An Examination of Boeing's Supply Chain Management Practices within the Context of the Global Aerospace Industry

by

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Abstract

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This thesis examines the supply chain management practices of the Boeing Commercial Airplane Company within the context of the global aerospace industry. The methodology used for this study includes a study of emerging supply chain management concepts and practices in the aerospace industry based on a review of the open literature, research performed on aerospace supply chain management issues by MIT's Lean Aerospace Initiative, and selected interviews with aerospace industry experts. The results show that there are significant changes in supply chain management practices in the aerospace industry. These changes include restructuring and closer integration of supplier networks to achieve efficiency gains, delegating greater design and production responsibility to major suppliers through strategic supplier partnerships along with having key suppliers evolve greater system and subsystem integration capabilities, emphasizing a lifecycle view supply chain design and management to reduce lifecycle cost of products and systems, and building supply chain capabilities supporting maintenance and aftermarket logistics services as a major new strategic thrust to provide improved customer satisfaction and retain long-term customer loyalty. The thesis focuses on Boeing's supply chain management practices through a case study to explore these developments in a more concrete enterprise context.

Acknowledgements

First, I would like to thank my advisor Dr. Kirkor Bozdogan for guiding me through an extremely dense learning period that underlies this work. I feel lucky for the frequent meetings we had where learning from him was both fun and very inspiring. I would also like to thank J.K. from Lean Aerospace Initiative for adding to my learning experience with his expertise.

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I would also like to thank three people whose lives were affected the most by my education at MIT. My father Yavuz, without whom I wouldn't have ventured into the areas of aviation and supply chain engineering. My mother Gunay, who set a very high standard for me at a young age as a successful scientist. And my girlfriend Zeynep, who made the sacrifice to be happy with a short phone conversation or an instant message from me for nearly a year.

Further, I dedicate this thesis to my grandfathers, Mustafa Sidki Uyar and Omer Cizmeci, the first aviators in my family.

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1 Introduction

This is a thesis on Boeing's large commercial aircraft supply-chain within the context of the global aerospace industry. The thesis structures the information in order to initially introduce the aerospace industry as a whole and subsequently to narrow the focus on the specific supply chain practices currently used in large commercial aircraft production. Boeing is the case-study subject of the thesis. The thesis is dated May 06 of 2005 and reflects the perspectives of this date.

This thesis was written in conjunction with the Supply Chain 2020 program at the Center for Transportation and Logistics at M.I.T. Following the guidelines of the program, the primary objective of this thesis is to identify the current excellent supply chain practices in the aerospace industry. The information in this thesis comes from four main sources. These are interviews with industry experts, ongoing and completed research at the Lean Aerospace Initiative at M.I.T. and a collection of refereed journals, trade journals, consulting reports and investment banking reports.

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. Boeing) as necessarily being "exemplary" or "best-in-class" but rather as an illustrative example of currently observed practices.

1.1 Motivation for Thesis

The business and political environments that shape demand for the military and commercial segments of the aerospace industry have each individually experienced one major structural change in the past 25 years. On the commercial side, the deregulation of the United States airline industry in 1978 led to the restructuring of the airline-aircraft manufacturer relationship as well as to the reshaping of the airlines' expectations in terms of aircraft performance and lifecycle cost.

On the military side, the fall of the Berlin Wall and the fall of the Soviet Union changed both the amount and the composition of U.S. military spending. The decades following these two structural changes led to consolidations in both segments of the industry at the lead manufacturer or system-integrator level. The supplier networks for both segments saw a decrease in the number of suppliers and suppliers increased their depth of specialization at the component level. The dominant theme changed from "performance at any cost" to affordability, leading to complete restructuring of the supply-chains.[1] All of these changes led to the emergence of different foci and metrics in designing and measuring aerospace supply chains. In practice, however, most of the

[1] Murman, E., & Allen, T., & Bozdogan, K., & Cutcher-Gershenfeld, J., & McManus, H., & Nightingale, D., & Rebentisch, E., & Shields, T., & Stahl, F., & Walton, M., & Warmkessel, J., & Weiss, S., & Widnall, S. (2002). Lean Enterprise Value. New York: Palgrave.

efficiency of the metrics and the relevance of the foci have not been time-tested due to the recent changes and the very long design and manufacturing lead-times experienced in the industry.

Another important issue to examine in the context of supply-chain design and operation is the sharp decline in Boeing's market share in the global large-scale commercial aircraft market in the face of strong competition from European Aeronautic Defense and Space Company (EADS) the parent company of Airbus. The relationships between Boeing and its suppliers are structurally different from the relationships between Airbus and wit its own suppliers, because Airbus has cross-equity holdings with its major suppliers. Also, the suppliers of Airbus are mostly geographically concentrated in Europe. Boeing, on the other hand, has a more geographically diversified supplier base. Chapter 5 will elaborate on the importance of this factor in light of market access and supplier relationship management issues.

The importance of examining both the military and the commercial segments of the aerospace industry lies in their dependence on a common supplier and technology base. Most of the emerging best practices in supply chain management appear to have been implemented to date in the military segment. This segment has always been a financially significant component of Boeing as a corporation and has influenced the supply-chain design mindset for the commercial segment. The cost-consciousness that came to dominate the industry in the last decade has served as a significant forcing function to alter the Cold-War era "performance at no-cost" mindset governing aerospace supply chain management practices. These changes are fast finding their way into the commercial aerospace as well under the pressure of intensifying international competition between Boeing and EADS.

Finally, the findings of this work are also useful to the airline manager. The expensive decision of fleet selection has many vital implications for an airline, making it, along with network selection, one of the two most important factors affecting airline success. Both of these decisions are made in the context of long-term plans spanning anywhere between 5 to 20 years and more. Hence, the factors affecting the cost, the availability and the after-market lifecycle support of aircraft are crucial to fleet selection. Therefore, the excellent supply-chain practices identified in this work can assist airline managers in understanding the underlying causes of aircraft purchase and lifecycle costs, leading to better informed decisions in fleet selection.

2 Literature Review

This thesis contains three types of information on aerospace industry. These are financial information, operational information and theoretical information on supply chain practices. All three types of information are obtained from literature as well as interviews.

2.1 Financial Information

The financial information about the aerospace industry is very accessible through several different sources. The main official source is the U.S. Bureau of the Census and its current and historical reports on the industry. All information is broken down by categories determined by the bureau itself. Many other sources use this information for their own publications. One such source, the Aerospace Industries Association (AIA), publishes current and historical statistics that were very helpful for this thesis. The information is well put together and concise. One problem that was persistent in collecting reliable and complete data for the industry was the lack of it for years before 1988.

The European counterpart of AIA is the European Association of Aerospace Industries. (AECMA). AECMA's "The European Aerospace Industry: Facts & Figures 2002" publication is the most comprehensive and useful document that I found throughout my research. The information is presented mainly in charts and graphs. The comparative information, both historical and competitive, that the report contains is the most useful part of this source.

