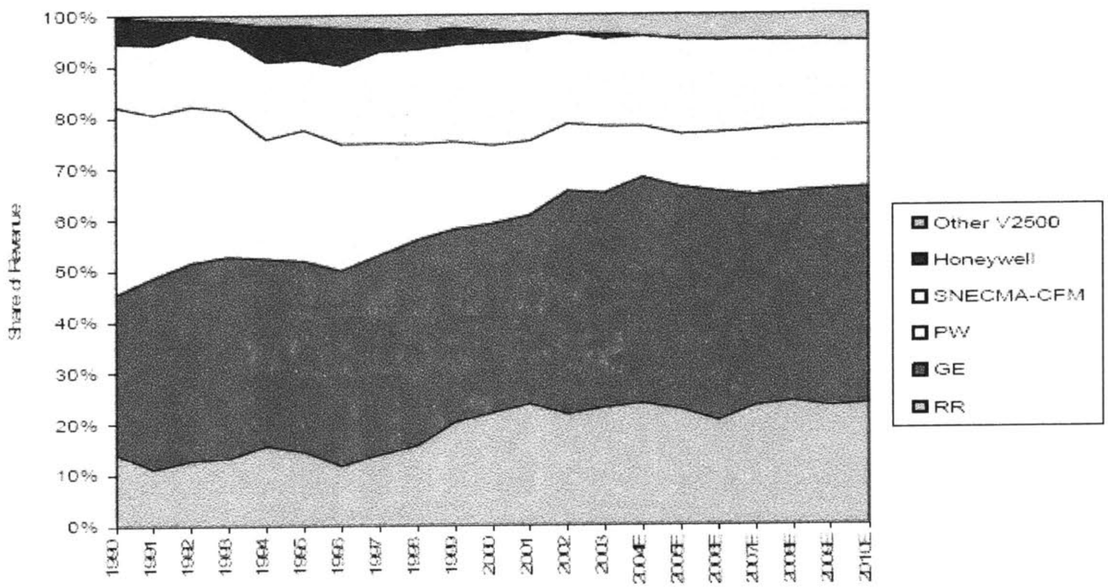
	2000	2001	2002	2003	2004E	2005E	2006E	2007E	2008E	2009E	201(
Total Engines	2,294	2,480	2,040	1,924	2,873	2,892	3,222	3,536	3,775	3,786	3,698
Single-Aisle	1,160	1,200	942	830	886	984	1,100	1,186	1,248	1,188	1,124
Widebody	488	512	438	412	384	418	464	516	592	552	536
Regional	646	768	660	682	748	678	716	708	684	702	680
Corporate	0	0	0	0	855	812	942	1,126	1,251	1,344	1,358
RR Market Share											
Single-Aisle	11%	12%	11%	9%	10%	9%	10%	9%	10%	10%	10%
Widebody	23%	25%	25%	38%	41%	41%	40%	43%	45%	44%	44%
Regional	59%	55%	46%	33%	36%	34%	23%	24%	21%	19%	19%
Corporate					36%	38%	35%	31%	32%	33%	34%
Total RR Market Share					**28%**	**28%**	**24%**	**24%**	**25%**	**25%**	**26%**

[54] From Morgan Stanley Research Report on Rolls-Royce, December 2004, compiled from Company data and Morgan Stanley Research.
[55] Ibid

5.1.2 Market share by revenues

Its revenue share in the worldwide market for aircraft engines is expected to grow stronger in its core widebody market, while it is expected to lose market share in small regional and business jet market, primarily to GEAE and P&W[56]. The overall market share, however, is expected to grow in the future, and it is expected to retain its number two position in the industry, as shown in Figure 15. The share in specific aircraft segments is given in Table 9[57].

Figure 15: Market share of major engine manufacturers by revenues 1990-2010 estimates



E = Morgan Stanley Research estimates

[56] From Morgan Stanley Research Report on Rolls-Royce, December 2004, compiled from Morgan Stanley Research
[57] Ibid

Table 9: Rolls-Royce share of engine revenues 2004-2010 estimates

Rolls-Royce Share of Engine Revenues 2004-10

RR Revenue Share (%)	2004	2005	2006	2007	2008	2009	2010
Widebody	39	39	36	44	45	43	44
Single Aisle	10	9	9	9	10	10	10
Regional	32	30	20	20	17	16	16

Excludes corporate engines
Source: Morgan Stanley Research estimates.

The reason for loss of market share in the regional aircraft segment is that in this segment, only one manufacturer is typically certified on an aircraft[58]. Hence loss of market share is proportional to loss of end-products' market share in this segment. GEAE and P&W are certified on more popular models, and hence they would gain market share over Rolls-Royce.

5.2 Rolls-Royce's products and their competitive positions in aircraft engines market

As mentioned in Chapter 3, the gas turbine engine market has three sub segments i.e. turbofan, turboprop and turboshaft engines. Rolls-Royce's position in each of these product segments is as follows:

5.2.1 Turbofan engines

The demand for turbofans comes from following segments[59]. We discuss Rolls-Royce's position in each of these sub-segments:

Heavy transport jets: This market is served by engines having thrust of 50,000 lb. of higher. The market is expected to have growth driven by new large aircraft such as Boeing 7E7 (uses GEAE GenX and Rolls-Royce Trent 1000) and Airbus A380 (uses GEAE-P&W GP7000 and Rolls-Royce Trent 900). Production rates for Boeing jets such as 777, 747, A340-500/600 and

[58] Interview with Henrique Marcondes from Embraer, March 2004
[59] Franus, David; *Aviation Week & Space Technology*, Jan 17 2005, pp 117

A321 provides gradual growth and Rolls-Royce is among the top three producers, along with GEAE and P&W.

Heavy military jets: The top three engine producers in this segment are P&W, GEAE and Snecma, in that order. Major demand comes from new aircraft programs like F/A-22, F-35 Joint Strike Fighter (JSF) and Rafale, which primarily use the three manufacturers mentioned above. The largest demand (estimated to be in thousands of engine sales) would come from the US JSF program where P&W and GEAE are the biggest competitors. In terms of volumes, Russia's Saturn and Klimov are larger than Snecma, but are smaller in revenue terms. Rolls-Royce is not among the larger players, and manufactures engines for the British Sea Harrier and Chinese Phantom and J-7 fighters.

Light military jets: The chief producers in this segment are Rolls-Royce and Russia's Klimov. This segment is small, with expected volumes of 125 engines in 2005, with demand coming from small European nations as well as Middle Eastern and Asian air forces.

Light regional jets: This segment is served by turbofan engines of up to 5000 lb. thrust. Rolls-Royce addresses this market with turboprop engines, and not with turbofan engines.

5.2.2 Turboprop engines

The turboprop market has been losing market to turbofan engines, and the primary application for turboprops is in the corporate and regional aviation market[60]. There are applications in the military segment too, as would be discussed below. The primary market segments for turboprop engines, and Rolls-Royce's position within them, are as follows:

Civil aircraft: The primary manufacturers in this segment is P&W (with the PT6A engine), which is projected to dominate the demand among the 6,100 turboprop engines (worth $3.3. billion) that would be manufactured for civil applications over the next decade. The primary

[60] Franus, David; *Aviation Week & Space Technology*, Jan 17 2005, pp 117

demand driver in this market is single-engine business or regional aircraft. Rolls-Royce competes in this market with the AE 3007 series which finds use in the Embraer ERJ 135, ERJ 140 and ERJ 145.

Military aircraft: The military turboprop market is also small (3,400 engines, worth $5 billion) and relies on a small number of turboprop powered models. Rolls-Royce is a prominent player in this market with the AE 2100 engine, which powers the four engine Lockheed Martin C-130J. The other prominent player is P&W with the PW 100 series, which powers the EADS CASA C-295. The single engine trainer market, where P&W dominates, is declining, and hence would affect P&W position in the market. Among the large programs on the horizon, the Airbus A400M program has not certified Rolls-Royce for production.

5.2.3 Turboshaft engines

These engines are primarily used in helicopters.[61]

Civil helicopters: P&W and Turbomeca are the leading players in this market. Civil applications are small compared to military applications for turboshaft engines.

Military helicopters: GEAE is the largest manufacturer in this segment (selling T700 to US Army). The 1200-2500 shaft horse power (shp) range constitutes 50% of the total turboshaft engine demand, and GEAE fulfills 50% of the 1200-2500 shp demand. Rolls-Royce is active supplying smaller engines like Model 250, which generate < 1000 shp, to British and French air forces (Bell and Augusta Westland helicopters).

The primary demand for turboshaft engines comes from new engines for existing helicopters, and new programs such as the Bell/ Boeing V-22 Osprey military rotorcrafts. The new programs that would drive the future demand are in the 2500-3000 shp range, being

[61] Franus, David; *Aviation Week & Space Technology*, Jan 17 2005, pp 117

designed for US Army requirements for high altitude and 2-3 engine medium-lift transport helicopters. Rolls-Royce is not yet competing in that segment.

5.3 Supply Chain Structure at Rolls-Royce

Rolls-Royce procures 70% of the components used in its final products, and only manufactures 30% of the most value added components[62]. It operates manufacturing facilities across the globe, and follows a strategy where each purchasing and manufacturing business unit services all four business segments.

Rolls-Royce has a tiered supply chain, as described in Figure 6, which delivers structured build packages for the engines. The focus in the company is on reducing the number of suppliers, and Rolls-Royce in 2003 had 765 suppliers, down from 900 in 2002. On the other hand, they are adding suppliers in emerging low cost countries, and have added 37 new suppliers in those geographies in 2003. Over the years, the focus on cost reduction and increased collaboration with suppliers has led to significant dependence on suppliers for success of cost reduction efforts finished in such components as sub-assemblies. In 2003, Rolls-Royce reduced its costs by 5%.

Different manufacturing facilities are at different levels of progress on this front. For example, The Indianapolis facility has reduced the supplier base from 1300 suppliers in 1999 to 300 suppliers[63] in 2004. However, it is still in early stages of establishing a tiered supply chain, and has not achieved it completely[64].

Rolls-Royce has learnt from and taught best practices to its supplier base[65]. Aerospace industry shares a common supplier base for all engine manufacturers. Hence, the suppliers are in

[62] Rolls-Royce Annual Report 2004
[63] Interview with John McLauchlin, formerly Field Quality Engineer, Rolls-Royce, April 2004
[64] Ibid
[65] Interview with Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004

good position to learn best practices of one customer, and initiate such practices in their customers. Rolls-Royce shares its suppliers with successful companies such as GEAE, and has used this captive knowledge from suppliers to establish certain best practices related to supplier management.

Supplier collaboration has made Rolls-Royce responsible for maintaining/ supplying spares and aftermarket services for parts that are not manufactured by itself. Hence, the focus on cost reduction, quality and performance has shifted from Rolls-Royce's manufacturing to include the entire supply chain. In this exercise, suppliers are teachers as well as learners.

Another focus area for the company is supply chain flexibility, which requires Rolls-Royce to be able to scale its production up or down, as required by market conditions. Rolls-Royce has negotiated flexible terms with its workforce to achieve such flexibility. Having such negotiated terms is considered a competitive advantage within the industry, as is discussed in Chapter 6.

5.4 Manufacturing Facilities and Suppliers

Rolls-Royce has a strategy where they use each manufacturing facility to service all four business units[66]. However, some facilities are primary producers in each category. The primary facilities for aircraft engines manufacturing are listed below, grouped by the customer segments they service[67].

Civil Aerospace: The primary facility is in Derby, UK, which makes engines that serve the airlines. It manufacturers the RB211 family of engines, which are used in Boeing 747/ 757 aircrafts. It also makes the Tay and heavier Trent family of engines, used in Fokker, Airbus

[66] Interview with Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004
[67] *Aviation Week & Space Technology*, Jan 17 2005, pp 312

A330/ A340, A380 and Boeing 777 aircraft. The regional and corporate aircraft are manufactured in Dahlewitz, Germany and Indianapolis, IN, USA. This includes the AE 3007 engines for commercial aerospace and those with their partnership with Williams International.

Defense Aerospace: The primary facilities are in Filton, Bristol, UK and Indianapolis, IN. All turbofan and turboshaft engines meant for military applications are manufactured here, though the production at Filton facility is primarily turbofan engines, while in Indianapolis they primarily manufacture non-turbofan engines. Many of the joint venture engines with Snecma, Turbomeca, MTU, Honeywell and Viper are also made in these two facilities.

Maintenance, Repair and Overhaul (MRO): The MRO, engineering and support activities for the military and commercial customers are done at Derby and East Kilbride in UK. Each of Rolls-Royce divisions derives about 50% of their revenues through service contracts, and hence this facility is a very strategic for Rolls-Royce' revenue growth and profitability.

Rolls-Royce outsources extensively to its key global suppliers[68] such as Alcoa (airfoils), BF Goodrich (measurement sensors), L-3 Communications (engine test beds), Northstar Aerospace (gear boxes), Sumitomo (heat management systems for fuel and oil), Kawasaki Heavy Industries (key engine parts), JJ Churchill (turbine blades), Whittaker Controls (fluid controls), Accuron (ceramics), Hindustan Aeronautics Ltd (gas turbine components), Intertek Caleb Brett (metallurgical analysis), Texas Composite (guide vanes), Hispano-Suiza (power transmission components) and Fern Engineering (joints/ coupling sections for energy systems).

5.5 Performance Metrics for Supply Chain

The key metrics used by Rolls-Royce to measure its supply chain performance are[69]:

- Quality of the delivered product

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[68] Information compiled from news releases and articles from the Lexis-Nexis Academic database and the Aviation Week and Space Technology database.
[69] Interview with Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004

- On-time delivery
- First pass test yields
- Past due receivables
- Cost of manufacturing and Return on Invested Capital

The single most important metric used by the engine manufacturing industry is quality of the product, followed by on-time-delivery to the end customer. In a cyclical market for aircraft deliveries, any time lost in an industry up-cycle is directly proportional to lost revenues. Hence customers are extremely sensitive to delayed deliveries. Further, without a strict control of quality in a highly regulated market, the company would not be able to satisfy other metrics such as on-time delivery and cost controls if the product required re-work and repeated testing.

5.6 Supply Chain Business Processes

The supply side, inside and customer side business process in the company's supply chain are described below. These are followed by description of the 40-day engine supply chain initiatives at Rolls-Royce which demonstrates the application of the business processes.

5.6.1 Supplier facing business processes

The supplier facing business processes studied are:

- Supplier selection and segmentation
- Collaborative product development
- Procurement
- Supplier Management and Development

Supplier selection and segmentation: Rolls-Royce uses a global base of suppliers and it shares this supply base with its competition. Since the aerospace industry has few large suppliers, Rolls-Royce uses all the large suppliers in the industry with no dedicated suppliers. It has a varied supply base, and (for example) its purchases from its supply base in the US ranges from $1 million for smaller suppliers to $40 million from the larger ones (for Indianapolis facility)[70] As mentioned before, the supplier base has been drastically reduced, and the exercise is expected to continue. For example in the US, the goal of the exercise is to reduce the supply base to 30 tier 1 suppliers from the current base of 300 suppliers. These suppliers would create sub-assemblies from tier 2 and tier 3 suppliers, and supply 30 sub-assemblies to Rolls-Royce, who would then assemble them to create an engine. The rationale behind the exercise is that Rolls-Royce has a higher cost of labor than its suppliers and hence outsourcing would result in lowering the overall cost of the final engine.