Another source of financial information is the yearly aerospace industry report of anyone of the investment banks or ratings institutions. The ones with the most insight on the industry, as well as the most current information, were the Standard and Poor's Aerospace & Defense Industry Survey (October, 2004) and the Morgan Stanley Global Aerospace and Defense Monthly Handbook (September 2004). The latter especially contains valuable historical analysis on the large commercial aircraft segment. Both reports also contain valuable company specific information on Boeing as well.

2.2 Operational & Organizational Information

Though much of the dependable operational and organizational information is gathered via interviews with industry experts, some publications also serve as useful sources. Aviation Week & Space Technology is the dominant trade journal in this field. Overhaul & Maintenance is another leading trade journal focusing on the aftermarket maintenance and logistics of aircraft. Both publications were helpful for finding operational information on specific topics in commercial aircraft logistics and supply-chain. These sources are also very helpful for the military segment as well.

2.3 Theoretical Information on Supply Chain Management Practices

Currently, the dominant overarching concept in the large commercial aircraft supply chain realm is the increasing adoption of lean supply chain design and management principles and practices. These overarching lean practices can be found in the Lean Aerospace Initiative Supplier Management Self-Assessment Tool (SMSAT) Below are the eight overarching practices stated in SMSAT that set up a very comprehensive framework for the assessment of the large commercial aircraft supply chain.

- Design supplier network architecture
- Develop complementary supplier capabilities
- Create flow and pull throughout the supplier network
- Establish cooperative relationships and effective coordination mechanisms
- Maximize flexibility and responsiveness
- Pursue supplier-integrated product and process development
- Integrate knowledge and foster innovation
- Demonstrate continuous performance improvement

The "Lean effects on aerospace programs (LEAP) project. 737 fuselage case study report" documents the lean practices and their results at Boeing's Wichita facility. It complements the Lean Enterprise Self Assessment Tool (LESAT) in providing practical examples to proposed lean practices in a lean "extended" enterprise. The details of the LESAT are explored in chapter 5.

Lean enterprises strive to create and deliver value to their multiple stakeholders both efficiently and effectively. The application of the lean concept to aerospace is best described in the collective work of LAI researchers called "Lean Enterprise Value".[2] The examples in this book highlight the lean concept as it was applied in the aerospace industry since the mid 1990s.

[2] Murman. (2002)

To understand the lean manufacturing concept, a segment of the lean enterprise concept, it is necessary to refer to the original work by MIT's International Motor Vehicle Program researchers that coined the term "lean". "The Machine that Changed the World" (Womack, 1991) is a great book that puts the "lean" concept in perspective by presenting it in the context of mass production, its historical competitor. It is important to note, however, that much of the emphasis in this work is on lean manufacturing whereas LAI's emphasis has been on developing "Lean enterprise thinking".[3] This came about through the evolution of the underlying concepts from elimination of waste to creation of value on the factory floor as well as the rest of the entire enterprise including the supplier networks.[4]

A best-practice included in a "lean enterprise" is the delegation of design and integration responsibilities to the suppliers from the aircraft manufacturers. This best practice is true for all the major components in aircraft manufacturing, namely aerostructures, engines and avionics. The United States International Trade Commission's 2001 study named "Competitive Assessment of the U.S. Large Civil Aircraft Aerostructures Industry" is a good recount of the applications of this concept in the global aerostructures industry. The study examines the application of this best practice by region as well as by supplier. The notes of this document are also excellent sources for further study of the aerostructures industry itself.

Finally a very good general description of Boeing's make/buy decision is given by Perrons in "Make-buy decisions in the U.S. aircraft industry".

[3] Comments by Dr. Bozdogan during thesis draft review.

3 The Global Aerospace Industry

The global aerospace and defense industry has integrated supply networks that span most of North America, Asia and Europe. The industry is often witness to cross – national, multi-company co-operations and partnerships. Many such co-operations are necessitated by the internationally dispersed nature of cost-effective manufacturing, research and development capabilities of suppliers. Many companies that are in the industry supply products or components for more than one sub-segment. This is especially common in the aircraft manufacturing segment and related aftermarket services segment. This is due to the many commonalities shared by military and civil aircraft technologies. The industry is characterized by very high levels of capital investment. The industry is also very regulated, especially for the safety of its products. Hence the industry has very high barriers to entry due to capital and regulatory requirements.

3.1 Industry Structure

The aerospace and defense industry has three main sectors. (See Appendix A) These are systems & frames, engines and equipment. (See Appendix B) These three sectors yield products in three main segments which are aircraft, missiles and space. (See Appendix C) The complete definitions of the industry sectors and products are included in the annex. Products in all three segments have a market globally for both government and private entities. The products sold to the military have had mostly stable demand in the past as opposed to the civilian products due to the private sector's

[4] Comments by Dr. Bozdogan during thesis draft review.

volatile and fragile demand. Hence, most of the system integrators, suppliers and support organizations serve both categories of customers. These companies can capture revenue opportunities in strong markets by shifting manufacturing and service capabilities to the right products and protect themselves against weak markets by diversifying into two markets with uncorrelated demand.

The extent of the integration and collaboration in the industry is observable in the difference between the consolidated and non-consolidated global revenues. The latter was approximately $400 billion in 2004, nearly doubling the consolidated revenues for the same year.[5] This phenomenon is becoming more and more visible in the industry as the largest companies in the industry are delegating more design and assembly functions to their first and second-tier suppliers. Such risk and responsibility delegation is most pronounced in the aircraft segment. The high value-added components and sub-systems such as engines and civil avionics, $31 billion and $10.2 billion industries respectively, are being joined by value-added sub-assemblies and composites in the aero-structures sub-segment, produced by the systems & frames sector.[6] This measure is one of the indicators that highlights the transformation of the large aerospace companies from manufacturers to system integrators with sophisticated marketing and sales organizations.

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[5] Standard & Poor's. (2004, October, 7). Industry surveys: aerospace & defense
[6] Standard & Poor's. (2004, October, 7)

3.2 Financial Perspective

The U.S. aerospace & defense industry is the global leader in both revenues and employment. In 2002, total consolidated revenues were in excess of $153 billion and total employment was at 714,000.[7] 410,000 of those employees were employed in the aircraft segment and 82,000 in the missiles and space segments combined. The remaining 222,000 jobs were in the supporting product and services sub-segments such as engines, avionics and other input industries.[8] The European aerospace industry was second with 74.6 billion Euros in consolidated revenues and 408,000 employees.[9] These figures compare favorably to the numbers from a decade ago. In 1992, the U.S. aerospace industry had revenues of $138.6 billion and 936,100 employees[10]. Increases in productivity through technological developments along with improvements in manufacturing and life-cycle maintenance processes have manifested themselves in lower employment and higher revenue numbers. As a testimony to this development the European aerospace & defense industry also experienced revenue growth along with a decrease in employment in the past decade. In 1992, the industry had 59.8 billion euros in revenues and 480,000 employees.[11]

The recent financial history of the overall industry has been discouraging. As a whole, the industry has seen yearly revenue increases below GDP growth. In 1988, sales as a percentage of GDP were 2.2%. This figure climbed to 2.3% in years 1991

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[7] Aerospace Industries Association. (2004). Aerospace facts and figures 2003-2004.