Collaborative Product Development: The company uses its primary suppliers to jointly finance and co-develop new products. Such suppliers are called Risk and Revenue Sharing Partners (RRSP's)[71]. Under the partnership, the suppliers invest capital in development of a new engine, as well as provide product development engineers. This reduces Rolls-Royce's investment in the project, and also reduces the critical development time (typically 3-4 years), since more resources are now being used to develop an engine. Therefore, the payback period for investment is also lesser than a typical period of 10 years.

Rolls-Royce writes revenue sharing contracts with the RRSP's, giving them more responsibility as business partners. The structure of the contracts and its comparison to earlier practices is as follows: Earlier, build-to-specification subcontractors used to recover non-

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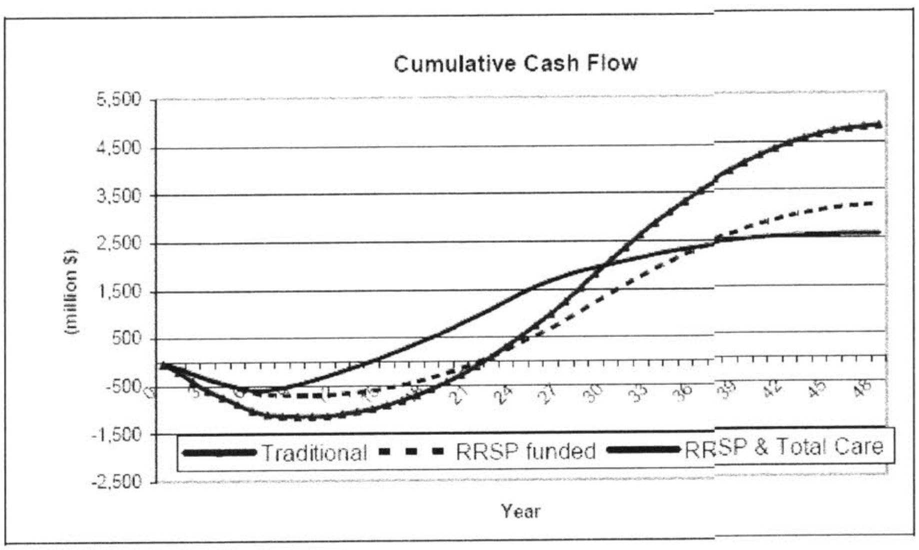
[70] Interview with John McLauchlin, formerly Field Quality Engineer, Rolls-Royce, April 2004
[71] Ibid

recurring costs up-front as they delivered the components, but now RRSP's prorate their investments in items such as tooling and testing equipment over an agreed number of aircraft. If the sales goal is exceeded, the partner recoups his costs, and earns additional profit. Else, he absorbs a portion of fixed, non-recurring costs. Similar terms exist in R&D investments.

The cash flows from such a project are far less cyclical, and hence the capital at risk is also low for Rolls-Royce. Typical cash flows (cumulative) from such a project in commercial aerospace are shown in Figure 16[72] (Total Care stands for cash flows from aftermarket services in the commercial segment):

Figure 16: Impact of RRSP's and Total Care on Rolls-Royce's Cash Flow



Source: Company data, Morgan Stanley Research

These practices are becoming more common with new engines development, or for redesigning of old engines, and not for existing engines.

Procurement: Rolls-Royce distinguishes between items supplied by its suppliers and classifies them as A, B or C class item. Any item less than $100 of cost is considered a C-class item. In North America, Rolls-Royce has outsourced the handling of C-class items (5000 items)

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[72] From Morgan Stanley Research Report on Rolls-Royce, December 2004, compiled from Company data and Morgan Stanley Research

to Wesco, a company based in California, USA. The agreement with this company is to establish a 2-bin Kanban, and quantity bands for control measures. Wesco is responsible for product availability and it does so using UPS as a logistics provider. For procurement of these parts, Wesco is authorized to negotiate the procurement, stocking and delivery of these parts and deals directly with Rolls-Royce's chosen suppliers to do so.

For procurement, Rolls-Royce is a pioneer in the use of paperless procurement by using the industry portal called Exostar. It was a founding member of Exostar and uses it extensively to communicate the demand and supply information with all of its 700+ suppliers. This has replaced earlier processes which were manual and paper based to a new process which is automatic, real-time and provides visibility to all suppliers who can track the status of purchase orders and receipts in the supply chain. The demand for all suppliers is communicated through Exostar, which is updated once each week. The payments are also electronic and the system uses SAP data which is well integrated with Exostar and enables the suppliers to see the data in Rolls-Royce systems in the format that they would want. The total value of Rolls-Royce's buy is $1 billion.

Supplier Management and Development: Rolls-Royce has established a Supplier Council which meets for 3 days twice each year- once in US and once in Europe. The goal of the council is to forge management level relationships and invite and share suggestions for supply chain improvements. This council is a core part of Rolls-Royce's strategy to reduce its costs and complexity in the supply chain and improve its efficiency. It uses these meetings to create functional working groups consisting of engineers from Rolls-Royce as well as suppliers, who then share ideas and practices related to these functions between themselves.

It also provides its suppliers with its own engineers who study the supplier's processes and their effect on Rolls-Royce's supply chain. It visualizes the bottlenecks of its suppliers as a bottleneck in its supply chain, and hence invests in developing the supplier's ability to deliver on time, at lowest cost and highest quality. The purpose of the exercise is to improve suppliers' processes, and mitigate the risk that their operations might put on Rolls-Royce's ability to deliver. This exercise is a data driven exercise using tools such as root-cause analysis, and results in score-cards being given to suppliers to track their progress on improvement initiatives.

The suppliers are encouraged to develop complementary capabilities by sharing knowledge and transferring technology. They are then certified for process capability and are delegated more responsibility such as managing the Tier-2 suppliers. These practices insure that lean manufacturing practices trickle down all through to lowest levels of the supply chain.

5.6.2 Internal business processes

Product portfolio management: A key factor of success in the aircraft engine manufacturing industry is to get certified on new aircraft programs[73] and maintain an active portfolio of products. Therefore, Rolls-Royce is continuously working on new products. These engines are developed in two ways 1) engines derived from existing models and platforms and 2) totally new engines.

The company finds it cheaper and faster to develop engines from existing platforms[74]. It also uses engines developed from military programs such as the F-35 Joint Strike Fighter (where R&D is financed by the government) as platforms from which commercial engines are developed. Using this strategy, the company has been able to act on its declared principle of

[73] Interview with John Weiss, i2 Technologies, VP Aerospace Practice, March 2004
[74] Interview with Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004

using its existing technology to produce engines for new aircraft programs. This also reduces the supplier certification and testing process and hence reduces the development time of the engine. As a result, very few completely new engines were required to be developed in recent years[75]. Product development is another focus area where the company has set a goal to be able to be develop derived engines in 24 months- and the new Trent 1000 engine to be used for Airbus A380 has been developed in 24 months.

Facility and Capacity planning: The facility and capacity planning at the company is done in accordance to the industry cycles. The company pursues to have the key capability to increase and reduce its capacity and hence fixed overheads as demand rises and falls. This is done through negotiated labor contracts that allow reduction in capacity, and also following JIT principles with its suppliers.

Planning Systems and Technology: The industry and the company do not seem to use much of Advanced Planning Systems and software[76]. That is perhaps because the industry is not a high unit volume industry which might face particularly taxing scheduling or distribution issues. The products are highly engineered and the focus is on supplier collaboration software, which integrates company and supplier's operations. Further, in a highly regulated environment, the ability to use conventional methods for optimizing is limited, which limits the use of APS software. Rather, the potential for optimization lies in synchronizing material deliveries and availability from suppliers. Overall, the industry looks at IT as an enabler, rather than a strategic tool, and IT outsourcing is a growing trend[77].

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[75] Ibid
[76] Interview with John Weiss, VP, i2 Technologies, March 2004
[77] Interview with Pete Wiese, CSC, Practice Manager, Aerospace, Defense and Industrials Group, March 2004

Rolls-Royce has linked its business processes and synchronized its IT/ IS infrastructure to allow seamless information flow between itself and its suppliers[78]. This allows for use of 'pull signals', two-way information exchange and visibility. An example of innovative use of IT is use of web cameras where the suppliers can see the product being built to get visual signals of when supplies might be required. Therefore, when an engine is pulled by the customer off the test bed, it sends a pull signal not only through Rolls-Royce supply chain, but all through the supplier network, reaching component level and raw material suppliers. This ensures flexibility and rapid response capability in the supply chain.

Inventory Management: For the purposes of inventory management, most components are maintained on a just-in-time (JIT) basis. However, certain components, such as castings and finished metals, as well as certain raw material inputs, have a lead time of up to 120 days. Other products, such as Fuel Controls, have greater than 30 day lead times, and the company stocks the necessary components and raw materials. The second kind of product kept in inventory is MRO parts.

Inventory Management for Aftermarket service parts: The inventory management for aftermarket service parts is not a mature science, since failure of some parts like turbine blades are predictable, while others are not. The majority of maintenance expenses are incurred after the warranty runs out. Therefore, Rolls-Royce can use its historical engine usage data to its advantage and assume the risk of maintenance of customers' fleets, which enables it to write long term high margin aftermarket service contracts with airlines. This exercise is harder to do in military segment since the military does not provide usage data as openly as the commercial segment due to the related security concerns.

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[78] Video cassette from Rolls-Royce about its supply chain initiatives in 2000-04. The project described was the AE 3007 flow line, where lean operations principles to improve operational parameters.

These parts are managed using advanced predictive software and tools which use engine use-data collected over several years[79]. These tools predictive failure rates for various parts and Rolls-Royce uses such forecasts to decide stocking levels and strategic locations for MRO parts. These aftermarket services are quite profitable (as mentioned in chapters earlier), and Rolls-Royce competes with different companies for this business. A capable inventory management technique for aftermarket services and parts is a key ability required to maintain market share in a high margin service offering. For example, it competes with its own customer Lockheed Martin in f providing such services in connection with the C-130 fleet owned and operated by the U.S. Department of Defense[80]. Boeing is planning to enter the aftermarket segment too as Airbus started doing last year, to be able to offer a complete lifecycle support solution for the product to the airlines[81]. It also competes against smaller firms that service engines with non-authentic parts. These parts reduce the maximum life of the engine, but are cheaper. Rolls-Royce uses its knowledge about the engine to price its services higher, in return for a promise to extend the maximum life of the engine.

The company does not hold any end-product inventory, since each engine is engineered and made to order.

Production Management[82]*:* The production management at the company is structured on lean principles and the idea of having a flow-line for each product. To cite the example of Indianapolis facility: until1999, Rolls-Royce used to manufacture engines by keeping engines on a stand. The parts would be brought to this specific location and the engine would be assembled. Further, the assembling of the engine would not be started until all the parts had arrived- which

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[79] Video cassette from Rolls-Royce about its supply chain initiatives.
[80] Interview with Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004
[81] Interview with CIBC World Markets, April 2004
[82] Interview with Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004

lengthened the manufacturing flow time of the engine. The parts were delivered to a location at the plant site by all suppliers and Rolls-Royce moved them to the manufacturing location of the engine. Furthermore, the stands on which the engines were manufactured acted as a bottleneck and multiple engines could not be manufactured due to shortage of space.

This process has now changed dramatically, and Rolls-Royce now uses what is called a flow-line concept. This concept was successfully applied to their AE 3007 engine in Indianapolis (as described in the 40-day engine initiative later in the chapter). The differences are:

- Now, the engine moves on a flow line from location to location on the shop floor for 8 different manufacturing stages. Its manufacturing is started as soon as parts sufficient for the first stage have arrived.
- The parts are now delivered by the supplier to the actual point of use on the engine flow line. This reduces the total time a worker has to walk to get the parts. It also makes suppliers responsible for the parts, which has increased the quality of the parts delivered.
- The tools and parts at each stage are now grouped in "kittings" (kitting is done either by their suppliers or by Wesco for C-class items).
- The manufacturing at each stage is organized into cells with cross-trained workers who could do multiple tasks in a cell. The workers were incentivised to create their own tool-kits and layout of the cell, which increased worker productivity by 40%.
- They have also attempted to reduce lead times for manufacturing of parts such as turbine blades, and the goal is that each manufactured part would also have its flow line. These parts were earlier machined completely in-house. But now, Rolls-Royce purchases 'near-net-shape' castings which are machined to specifications in-house- the lead time for this process is now 2 days, and the yields are much higher.

Rolls-Royce, therefore, has been able to implement the lean production approach using pull signals to generate downstream demand, produce on a flow line, use kitting for procurement, involve suppliers in design and development of products and also use JIT and Kanban for its material planning. All these production methods were learned from best practices that had been adopted earlier by the automobile industry. These lean practices were originally developed by Toyota and are generally known as the Toyota Production System. This unique blend of best practices that works well for Roll-Royce has been termed the Rolls-Royce Production System (RRPS), and the suppliers are expected to learn and transform using it[83].

These production methods are designed to support the 40-day engine initiative, with 30 days for parts sourcing and parts manufacturing, and 10 days for assembly and testing.

Transportation and Warehousing: The company uses third party logistics (3PL) providers for transportation and warehousing. Since it considers these activities as non-core activities, it outsources them to providers such as UPS. Different 3PL providers are used in Europe and US.

5.6.3 Customer Facing business processes

The aerospace industry is an engineering-driven environment. Since the customers in the industry are engineering companies buying highly advanced made-to-order engineering products, the typical customer-facing supply chain processes (e.g., distribution and channel management, customer segmentation and customer management, order quoting and order fulfillment) are not generally practiced, in the traditional sense, within Rolls-Royce.

However, Rolls-Royce's customers are few and powerful due to the recent industry consolidation. Hence, Rolls-Royce's focus is to retain customers, and acquire new ones by providing them the best product quality, competitive cost and on-time delivery. It also has to

[83] Interview with Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004

offer creative innovative aftermarket services to differentiate itself and maintain high margins. It does so by offering differentiated prices to different customer segments, as noted below.

Differentiated pricing to different customer segments[84]*:* Rolls-Royce discounts the prices of the engines to ensure aftermarket parts and service revenues (which are usually twice the revenue from the sale of the engine and higher in margins). Therefore, Rolls-Royce distinguishes between customers that buy smaller quantities and do not buy service contracts, and larger customers, such as airlines, that buy large numbers of aircraft and award long term service contracts. This practice is fairly prevalent in the industry. For example, GEAE financed the Airbus A350 program to get exclusive aftermarket service contracts for its engines.

Further, Rolls-Royce also offers different pricing for aftermarket services to military and commercial customers. Since military customers do not share usage data, it is hard to predict the failure rates, and the risk of offering aftermarket service warranties is higher. Therefore, it prices the aftermarket services for commercial customers (Total Care program) differently from the "Power by the Hour" or Mission Ready Management Solutions (MRMS), even though the engine would be the same. For example, Embraer aircrafts uses the same engine as installed on V-22 aircraft used by the US Marine Core. However, Rolls-Royce prices its services at $50-60 for Embraer aircrafts and $150 for the V-22 aircrafts of the US Marine Core.

5.7 Supply chain initiatives: 40-day Engine

Rolls-Royce started several initiatives in 1998, when it became a member of the Lean Aerospace Initiative at MIT[85]. These initiatives are based on adoption of lean manufacturing

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[84] Ibid

[85] Interview with Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004

principles in its operations and supply chain. The key supply chain excellence initiative at Rolls-Royce is the 40-day Engine initiative.

The 40-day initiative is an umbrella initiative under which multiple supply chain excellence programs would be started to address various operational issues at Rolls-Royce. The initiative is planned to cut down a key supply chain metric i.e. manufacturing, assembly and testing lead times for its engines to 40 days. Out of these 30 days would be for parts manufacturing and procurement (from suppliers), and 10 days for assembly and testing[86]. Lead times are directly responsible for higher inventory and slow reaction to change in demand picture. A cut in lead time would significantly reduce the working capital invested in the supply chain, and hence the capital at risk which is exposed to uncertainty. The company has a goal of producing all engines within this 40-day timeline by end of 2006[87]. By March 2003, five engines met the 40 Day Engine targets[88].