[8] Aerospace Industries Association. (2004)

[9] AECMA. (2002). The European Aerospace Industry: Facts & figures.

[10] Aerospace Industries Association. (2004)

[11] AECMA. (2002)

and 1992 but then started to decline steadily until 2002, settling at 1.5% for the year.[12] The decrease in prices of aircraft and related products & services in the civil sector after the deregulation of the airline market in 1978 was a major reason for the revenue decline relative to GDP. Also, on the military side, the decrease in the defense budget after the end of the cold war era was the other main factor in the poor revenue growth performance.

The profit picture has been disappointing for the industry overall as well with all segments experiencing significant declines year over year in 2003. 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 & regional jet segments' 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 -.7% average margin over the same period of time[13].

The last decade was also characterized by low profitability for both the U.S. and European aerospace industries. The more mature U.S. aerospace industry had after tax net profit margins between 4% and 6% throughout the decade. The European industry, on the other hand, was in the middle of a multi-decade effort to capture market share in large commercial aircraft and its related product segments as witnessed by the emergence of Airbus Company. This effort led to the trading-off of profit for higher sales for the entire decade. Hence the net profit margin for the European aerospace industry has been volatile in this period of time. One important distinction between the two

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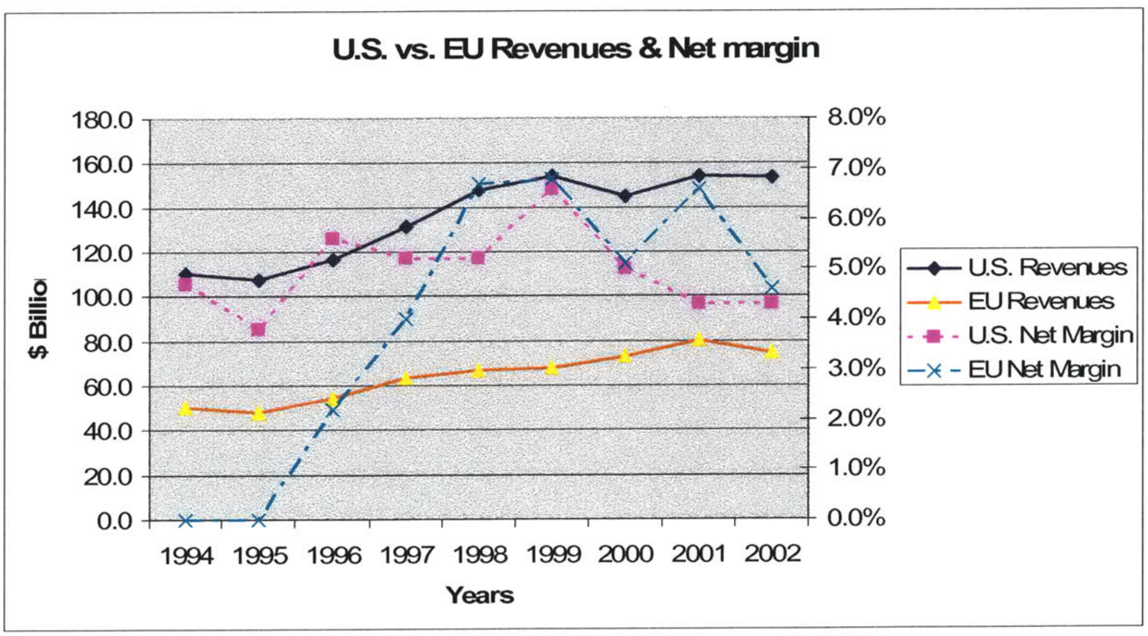
[12] Aerospace Industries Association. (2004)

[13] Standard & Poor's. (2004, October 7)

industries is that the European Aerospace Industry has been supported by loans and grants from the EU governments for the purposes of developing the region's competitive strength through higher market share. The U.S. government has long been objecting to this practice through the World Trade Organization, but its assertions have been rebutted by probes into the lucrative defense contracts that are supporting the country's large aerospace companies.

Figure 3.1. U.S. vs. E.U. Aerospace Industries Revenue vs. Net Margin



One important distinction between the two dominant aerospace industries is the balance between military sales and civil sales of their products. The U.S. aerospace industry has reliable data from 1988 until 2002. This data shows that from 1988 to 1996 Military sales were greater than civilian sales. The trend was towards a more balanced ratio throughout those years as military sales' share of the major U.S. aerospace companies declined from 61.2% in 1988 to 51.5% in 1996. In the following year, the balance shifted dramatically in favor of civil sales. From 1997 until 2001, the civil sales constituted approximately 60% of industry revenues. In 2002, the sales from the two markets were balanced with the military sales constituting 51% of overall sales.[14]

The European aerospace & defense industry revenue division shows a more biased trend towards the civil sector. There is reliable data from 1980 until 2002 for the European share of the industry. In 1980, military sales constituted 32.5% of overall industry revenues. This percentage increased steadily throughout the years until the year 2000 and, despite a minor pullback, was at 68.4% in 2002.[15]

3.3 The Space Segment

The global space segment has the second highest revenues among the three main product segments. The two major product sub-segments in this segment had revenues of $20.6 billion in 2002.[16] The two major sub-segments of the space segment are satellite manufacturing and rocket manufacturing & launch services. The satellite manufacturing sub-segment had revenues of $14.9 billion in 2003. The markets for this product sub-segment were government and university, military and commercial. In the U.S., this sub-segment is dominated by Boeing's satellite systems division and Lockheed Martin's space systems segment. In Europe, Alcatel and Astrium, an EADS

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[14] Aerospace Industries Association. (2004)

[15] AECMA. (2002)

[16] Standard & Poor's. (2004, October, 7)

subsidiary, dominate the supply picture. The rocket manufacturing and launch sub-segment was a $5.7 billion market in 2003. The satellite manufacturing sub-segment drives this sub-segment hence the demand for the two sub-segments are highly correlated. On the supply side there are several more companies then those in the satellite manufacturing sub-segment. Boeing, Lockheed Martin, Khrunichev of Russia, Starsem, Great Wall Industries of China, Orbital Sciences Corporation and Yuzhnoe Design Bureau of Ukraine are the major players in this sub-segment.[17] The demand for the civil space segment is driven by sales to broadcasting, telecommunications and broadband data services providers. The ambitious growth forecasts and resulting satellite launches in the latter part of the 1990s led to idle global communications satellite capacity with the slowdown experienced in the telecommunications sector after the year 2000.

3.4 The Missiles segment

The missiles segment has the least revenues among the three main product segments. The customers for this segment are military institutions. In the European aerospace industry, revenues derived from this segment made-up 3.2% of total revenues in 2002.[18] In the U.S., the missiles' share of the total revenues in 2002 was 8.3%.[19]

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[17] Standard & Poor's. (2004, October, 7)..

[18] AECMA. (2002).

[19] Aerospace Industries Association. (2004).