One of the engines being produced in 40 days is the AE 3007, which is used as a case study below to understand this strategic supply chain practice at Rolls-Royce. The case study shows the typical supply chain problems that Rolls-Royce faced, and the strategy, methodology and steps it took to address these problems.

5.8 Case study of AE engine flow line at Indianapolis plant (Plant 5)

This case study describes a 4 year effort (2000-04) at Rolls-Royce Royce to streamline the AE engine flow line under the 40 Day Engine program[89]. This resulted in a total of $250M worth of plant improvements by 2004.

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[86] Interview with Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004
[87] Ibid
[88] Rolls-Royce Annual Report 2004
[89] Video cassette from Rolls-Royce about its supply chain initiatives in 2000-04. The project described was the AE 3007 flow line, where lean operations principles were applied and the project was used as a template for improvements in other products.

5.8.1 Background (2001):

The Indianapolis operation (founded in 1915 as Allison, acquired by Rolls-Royce in 1995) produces three major product families (i.e., AE series, T56/501 series, and Model 250). The facility produced 2 Engines/day, and utilized $1M worth of spare parts /day. It had $1.5B in annual sales in 2001. The facilities employed 4,400 People, including 1950 UAW members, and had 3,000,000 sq. ft. of active floor space. It had 2,700 active machine tools and 7,000 active part numbers.

5.8.2 Supply Chain problems

The symptoms that were indicators of supply chain problems at Plant 5 were:

- Inventory stockpiling: Sub-assemblies were being built all across the facility, and therefore inventory was collecting in multiple locations. As a result, the employees were spending 40% of their time in locating the required parts for production, or in acquiring them from suppliers.
- Lack of any process flows: Different processes were done in different locations with no relation to their position in the sequence of manufacturing operations for an engine.
- Delayed deliveries to airlines and other end customers.
- Manufacturing was regularly behind its manufacturing schedule, thus increasing the need for costly material expediting.

5.8.3 Supply Chain improvement process under the 40 Day Engine initiative

The initiative includes implementing the following six steps in order to improve the velocity and responsiveness of the supply chain:[90]

1. Simplify the gas turbine as a product, which would also simplify its manufacturing.

[90] Video cassette from Rolls-Royce about its supply chain initiatives in 2000-04. The entire process described through step 6 about the improvement steps is taken from the video cassette, unless specified otherwise.

2. Synchronize the supply chain activities across the organization so that all departments execute to a common plan.
3. Manage the supply chain at the correct level of detail (choosing what to manage).
4. Reduce variability in manufacturing and supply chain processes.
5. Implement 'pull signals' throughout the supply chain to manage materials in the product flow line.
6. Optimize the entire value stream from suppliers to customers, so as to meet the common supply chain goals i.e. what is needed, where it is needed and at what price is it needed.

These are elaborated as follows:

1) Simplify the gas turbine: The goal of this step is to simplify the design of the gas turbine, which is expected to simplify the manufacturing of the turbine. This would be a major initiative, since it would directly affect the number of parts, number of suppliers, supplier selection, outsourcing decisions and Rolls-Royce' ability to service its customers.

The first exercise in this direction would be to ensure that the physical part and information flow together, rather than separately. Hence, at any stage, the product should have a sheet of paper with all the relevant information that would be needed for a given stage. This succinct presentation of relevant information would reduce the time a worker/ engineer would need to understand the requirements of the stage and take decisions if required.

The second exercise would focus on reducing the number of parts that were actively maintained in Rolls-Royce's systems. For example, in its turboprop manufacturing operation in Indianapolis, Rolls-Royce maintained 2,700 Active Machine Tools and 7,000 Active Part Numbers in 2001 [91]. The focus is to reduce the number of parts, while increasing the number of components that are ready to be integrated with the engine. This puts more responsibility in the

[91] Information from Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004

hands of the suppliers, as well as makes Rolls-Royce depend on them for quality and after market services to the customer.

The third exercise in this regard would be to reduce the lead times throughout the supply chain. This would directly impact the amount of parts inventory required to maintain the customer service levels, and the need for safety stocks.

2) Synchronizing the supply chain plan: Rolls-Royce has directed all departments of the supply chain to work on a single plan. The departments are procurement, inbound logistics, manufacturing, systems integration, product delivery, outbound logistics and after market support. This reduces the variability in plans across the divisions, as well as potential conflicts of interests. All departments now know what to expect, and hence inter-departmental collaboration is faster and smoother. The performance parameter such as what is required, at what price, frequency, quality and efficiency is dictated by two things: a) the model of engine b) the customer of that engine.

Therefore, when these parameters are known and agreed upon by all departments, then the entire supply chain works to deliver to the expectations, and looks at achieving the global optimum, rather than local optima.

3) Managing the supply chain at the right level: A significant thought in supply chain planning at Rolls-Royce is the idea of managing the chain at the right level. The idea is to avoid managing supply chains at those levels where the value added or the value-at-risk is minimal. Therefore, for example, they would not manage the suppliers of certain raw materials which are not critical to Rolls-Royce's products. They would focus on the actual supply quantity and quality, rather than pay attention to the actual supplier performance.

On the other hand, they would collaborate with and invest heavily in a supplier that, for example, provides the front end or back end assembly of an engine. That is because such assembly is a highly engineered product that is unique to an engine design. Further, the Rolls-Royce powerplant connects to the customers' systems though its front and back end. Hence, these parts are critical to ensure that the Rolls-Royce powerplant integrates and performs well in the customers overall aircraft, marine or energy systems.

4) Reduce variability in manufacturing and supply chain processes: Achieving consistency in product and process quality is key to using lean principles successfully. If the product quality is not consistent and requires frequent re-work, then any time and material saved by other lean processes would be wasted. Similarly, if lead times or yields of a process are highly variable, then it makes difficult to plan such a system, and hence optimize it.

Therefore, Rolls-Royce has established quality teams to increase the quality of its suppliers, its own manufacturing processes and reduce the variability of lead times and throughput times across the supply chain. These teams use principles of continuous improvement and regularly meet in councils to share ideas and transfer best practices.

5) Implement pull systems in the engine flow line: Rolls-Royce has implemented lean manufacturing principles in order to reduce material and time waste from the engine flow line. An important principle of this methodology is the use of pull signals, which starts from finished goods inventory to trickle down to raw material supplier. An engine is built only when a customer pulls a finished engine. Till such time that all finished engines are allocated to confirmed orders, a new engine is not built.

To enable tracking and visible signals about the status of production of an engine in its flow line, Rolls-Royce is using information technology heavily. This includes real time information on parts, status at any stage of manufacturing and the related processes. Additionally, Rolls-Royce uses webcams of the shop floor to provide visible indication to all departments as well as suppliers and customers about where an engine is in its stage of manufacturing at all times.

6) Optimize the entire value stream: Finally, the focus of Rolls-Royce supply chain strategy is to focus not only on the internal processes, but also those that lie outside its walls but affect the supply chain directly. Hence, Rolls-Royce manages some of the critical suppliers very closely. The various aspects of the task are:

Choosing a supplier: Rolls-Royce's process for selecting its suppliers is dictated by its supply chain goals. This includes the decisions such as where the supplier is located and its capabilities, and is also guided by the location of the customer. If required, Rolls-Royce chooses a supplier closer to the end customer for improving the customer service or reducing the lead times.

Understanding supplier bottlenecks: The company actively participates in supply chain management at its critical suppliers. A bottleneck at a supplier's end has the potential to disrupt the entire value stream. Hence, Rolls-Royce tries to understand the quality, delivery performance, responsiveness and reliability of the supply chains of its suppliers as well.