3.5 The Military Contract Process

It is important to note that a military buyer has different rules and guidelines than a commercial buyer. In the U.S., every year the defense budget's two primary components, the authorization bill and the appropriations bill, are reviewed and revised if necessary. The authorization bill sets the budgetary limit on each military program. The appropriations bill, on the other hand, sets the amount of defense spending in a given year. The budgets that are authorized for specific programs do not have to be spent in the year that they are authorized. After the budget is determined, the government selects suppliers according to its needs driven by price, performance, and politics. Recently, there have been two types of payment systems that have been used for U.S. military contract work. One payment system is the cost-reimbursement method which allows the contractor to be reimbursed for allowable costs. An additional fee is then paid at a predetermined time. The fixed-price contracts, on the other hand, leave the contractor exposed to the risk and reward of its own performance.

3.6 Realm of Aerospace Companies

A true perspective on the level of diversification of the major aerospace companies can be shown by examining the revenue divisions of the current top defense contractors. The division of revenues of the top 50 global defense companies shows that the portion of revenues derived from military-related sales make-up anywhere from 2.3% to 100% of total sales. (See Appendix E) Hence, many companies in the industry are exposed at some level to the civil as well as the military markets. The asset intensive nature of the industry makes it prohibitively dangerous to be specialized for a certain market or niche as a system integrator. Also, the recent industry trend towards delegation of design and system integration responsibilities to first and second tier suppliers will make it highly unlikely for a specialized supplier to financially survive in the long-run. For a system integrator, a high-level of exposure to civil markets is risky due to the cyclical nature of the demand for the civil aircraft and space sub-segments. Similar levels of high-exposure to military contracts are equally dangerous for such companies as defense contracts are long term and high-value engagements in nature and can cause the losing bidder to terminate operations due to insolvency. In the interest of the U.S aerospace industry and the government, some of the industry consolidation in the past has risen from such insolvency situations. As a result, manufacturing capabilities and assets in this vital sector have been preserved.

3.7 Research and Development

The research and development efforts in the industry have historically originated in the military segment followed by a gradual migration to the commercial segment. This technology transfer started to disappear in the aircraft segment with the deregulation of the airline industry in 1978. The deregulation of the airline industry exposed it to competition and hence tighter profit margins. Though the industry failed to react very quickly, the airlines, in turn, became more cost conscious over time. At this point, the goals of the customers in the aircraft segment's two markets, namely civil and military, started to diverge. At the time of deregulation, the cold war era mentality of "higher, faster, farther" was still the dominant motto of the military buyer market.[20] The cost consciousness of the airline industry, the civil market's only true end customer, prohibited the civil aircraft market from sharing the same vision with the military market. The end of the cold war presented a similar shift in mentality in the military market in all product segments due to significant reductions in the U.S. defense budget. As a result, a new era of "higher, faster, cheaper" came to dominate all segments of the aerospace industry with the temporary exception of the civil space segment during the telecommunications bubble of the late 1990s.

In 1987, the aerospace industry was the beneficiary of the most research and development funding in the U.S. Of more than $92 billion of total R&D funding in that year, the aerospace sector received $24.5 billion, or 26.5%. The government funding for the sector was even more pronounced, with the industry receiving 60.2% of a total of $30.75 billion in federal R&D funding for that year. Company funds made up %24 of total aerospace R&D funding for that year. With the rise of the telecommunications and biotechnology industries, the aerospace industry lost its position as the R&D leader in the U.S. Declining federal R&D funding for all industries over the years along with the declining R&D investment by companies lead to a total R&D funding of $7,9 billion in 2001, 32.2% of the amount allocated in 1987. The industry's share of the federal R&D funding decreased by almost two-thirds to %22.4.[21]

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[20] Murman, E., & Allen, T., & Bozdogan, K., & Cutcher-Gershenfeld, J., & McManus, H., & Nightingale, D., & Rebentisch, E., & Shields, T., & Stahl, F., & Walton, M., & Warmkessel, J., & Weiss, S., & Widnall, S. (2002). Lean Enterprise Value. New York: Palgrave.

[21] Aerospace Industries Association. (2004)

3.8 The Aircraft Segment

The aircraft segment is the largest segment of the aerospace industries of both the U.S. and Europe. In 2002, the total aircraft related revenues of the U.S. aerospace industry was $80.2 billion. The revenues in the same year in Europe were $74.6 billion. The aircraft final product segment made up 52.2% and 46% of total aerospace revenues in the U.S. and Europe, respectively.[22] 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. [23]

At the end of the 1980s the military component of the aircraft segment was nearly double the civil segment in terms of revenues. The following five years saw the civil segment leap tremendously 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 civil segment in the same period. The effects of economic weakness along with the terrorist attacks of September 11 were manifested by a $9 billion, or 18%, drop in revenues from 2001 to 2002 in the civil segment.

The aircraft segment is broken down into two categories: civil and military. The U.S. military aircraft segment is dominated by a few large defense contractors. These are Boeing, Lockheed Martin and Northrop Grumman. Among the major military aircraft programs, Boeing is the prime contractor for the V-22 Osprey, a hybrid

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[22] AECMA. (2002)

[23] Aerospace Industries Association. (2004)

helicopter/aircraft transport plane, the F-18 fighter jet and the F-15 fighter bomber. Lockheed Martin is the prime contractor for the F-16 fighter jet, the F-35 and the F-22 F/A Fighter Bomber. Northrop Grumman is the prime contractor for the Globalhawk unmanned reconnaissance aircraft. These military aircraft programs are multi-year concerns that are approved within the defense budget and have yearly approximate delivery targets as determined by the appropriations bill.

The civil aircraft segment, the focus of this paper, is broken down into three main sub-segments. These are large commercial aircraft, regional aircraft, regional & business jets and general aviation aircraft. The large commercial aircraft (LCA) segment is the largest among the three segments in terms of revenue. There are only two competing brands in this segment, Boeing and Airbus, owned by Boeing Company of in the U.S. and Airbus Company of Europe, respectively. Though many other nations manufacture final products such as jet aircraft and rockets, for the purposes of this paper, none have large commercial aircraft products. A large commercial aircraft is defined as a passenger transport aircraft with capacity of one hundred passengers or more and an empty weight of 33,000 lbs or more.

The two companies have very similar product lines and compete globally on every single sale of new aircraft. Both companies offer passenger and cargo aircraft. The passenger aircraft series of both companies currently range from 100 passengers to more than 500 passengers. The recent addition of the A380 to the Airbus aircraft series completed the upper end of the range in terms of capacity for this company.