E-procurement: The company uses e-procurement (Exostar) to get visibility into delivery quantities and delivery schedules. This also helps maintaining quality standards and expediting processes such as invoicing and accounts payable.

5.8.4 Steps in implementing a supply chain process improvement

Rolls-Royce executed the effort to increase the efficiency of the AE engine supply chain in the following steps:

1) Create an organizational buy-in: The first step was to create an agreement about the recognition of the problem, and about a need for change. This was done at all levels- from employees to senior management responsible for the AE engine's manufacturing.

2) Communication: The next step was to accelerate the buy-in through presentation of factual data that emphasized the problem. This data presented statistical, financial and customer service metrics.

3) Establishing a vision: This was followed by communicating the solution to the problem i.e. to create a smooth AE engine manufacturing flow line.

4) Confirm management's commitment for change, and create a competent team: The best people available were staffed on the process improvement team. This confirmed management's involvement in the process and was a sign of long term push towards the use of lean manufacturing principles.

5) Measure success: Each milestone and success was measured and feedback loops were created to study the results, thereby modulating the inputs in the improvement process.

5.8.5 Results

The following results in Table 10[92] demonstrate the success of the exercise, and how it affected operational metrics, supply chain flexibility and worker productivity. The metrics show a year by year improvement as the implementation progressed.

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[92] Information from Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004

Table 10: Performance metrics 1999-03 for 40-day engine implementation (AE engine)

	1999	2000	2001	2002	2003
ROIC Index	17	40	90	67	153
Customer Satisfaction Index	57	64	71	72	74
On-Time Delivery Index	6	18	49	84	84
Cost of Non-Quality Index	291	218	171	172	144
Inventory Turn Index	--	44	62	60	58
Cycle Time Index	652	436	326	273	200
Employee Turnover Index	100	106	107	109	101
Hourly Skill Index	24	30	38	41	59
Salaried Skill Index	6	23	31	48	66
Training Index	89	81	81	71	110

1) Improvement in performance metrics:

The assembly and testing cycle time for an AE 3007 engine was reduced from 13.8 days in 2000 to 11.5 days in 2001 and to 6.5 days in 2002. The quality, delivery performance and customer satisfaction improved while inventory fell significantly. Rolls-Royce shared the resulting financial benefits among managers and workers, creating a sense of responsibility and ownership among workers, thus setting in place incentives for a virtuous cycle of continuous improvement.

2) More flexible supply chain

The supply chain is more flexible due to use of cell layout for manufacturing, and the use of pull signals. The changes inspired by lean manufacturing were as follows:

1) The factory layout was changed, and the entire assembly operation was located to a new site within the same plant. The manufacturing changed to cell layout with cross trained teams in each cell.

2) Parts were located close to their point of use, and the suppliers delivered the parts directly to these locations. For each stage of manufacturing, a kit was created with all the required parts. This reduced lead time, total distance traveled for workers, variation in manufacturing times of each step and improved the quality and reliability of each manufacturing operation.

3) Tool management was introduced as a practiced, requiring each tool to have a 'home' and be accounted for at the end of each shift.

4) The union was consulted and agreed to a flexible workforce, which is critical to having a responsive as well as profitable supply chain.

3) Improvement in worker productivity

Workers were allowed to design their own flow line and their tool kits. This allowed the company to utilize the knowledge of the workers, and improved employee productivity by 40%. Focus shifted from individual performance to team performance, as success was measured by the end product i.e. a high quality and on time delivery, rather than individually. Hence team dynamics improved, leading to further productivity gains.

6 Role of Rolls-Royce's Supply Chain in its Business Strategy

This chapter explores Rolls-Royce's business strategy, and the important competencies that make a supplier competitive in the current aerospace landscape. This framework is used to explore how Rolls-Royce's supply chain operating model contributes to strengthen its strategic positioning and business strategy as a tier 1 supplier in this industry. Four strategy models (i.e. those proposed by Simchi-Levi[93], Fisher[94], Hammer[95] and Porter[96]), which study the relationship between supply chain design and its role in the company's business strategy, are used to analyze the role of Rolls-Royce's supply chain operating model in its business strategy.

6.1 Rolls-Royce's Business Strategy

Rolls-Royce pursues parity in operational excellence with its competitors[97]. It believes that in a mature industry with stable and large competitors such as GEAE and P&W, it does not have a strategic technological or financial competitive advantage. Therefore, the long positions in the industry would be that of parity, rather than any one firm having sustained strategic advantage. However, its supply chain is an integral part of its business strategy and helps maintain a strategic parity with the competitors. This role is studied in this chapter in perspective of the models referenced in Chapter 2.

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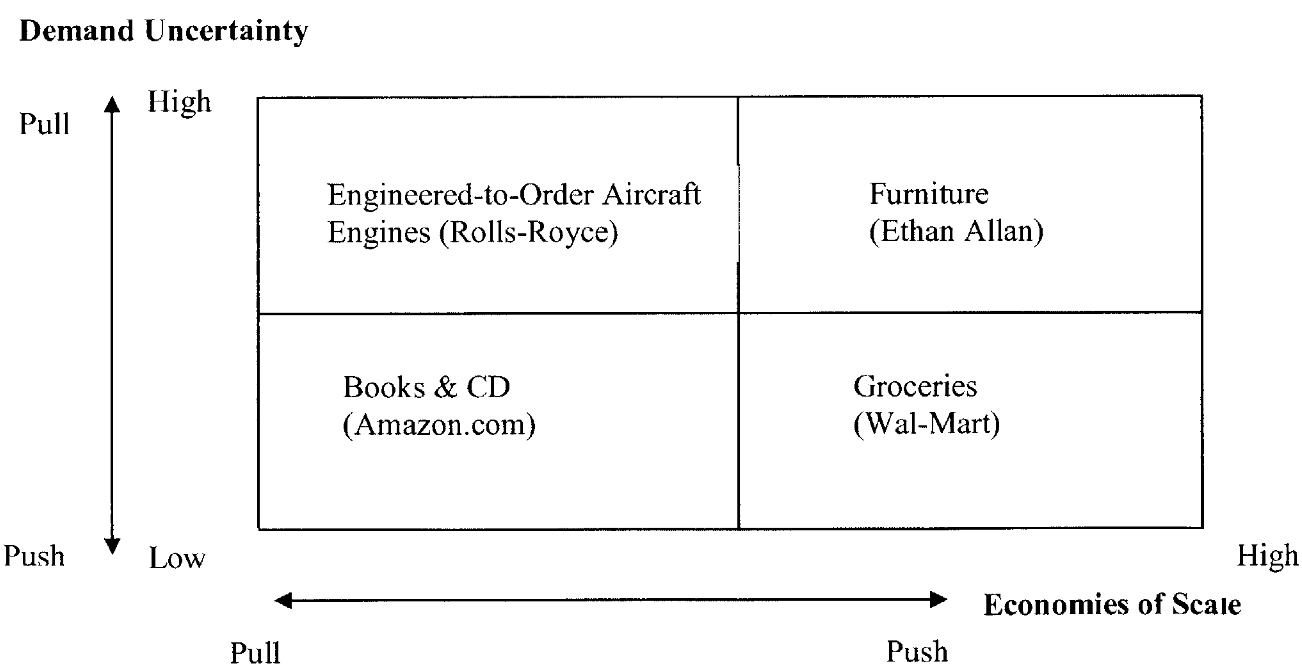
93 D. Simchi-Levi, P. Kaminsky, E. Simch-Levi, *Designing and Managing the Supply Chain*, Mc-Graw Hill, NY 2000. pp 121
94 M. Fisher, *What is the Right Supply Chain for Your Product?*, Harvard Business Review, March-April 1997
95 M. Hammer, *Deep Change,* Harvard Business Review, April 2004
96 M. E. Porter, *What is Strategy?,* Harvard Business Review, November-December 1996
97 Interview with Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004

6.2 Role of Supply Chain Operating Model in Rolls-Royce's Business Strategy

Rolls-Royce operates with an engineer-to-order business model, and its supply chain is geared to support that product manufacturing and delivery structure. Using Simchi-Levi's model[98] of push versus pull based strategy[99], Rolls-Royce uses a pull-based strategy since it operates in an uncertain demand environment in its orders products, and they each engine produced is one of a kind, with no mass production of a the specific designs. The strategic positioning of its operating model is shown in Figure 17. This strategy ensures minimal investment of capital and reduces the capital at risk in raw material and work-in-process inventory, which is also assisted through the use of JIT principles as well as through a reduction in need by shortening manufacturing lead times.