Large commercial aircraft are traditionally placed in three general categories, “short-range”, “medium-range” and “long-range”. Within these categories, the passenger capacity of the aircraft increases as the aircraft's range increases. The short-range aircraft series for both companies have ranges between 1500 and 1800 nautical miles and have passenger capacities between 106 passengers and 125 passengers. The medium-range aircraft can fly up-to 3500 nautical miles and carry between 150 and 250 passengers. The long-range aircraft have ranges up-to 8000 nautical miles and carry anywhere between 300 and 524 passengers.[24]

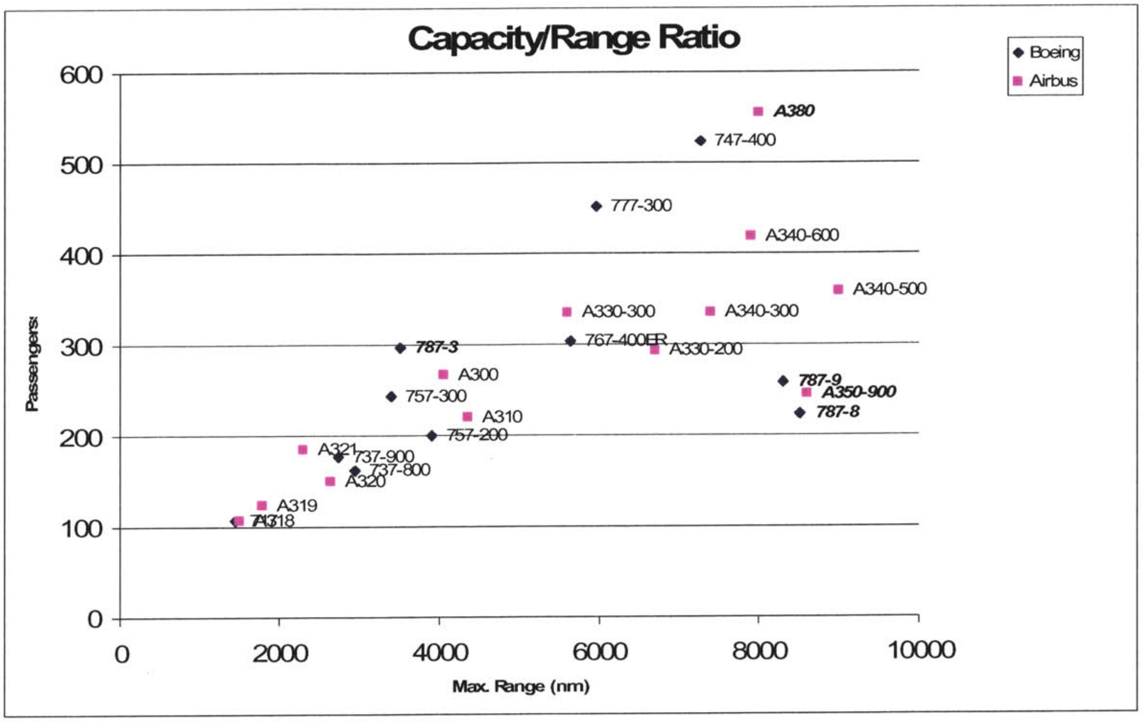
This traditional categorization of aircraft is clearly disappearing as both Airbus and Boeing are investing in different designs based on changing travel patterns. The A380 will be the largest western aircraft ever produced. Its technical specifications are geared towards achieving lowest cost per seat mile in the 500-plus capacity market. [25] It is, however, in compliance with the traditional range to capacity ratio. The 7E7 Dreamliner series of Boeing, on the other hand, does not have a traditional approach towards range and capacity.[26] This aircraft series will serve the emerging airline business plans of connecting more cities directly versus the traditional hub and spoke system. The chapter on the demand drivers of the large commercial aircraft industry will further explore this divergence in strategy between the two companies.

[24] www.airbus.com/dynamic/product/index_h.asp (visited 2005, January 4)

[25] URL www.airbus.com/product/a380_introduction.asp (visited 2004, December 28)

[26] URL boeing.com/commercial/7e7/facts_sr.html (visited 2005, March 28)

Figure 3.2. Large Commercial Aircraft Capacity vs. Range Linearity



The major customers of large commercial aircraft manufacturers are airlines and leasing companies. Therefore, major drivers for aircraft sales are airline profitability and air traffic growth. Also a general mega-factor is the overall state of the global economy. Additional factors at a company level include average fleet age and fuel price.

Average economic life of an aircraft is 20 years. Aircraft can, however, operate for as much as 50 years if they are maintained in accordance with federally regulated maintenance standards. This long lifetime affects the retirement rate of the world's airline fleet and in turn affects the demand for new aircraft. The advantage of owning a new versus an old aircraft depends on one main factor: lower direct operating cost per seat, or per ton, related to better technology. Direct operating cost is currently most affected by fuel cost, followed by crew cost and maintenance costs. The rise in fuel prices has increased the contribution of fuel costs in the overall cost of a flight. Hence, the more fuel efficient aircraft are replacing older, less fuel efficient aircraft as they are retired earlier than their expected economic lifetime.

There are approximately 500 airlines globally that operate large commercial aircraft. The existing fleet of aircraft, including Boeing, Airbus, McDonnell Douglas and some others that are out of production, number around 11,500. Due to their long lifetime, aircraft are traded several times during their lifetime. As the economics of an aircraft become unfeasible for a legacy or a national airline, it is sold to a secondary or a charter carrier. As prices of aircraft drop during troughs in the business cycle, the buyers of these second-hand aircraft can turn an overall operating profit due to low acquisition costs. Hence, due to a second-hand aircraft finding markets easily, majority of new aircraft are bought by either legacy carriers or national airlines. Lastly, the 50 largest airlines in the world operate 35% of the world's fleet. [27]

The other major customers of the aircraft manufacturers are leasing companies. Leasing companies are capital financing organizations that purchase aircraft either directly from the manufacturer or from the secondary market in order to lease them to airlines. In 2004, 29% of Boeing's backlog was made up of orders from leasing companies. These companies offer several different financial solutions to airlines depending on their capacity needs over a certain time-frame. By handling a major portion of the asset holding cost of the airline industry, leasing companies become very significant catalysts during downturns in the airline industry. The state of the airline industry along with interest rates and aircraft prices determine the behavior of leasing companies. The major players in the leasing market are International Lease Finance Corporation, Ansett Worldwide and General Electric Commercial Aviation Service.

The global regional & business aircraft sub-segment had $15.9 billion in revenues in 2003. The major players in the regional jet segment are Bombardier of Canada and Embraer of Brazil. In the business jet segment, these two players are joined by General Dynamics, Textron and Raytheon as the major competitors in the industry.[28] The players in the regional jet market have recently announced large-commercial aircraft production of their own. Though targeting the lower-end of the spectrum, from 100 to 130 seat aircraft for both manufacturers, this is a significant move for the industry as these manufacturers have very different operating characteristics and economics compared to the duopoly that is currently supplying the market.

A large commercial aircraft can be divided into three major groups of components. These are aero-structures, avionics and engines. Aerostructures make up the structure of the aircraft. Some major aerostructures include the fuselage, wing components, flaps, landing gear and nacelles. Chapter 4 will examine further into the specific aerostructures suppliers for the two big aircraft manufacturers. The avionics sub-segment includes the production of cockpit instruments such as communications equipment, computer displays, radar, anti-collision systems, fuel indicators, engine controls and autopilot systems. The big players in this sub-segment include Honeywell International Inc., Rockwell Collins Inc. and Thales SA of France. The increase of the use of technology in aircraft cockpits enabled the avionics portion of the equipment

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[27] JP Morgan. (2004, December). Global aerospace and defense: Monthly Handbook.