Figure 17[100]: Matching Supply Chain Strategies with Products



[98] D. Simchi-Levi, P. Kaminsky, E. Simch-Levi, *Designing and Managing the Supply Chain*, Mc-Graw Hill, NY 2000. pp 121
[99] Ibid
[100] Ibid

Further, delivery time is an important factor for success in the industry. To evaluate the supply chain on this front, we can apply Fisher's model[101] for designing the right supply chain for a given product. Since Rolls-Royce's products have an unpredictable demand, yet require a high degree of customization, Rolls-Royce has a 'responsive' supply chain focusing on delivery times. This design ensures that the company retains its customers and hence its market position. Responding to a customer deadline is critical to get repeat business, and the sale of each new engine leads to twice as much revenue in aftermarket services. Also, quality issues or late deliveries can affect future contracts with its customer base, which are few in number with each customer making large purchases. Hence a customer oriented, responsive supply chain supports the key success factors for the company and its long term positioning.

6.3 Key Operational Objectives, and their Role in Strategy and Operating Model

Rolls-Royce's key metrics for operational performance are Quality, Cost and Delivery. In a mature and consolidating industry, it seeks to retain customers, as well as do so profitably. Therefore, the operational objectives for a supplier are customer response oriented (quality and on-time delivery), as well as efficiency oriented (product costs and labor productivity). Given the fact that the aerospace suppliers compete on these parameters, the operating model is designed to continuously drive forward to excel at these operational objectives.

As discussed above, performance on delivery times is essential to success of the firm. In case of a pervasive tendency of a given supplier to miss delivery dates, a manufacturer must either find a secondary source (which often may not exist due to highly engineered nature of products), or delay production. In such a scenario, the aircraft manufacturers might risk present and future contracts with airlines or they may run into serious schedule delays and cost overruns

[101] M. Fisher, *What is the Right Supply Chain for Your Product?*, Harvard Business Review, March-April 1997

on military acquisition programs. Airlines report that inability to take delivery of an aircraft in a timely manner can result in significant foregone profits[102].

Rolls-Royce's primary supply chain initiatives 40-day Engine (discussed in Chapter 5) is a key exercise that focuses on quality, cost and delivery. It has the following six objectives:

- Simplify the gas turbine as a product, which would also simplify its manufacturing, impacting quality, cost as well as ability to deliver on time.
- Synchronize the supply chain activities across the organization so that all departments execute to a common plan.
- Manage the supply chain at the correct level of detail (choosing what to manage).
- Reduce variability in manufacturing and supply chain processes.
- Implement 'pull signals' throughout the supply chain to manage materials in the product flow line.
- Optimize the entire value stream from suppliers to customers, so as to meet the common supply chain goals i.e. what is needed, where it is needed and at what price is it needed.

These steps strongly impact the quality, cost and delivery measures. Other initiatives such as the Rolls-Royce Production System are also designed specifically to improve these parameters. Using Hammer's model[103] to understand the metrics that are important to Rolls-Royce, the role of the supply chain in delivering to these metrics, and to therefore understand the role of these objectives on its strategy, it is clear that the company's operational excellence efforts maximize the activities related to quality, costs and delivery. As a result, Rolls-Royce has been able to maintain as strong a supply chain as any in the industry, and has been able to compete and gain market share by strengthening its capabilities to perform well on these measures.

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[102] US International Trade Commission, *Competitive Assessment of US Large Civil Aircraft Aerostructures Industry*, June 2001

[103] M. Hammer, *Deep Change,* Harvard Business Review, April 2004

6.4 Other Operational Objectives that Determine Competitiveness

The aerospace suppliers function in a highly regulated environment, and compete for business from only a few buyers[104]. Since this industry has few large manufacturers which buy and sell from each other, there is no clear owner of market power. Further, though quality is an important factor for choosing a supplier, the ability to produce quality products is a primary factor, yet not the only determinant of competitiveness.

The determinants of competitiveness for a supplier to aerostructure manufacturers depend on the tier of supplier. As the aerostructure manufacturers shift more and more responsibility to tier-1 suppliers such as Rolls-Royce, generally higher the tier, the morc important is the supplier's ability to share risk. This requires a sufficiently large financial base and a high level of technical expertise.

The other key factors that affect competitiveness can be divided into cost based and non-cost based factors, as analyzed by a USITC study[105], and are discussed below in detail. The cost factors that can affect price include production efficiency, labor, capital and economies of scale and learning effects. The primary non-cost factors include technological capabilities, on-time delivery and flexible production capacity. Finally exchange rates can also affect the competitiveness of a supplier.

6.4.1 Cost Factors

The following cost factors are determinants of a supplier's competitive strengthens:

1) Production efficiency: The manufacturers expect suppliers to have the ability to reduce cost of their products continuously using innovative manufacturing techniques, which reduces the

[104] US International Trade Commission, *Competitive Assessment of US Large Civil Aircraft Aerostructures Industry*, June 2001
[105] Ibid

total cost of a new aircraft program. The ability of a supplier to achieve productivity and efficiency step increases is a function of their technological and financial resources.

Rolls-Royce's 40-day engine program is designed to decrease the inventories throughout the supply chain, and increase worker productivity, thereby improving production efficiencies. This increases the Return on Assets of the company, and uses information technology to co-ordinate and collaborate with suppliers, and develop them (through the Supplier Councils) using continuous improvement philosophies. This program, therefore, adds significantly to the company's strategic ability to compete in the market.

2) Labor flexibility: Low labor costs and ability to expand or contract the labor force in accordance to production levels is a key element of having the flexibility to react to a cyclical market while minimizing costs. The labor cost share of total costs depends on complexity of the structure and the equipment being used. The companies focus on labor flexibility because a lack of restrictive labor laws and contracts is considered a competitive advantage.

Rolls-Royce has a policy to outsource 70% of its manufacturing. That ensures that it only keeps the highest value added operations in-house. This enables it to achieve highest returns from its expensive labor force, while outsourcing low value manufacturing to suppliers that have lower labor costs[106] to reduce its workforce. The company has been able to reduce employee base from 43,300 in 2001 to 36,100 by end of 2003, while increasing revenues per worker from $203,000 in 1999 to $280,000 by end of 2003[107]. It has also been negotiating with its unions to allow the flexibility to react to demand changes. Therefore, Rolls-Royce is making its supply chain lean and flexible to compete well on this key parameter.

[106] Interview with John McLauchlin, formerly Field Quality Engineer, Rolls-Royce, April 2004
[107] Rolls-Royce Annual Report, 2004

3) Capital: Aerospace industry is a highly capital intensive industry, and is unique in that sense from most other manufacturing sectors. Participation in large aircraft programs requires large investments. Therefore, the ability to raise capital for investment is a competitive advantage. Capital may be used for several purposes, such as acquiring new tooling, managing supply chain, R&D, training, and developing new manufacturing capabilities. It is also required to enter increasingly prevalent risk sharing programs. Therefore, access to financing and having a high credit rating is important, as well as having a supportive government can help a company get subsidies/ cheap loans and offer a lower bottom line prices to customers.

Rolls-Royce, with $10.1 billion revenues and a proven ability to manage supply chains, improve its technology and manufacturing practices so as to contribute strongly to development of new products, is well positioned in the industry.