[28] JP Morgan. (2004, December)

industry segment to reach $10.2 Billion in revenues for the year 2003. As the control systems of aircraft are getting more and more advanced, avionics will increase its share of the unconsolidated revenues in the aerospace industry.

The after-market maintenance operations and the aircraft engine supply chains are very important factors in the wellness of the aircraft manufacturing industry. The global maintenance and reserve organization (MRO) market had revenues of $36 billion in 2003 and the global engine market had revenues in excess of $31 billion.[29] 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 started to enter the maintenance market in order to be able to offer a life-cycle solution to the airlines instead of a one time sale. The U.S. International Trade Commission estimated the maintenance market for the civil aircraft industry to be higher than the aircraft manufacturing market by a ratio of 3 to 2 in the next 15 years.[30] Taking into account the growing world airline fleet, which is estimated to reach 18300 by 2013, and the growing average age of the world's airline fleet, the growth in the maintenance segment will likely exceed the growth in any other segment in the long run.

The overview of the entire aerospace industry helps put the aircraft segment into perspective. Chapter 5 will describe the supply capabilities of major aerospace manufacturing countries by identifying their significant aerostructures, engine and avionics manufacturing companies and respective supply chains.

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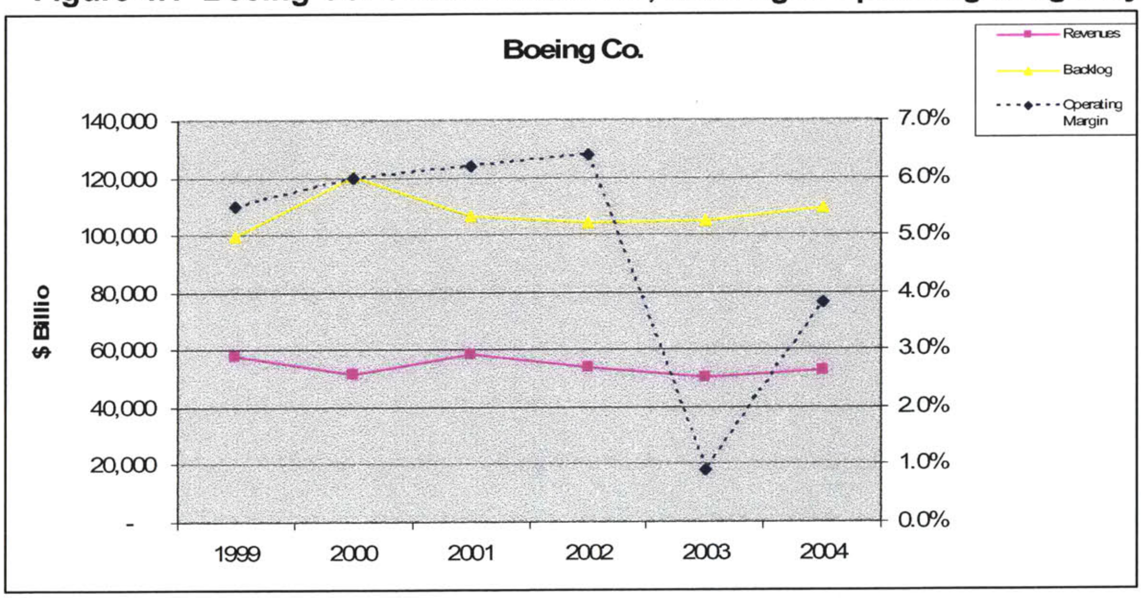
[29] Standard & Poor's. (2004, October, 7)

[30] United States International Trade Commission. (2001, June). Competitive assessment of the U.S. large civil aircraft aerostructures industry.

4 Boeing: A Company Overview

Boeing is the leading aerospace and defense company in the world. It employs 157,500 people in more than 70 countries.[31] Boeing supply networks included a total of 6443 suppliers in 2003. The company's revenues for the year 2004 were $52.46 billion and the operating margin was 3.83%.[32] The decline in commercial airliner deliveries after September 11 interrupted a steady average operating margin of 6% in the past 5 years.[33]

Figure 4.1 Boeing Co. Overall Revenues, Backlog & Operating Margin by year



Boeing's 2004 revenues were dominated by their two major business units, Integrated Defense Systems and Commercial Aircraft, generating 58% and 39% of total revenues,

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[31] URL Boeing.com (visited 2004, December 2)

[32] JP Morgan. (2004, December)

[33] URL http://biz.yahoo.com/e/050228/ba10-k.html

respectively. The rest of the revenues were mainly generated by Boeing Capital Corporation.[34]

4.1 Business Units

Boeing has 6 main business units. The two major revenue generating business units, IDS and Commercial Airplanes are supported by Boeing Capital Corporation, Connexion, Phantom Works and Shared Support Services.

4.1.1 Integrated Defense Systems (IDS)

Integrated Defense Systems: IDS is the largest business unit of Boeing with 2004 revenues of $30.5 billion and employing more than 80,000 people.[35] IDS has seven customer facing business units that have their individual sales channels. These are Aerospace Support, Air Force Systems Army Systems, Missile Defense Systems, NASA Systems, Naval Systems and Space & Intelligence Systems. The products of these units are summarized in the table below.

[34] JP Morgan. (2004, December)

[35] URL www.boeing.com/ids/ids-back/index.html (visited 2005, February 5)

Figure 4.2 Boeing IDS Sub-Units Products and Facilities

Sub-Units	*Products*	*Locations*
Aerospace Support	Maintenance, Modifications & Upgrades; Supply Chain Services; Engineering and Logistics Services; Training and Support Systems; Advanced Logistics Services	St. Louis, MO (Headquarters); Operations in Wichita, KS; San Antonio, TX; Long Beach, CA; Jacksonville, FA; Philadelphia, PA; Mesa, AZ; Fort Walton Beach, FL; Oklahoma City, OK; Australia; U.K
Airforce Systems	737 AEW&C; KC-767 Tanker; AMF JTRS; AWACS; C-17 Globemaster III; CSEL; Delta II; Delta IV; F-15E; FAB-T; GPS; JDAM; J-UCAS X-45; SDB; TSAT SS; WGS	Long Beach CA (Headquarters); Operations in Southern California Florida, Missouri and Washington
Army Systems	Apache Longbow; Chinook; Future Combat Systems; JTRS Cluster 1	Newtown Square, PA (Headquarters) 10 operating locations
NASA Systems	Propulsion Systems (RS-27A; RS-68, Space Shuttle Main Engine); CAPPS; Future Systems; International Space Station; Space Exploration Systems; Space Shuttle; X-37	Houston, TX (Headquarters) Operations in Kennedy Space Center, FL; Huntsville, AL; Washington D.C.; Canoga Park, Pasadena, Palmdale and Huntington Beach in CA
Naval Systems	F/A-18E/F Super Hornet; Harpoon Block II; SLAM-ER; T-45 Training System; V-22 Osprey; B737 MMA	St. Louis, MO (Headquarters); Operations in Philadelphia, PA; San Diego, CA; Washington D.C.;
Missile Defense Systems	ABL & ATL; GMD; PAC-3; Arrow; Avenger	Washington D.C. & Huntsville, Alabama (Headquarters) 7 operating locations
Space & Intelligence Systems	Boeing 601; Boeing 702; Future Imagery Architecture; Mission Systems; Other Classified Programs	Seal Beach, CA (Headquarters) Operations in 20 locations in the U.S.
Joint Ventures	United Space Alliance with Lockheed Martin	Texas, Florida, Alabama, California and Washinton D.C.