4) Economies of Scale and Learning affects: Reduction in direct costs and fixed costs over the long term is a goal which the manufacturers seek, and they want their suppliers to spread costs over large production runs. The ability to do so is dependent on access to raw materials, skill levels of workers and efficiency of equipment. It is also a function of overall corporate structure.

Furthermore, large production runs lend opportunities for learning and continuous process improvement. Working with a manufacturer over a long period of time allows the supplier to learn about what might be of major importance to that manufacturing customer. Such learning also leads to developing a competitive advantage when bidding on new projects. Once such procedures are learned, they can yield important benefits over recurring projects.

Rolls-Royce has demonstrated its ability to reduce costs over long production runs by improving revenue per employee and the ability to use similar product platforms to serve a variety of markets, which enable it to use its supply chain infrastructure to increase the production runs and further reduce costs. It has also been able to compete well for new programs such as the Airbus A380, Boeing 787 and the F-35 Joint Strike Fighter based on its existing learning about customer needs and requirements.

6.4.2 Non-Cost Factors

The non-cost factors are core competencies of the company; ability to deliver on time and have flexible manufacturing capabilities, and whether the supplier is specialized or diversified.

1) Core competencies: The ability of a supplier to meet the technological needs, meet design responsibilities and to maintain an efficient supply network are critical to its success as a supplier. Increasingly, most aerostructure manufacturers prefer dealing with fewer, capable suppliers who can not only handle their own networks but those of tier-2 and tier-3 suppliers.

Rolls-Royce supply network based initiatives (discussed later) lend strength to its competitive position in the industry.

2) Flexible manufacturing capacity: Also, a flexible production capacity is important since airlines often change or cancel orders due to market fluctuations, which requires a supplier to quickly react to the situation as well as remain profitable.

3) Specialization and Diversification: A challenge for a supplier in this industry is whether to specialize in certain types of components, which is viewed favorably by aircraft manufacturers, or to diversify into related businesses such as aircraft MRO or supplying to non-aircraft manufacturers. Specialization increases the risk of having a bigger impact in low demand periods, while diversification spreads the risk, but at the cost of losing reputation for being the 'expert' from aircraft manufacturers' perspective. Being able to balance the two planks also lends advantage to a supplier.

6.5 Business Practices that Strengthen Rolls-Royce's Competitive Position

The role of business practices that impact the strategy, operating model and operational objectives as can be understood by studying the key business initiatives and practices (Section 5.6 and 5.7) at Rolls-Royce, and how they impact its operational objectives as discussed above in Section 6.3 and 6.4. Using Porter's model[108] to understand the unique set of activities that create a competitive advantage for Rolls-Royce, we study the role of business practices in fulfilling key operational objectives.

6.5.1 Supplier Network Management

Rolls-Royce has among the best supplier management practices in the industry and it considers itself a pioneer in the field[109]. These practices are described below[110], and its affect on strategy and operational objectives is discussed.

Supplier involvement in product design and development: Rolls-Royce integrates key strategic suppliers early in the product design and development phases to ensure that maximum value is delivered throughout the product lifecycle. Strategic collaborations with suppliers are managed by 'System Integrators' at Rolls-Royce (as described in 6.5.3), who are at a high level of management hierarchy. Collaboration is executed at all levels of organization from Program Managers to Engineering. This results in a collaborative design and architectural innovation that reduces design lead times.

Its ability to collaborate with its RRSP's also enables it get access to vital capital and reduce its own exposure to market risk, and reduce the invested capital-at-risk. This ability is crucial for a tier 1 supplier, as it helps aircraft manufacturers (customers of Rolls-Royce) to reduce the

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[108] M. E. Porter, *What is Strategy?*, Harvard Business Review, November-December 1996
[109] Interview with Richard B. Lewis II, formerly COO, Rolls-Royce, April 2004
[110] Information from interviews with Rolls-Royce and related research at Lean Aerospace Initiative at MIT, April 2004

overall cost of new programs. This activity fits well with activities that require capital to build economies of scale to lower cost, as well as building core competence in new technologies.

Continuous improvement in supplier base: Rolls-Royce establishes joint-targets (such as 7% annual cost reduction goals), and then institutes rewards when the goals are met. These rewards include benefit sharing schemes which focuses of creating win-win situations and further incentives to improve. They also ensure that lean principles are continuously being practices and improved upon by using metrics to drive network-wide performance, including its own.

This practice further drives collaboration and sharing of risk with RRSP, and makes more capital available for investment in its suppliers in a virtuous cycle of further integration with suppliers.

Investments in supplier's capabilities: Rolls-Royce has found that gains from investments in supplier's capabilities can outweigh the costs of building in-house capabilities such as flexible tooling, enhanced support functions and workforce re-training over the long term. Lean practices have had slower penetration to lower level suppliers, since unexpected changes in delivery dates or quantities affect them more severely, and can be prohibitively expensive with lean manufacturing. But as new programs are launched, with Rolls-Royce investing in suppliers, more and more suppliers start using lean manufacturing principles since the benefits accrue over the life of the program.

These practices further drive production efficiencies (as described in 6.5.2) and fit well with other business practices to form a positive reinforcing loop that drives strength in these core activities.

6.5.2 Production Management

Rolls-Royce's production improvement initiatives such as the 40-day engine and Rolls-Royce Production System enable it to achieve production efficiency. Its supply chain enables the company to deliver quality product to its customers at the cheapest cost and rapidly adjust to dynamic market situations. It also enables it to use same product platforms to serve multiple markets, thereby creating scale and spreading the costs over long production runs. Together with its outsourcing and supplier network development capabilities (described in 6.5.1 and 6.5.3), it reduces labor overheads and increase its flexibility to react to a cyclical market demand. This further drives its market penetration and thus builds economies of scale, which further lower the cost structure and increase quality and delivery standards. Therefore a virtuous cycle involving outsourcing and collaboration with suppliers is created which drives production efficiency and vice-versa.

The company and its suppliers use their scale to invest heavily in maintaining technological leadership and product innovation, which can be reaped with high market share and over long time horizons. This then helps the supply chain to build core-competence, as described by Porter[111] and creates an integrated set of activities (together with 6.5.1) that provide strategic strengths, not only due to their fit with the business strategy and operational objectives, but also due to their fit with each other.

6.5.3 Management Structure

Rolls-Royce's corporate structure uses 'System Integrators' to collaborate at high level with the suppliers and share knowledge and best practices in production and operations management with them. This enables it to have a technologically capable supplier base that can contribute significantly to a new program. Thus, this activity combines the strength of supplier management (6.5.1) with its own strengths in production management (6.5.2) to affect Rolls-Royce's ability to launch new programs cheaply, quickly and yet do so with high quality products due to competence of its suppliers and its own operational excellence. This activity,

[111] [111] M. E. Porter, *What is Strategy?*, Harvard Business Review, November-December 1996

therefore directly impacts the operational objectives of quality, cost and delivery and strengthens Rolls-Royce's competitive positioning.

Thus, working together, the company's supplier management activities such as the Supplier Council, its production management activities such as the 40-day engine and Rolls-Royce Production System, and its management structure which uses 'System Integrators' to multiply its capabilities with those of its suppliers creates a powerful synergy which lends strength to Rolls-Royce's business strategy and competitive positioning.

To summarize, Rolls-Royce competes not just with its internal operational capabilities, but also leverages a symbiotic management structure with the capability of its suppliers. It has learned new principles, techniques and practices from its collaboration with MIT's Lean Aerospace Initiative, from benchmarking against its competitors and other industries such as the automobile industry, as well as its suppliers. It has used this knowledge to design business practices that fit well with its business strategy, its supply chain operating model and key operational objectives. These initiatives have had a positive impact on its enterprise-level performance in the recent years, as well as on the performance of its supplier network. The result of these improvements are on-going and are expected to continue in the future. Indeed, Rolls-Royce has demonstrated its competitiveness by gaining market share in a mature industry since the late 1990's by using a variety of operational techniques and innovative initiatives that have made its supply chain excellent.

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