4.1.2.1 Commercial Airplanes

Commercial Airplanes is the other major revenue generating business unit of Boeing. This business unit produces large commercial aircraft varying from a capacity of 100 to 550 passengers as well as providing various support services for life-cycle management of its product lines. The current product lines of this unit are described in the table below[36]:

[36] URL www.boeing.com/commercial/prices/ (visited 2004, December 28)

Table 4.1: Boeing Commercial Aircraft Product Families & Information.

Product Familty	Product series	Average Passenger Capacity	Published Price ($ million)	Final Assembly Locations
717	717-200	106	38 - 42	Long Beach, CA
737	737-600	120	44 - 52	Renton, Washington
	737-700	140	50 - 59	
	737-800	162	61 - 69	
	737-900	177	64 - 74	
747	747-400	524	198 - 227	Everett, Washington
767	767-200ER	220	108 - 120	Everett, Washington
	767-300ER	269	123 - 136	
	767-400ER	304	135 - 148	
777	777-200LR	290	202 - 225	Everett, Washington
	777-300	451	191 - 218	
	777-300ER	451	218 - 245	
Cargo	747-400F	124 tons	202 - 228	Everett, Washington
	767-300F	61 tons	123 - 136	

4.1.3 Commercial Aviation Services

The Commercial Aviation Services sub-unit provides global customer life-cycle support for Boeing aircraft operators. This service includes 5 main categories. The global customer support category handles general inquiries from Boeing aircraft operators. The spares and logistics support category coordinates the on-time availability of spare parts to airlines on an ad-hoc or contract basis. Boeing outsources the operation of this task to distributors that are located around the world with appropriate inventory to support its aircraft. The maintenance & engineering services category provides comprehensive maintenance services, also known as “C” and “D” checks, through third party maintenance & repair organizations that are certified by civil aviation authorities (FAA in the U.S. and EASA in the E.U.) for maintaining Boeing aircraft. These MRO organizations can also perform modification and conversion work on Boeing aircraft if they are certified for the necessary procedures. Such certifications are given by both civil aviation authorities and Boeing itself. Lastly, Boeing provides support for Flight Operations, consisting of flight and simulator training, light technical manuals and engineering support.[37]

4.1.4 Connexion

The Connexion business unit serves airlines and passengers as well as private and government aircraft owners with broadband access to the internet. Passengers use this service to connect to the internet in-flight. Airlines, on the other hand, use this service for in-flight data and voice communication with ground dispatch centers.[38]

4.1.5 Phantom Works

The Phantom Works is the research and development unit of Boeing. This unit works on advanced technology projects as well as process improvement for current practices. Its research is directed towards commercial airplane, space, communications and defense products. Phantom Works has improved cost structures of various Boeing commercial airplane programs through its achievements in high-speed machining, friction stir welding, automated fiber placement and stitched resin film infusion. These processes decrease the amount of assembly work on aircraft by making it feasible to produce strong and light large aerostructures that bring together several parts into one component part.[39]

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[37] URL boeing.com/commercial/aviationservices/capabilities.html (visited 2005, February 2)

[38] URL boeing.com/connexion/backgrounder.html (visited 2005, March 12)

[39] URL boeing.com/phantom/pw_sfa.html (visited 2005, February 8)

4.1.6 Shared Services Group

The shared services group business unit provides administrative and non-product related general logistics support for all other business units. It employs 21,000 people worldwide.

4.2 Customers

Boeing's customer base is very small and steady in terms of number of customers due to the nature of the industry. The IDS business unit sells only to governments. Its main customer is the U.S. military but it does export a portion of its production to the armed forces of U.S. allies.

Table 4.2: Boeing's Military Customers by Product.

Product	Customer
737-700 Airborne Early Warning & Control (AEW&C)	Australia and Turkey
767 Tanker Transport	Italy and Japan
AH-64A Apache	Egypt, Greece, Israel, Saudi Arabia and United Arab Emirates
AH-64D Apache	Egypt, Israel, Japan, Kuwait, The Netherlands, Singapore and United Kingdom
AV-8B Harrier II	Italy, Spain and United Kingdom
Boeing 376, 601 and 702 satellites –	Australia, Brazil, China, Cyprus, France, Hong Kong, Indonesia, Japan, Luxembourg, Malaysia, Mexico, Norway, Russia, Singapore, Sweden, Thailand, United Arab Emirates and United Kingdom
C-17 Globemaster III	United Kingdom
CH-47 Chinook	Argentina, Australia, East Asia, Egypt, Greece, Italy, Morocco, Singapore, Spain, Taiwan, The Netherlands and United Kingdom
Delta family of rockets (Delta II & IV)	France
F/A-18 Hornet	Australia, Canada, Finland, Kuwait, Malaysia, Spain and Switzerland
F-15 Eagle	Israel, Japan, Korea and Saudi Arabia
Harpoon	26 international customers
JDAM	12 international customers
Sea Launch Company, LLC	Japan, The Netherlands, United Arab Emirates
SLAM-ER	Korea

The commercial airplane business unit sells to commercial airlines as well as leasing companies. It's best selling product is the 737 series which has sold more than 5,300 units until since 1967.[40] Boeing's customers range from small start-up carriers to

[40] URL boeing.com/commercial/737family/background.html (visited 2005, January 30)

large national principal flag carriers. The airlines deal with either Boeing itself or one of the leasing companies in order to secure financing for their purchase. Boeing Capital business unit assists the commercial airplanes unit in facilitating sales. The larger airlines have greater bargaining power and receive both lower prices and lower interest rates for their leases. The evolution of the all-in-one life-cycle solution leads to innovative deals between Boeing, Airbus and their important customers.

One recent deal between Easyjet and Airbus proves that aircraft pricing alone is no longer sufficient for winning customer orders. In 2002, Easyjet, then a Boeing 737 operator, decided to purchase 120 Airbus aircraft along with options to purchase an additional 120 aircraft by 2013. Easyjet chose its preferred supplier for the major components in the aircraft such as engines and avionics. These suppliers, in turn, joined Airbus in providing financing for the purchase of these aircraft through operating leases for Easyjet. Airbus also agreed to provide the following services free of charge for the A319, A320 and A321[41]:

- Operations and field service engineering.
- Technical support and training.
- Spare parts support.
- Training and technical manuals for all delivered aircraft along with software and other materials and upgrades for all delivered aircraft.

Airbus also gave Easyjet to change the mix of aircraft within the A320 family that it wishes to purchase after it enters the contract. Hence, Easyjet did not have to forecast its demand out until much closer to the time of delivery of its aircraft. Lastly,

[41] URL easyjet.com/en/news/20021014_01.html (visited 2005, February 12)

Airbus guaranteed Easyjet that the new product family that it was purchasing would have maintenance costs less than or equal to that of its then only aircraft, the Boeing 737-700, hence entering into an aftermarket support agreement for the life-cycle of its product.

4.3 Competition

Currently, Boeing's only competitor in the large commercial aircraft segment is the Airbus Company. Embraer of Brazil and Bombardier of Canada are both moving in to the lower capacity end of the large commercial aircraft market in the coming years. Embraer's 190 and 195 product lines along with Bombardier's C110 and C130 will compete in the 100 to 130 passenger segment. Boeing will terminate the production of the 717 in 2006, hence pulling out of the growing large regional jet market.

Airbus was formed in 1970 as a pan-European consortium dedicated to establishing a competitive series of aircraft families that were European supplied and built. The consortium became a single entity in 2001 with Aerospatiale Matra SA of France, Daimler Chrysler Aerospace AG of Germany and Construcciones Aeronauticas SA of Spain merging to become The European Aerospace and Space Company (EADS). EADS now owns 80% of Airbus Company with the rest of the shares owned by BAE Systems of the United Kingdom.[42]

Airbus overtook Boeing in 100-plus seat aircraft market share after several tremendous growth spurts starting in the early 1980's and continuing through the mid-1990s. (See Appendix D) The company's first product was a mid-range small wide-body aircraft, the A300. The following product was a derivative of the first that had less capacity but more range. After the establishment of core product families such as the A320 and the A340, each subsequent product line was part of a product family and shared increasing levels of commonality with other members of the product family. Airbus made an attempt to design specifically for parts, maintenance and operational commonality. The company's other product families were directed towards competing with Boeing's existing product families. The newest product line of Airbus, the A380, enables the company to compete in the 500-plus seat market with the Boeing 747 family.

The current competitive positioning of Boeing with respect to Airbus can be analyzed in terms of product development and supply networks evolution. Product development determines the vision of Boeing in terms of the direction towards which the trends in aviation are evolving. The speed of evolution of the supply networks determines if Boeing can delegate design and supply-chain integration responsibilities for its new product lines to its first and second tier suppliers. This, in turn, will translate into decreased design and production lead-times, enabling Boeing to ramp up or scale down its production capacity in order to cost-effectively handle the commercial aircraft business cycle.

Boeing's product development strategy over the past few years seems to suggest that it is diverging from its previous emphasis on traditional capacity configurations with respect to range. Boeing is still continuing to produce the 717, 737, 747, 767 and 777 series. The new 787 Dreamliner product line includes 2 long-range and 1 short to medium range aircraft.[43] The long range aircraft have less capacity then

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[42] URL www.airbus.com/about/history.asp (visited 2005, January 30)

the short to medium range aircraft, a counter-traditional approach to aircraft design. The emerging emphasis on point-to-point transportation in the airline industry, in contrast with the traditional emphasis on the hub and spoke system, would seem to indicate potentially high demand for commercial aircraft such as the 787 Dreamliner series. Airbus, in turn, had been exploring this market by designing aircraft in response to its bigger launch customers such as Lufthansa and Singapore airlines. Their move into the longer range, lower capacity arena came in 2003 with the release of the A340-500 and later on the A340-600 series. These aircraft were derivatives of the already established A340 product family, creating cost advantages for both Airbus and its customers due to fleet commonality. Hence, the ability of Airbus to provide these new aircraft without having to redesign a complete new family is a big advantage in terms of manufacturing and design cost and life-cycle marketing power.

Boeing's 787 series is a totally new product family. Therefore, its cost structure will be different from the competing product lines from Airbus. Airbus also recently announced the A350, a series that will go head-to-head with the longer range 787-8 and 787-9 aircraft. The A350 is a derivative of the A330 series that also has high commonality with the A340. Hence, Airbus has an advantage with the A350 as well due to the high commonality vis-à-vis the new Dreamliner series. Such commonality has great advantages for Airbus in marketing its new products. The installed base of crew training and certification, spare parts, maintenance equipment and technical expertise reduce the life-cycle costs of the new aircraft for airlines. Also, the ability to amortize the immense design cost of aircraft over the new series of aircraft enables Airbus to

[43] URL www.boeing.com/commercial/7e7/flash.html (visited 2005, February 25)

offer better prices for the purchase of the aircraft. Boeing's positioning in the industry has been changing faster than anytime in its history.

The emergence of Airbus and the industry's transition into a duopoly has changed the nature of competition. The concurrent transformation in the airline industry and the cost-consciousness exercised by Boeing's customers will drive the factors affecting competition in the next few decades. There are potential overarching practices that will provide competitive advantage to Boeing if it succeeds in accomplishing them better than Airbus. These are lifecycle-cost management of aircraft, design and operational commonality in new aircraft series and global selection of suppliers considering access into growing markets.

5 Boeing's Commercial Aircraft Supply Chain

This century's emerging trends and practices in supply chain management in the commercial aircraft industry are guided by basic lean supply chain management practices that have been spreading more widely within the defense aerospace industry over the past decade. During this period, as part of the wider diffusuon of lean practices, the most striking improvements across supplier networks in terms of cost reduction has been through process improvements, including the adoption of process technologies. The most recent examples in the large commercial aircraft supply chain indicate that process improvements have much more to contribute in terms of both cost reduction and lead time savings.[44] Within Boeing itself, important cost savings have been attained through process improvements, particular in connection with assembly operations. It is important to note that many of these process improvements, which differ in terms of their scope and goals, are used in conjunction with one another, to derive the maximum complementary effects.

The important benefits of project level deployment of these process improvements have become more widely known in recent years .[45] Much greater value is obtainable, however, through engaging the entire supply chain in these process improvement initiatives to achieve greater value at the enterprise level, or across an enterprise's entire supplier network, it major changes are taking place in traditional roles

[44] Comments by Joe Leonard, CEO of AirTran Airways, Aviation Week MRO Conference. (2005, April 19-21), Dallas, TX.

and responsibilities in the supply chain. In the case of the commercial aircraft supply chain, manufacturers are delegating greater responsibility to their suppliers. This empowerment is taking place mainly in two areas, design and systems integration. The same practice have already been in place in the military aircraft segment of the aerospace industry.

Delegation of greater responsibilities to suppliers, involving strategic partnerships with major suppliers, enables the manufacturers, and prime contractors on the military side, to concentrate on complete aircraft design as well as on high-level integration and assembly technologies and processes. This shift in the traditional relationships between suppliers and manufacturers requires greater trust between the two parties. Hence, the traditional arm's length relationships in the aerospace supply chain are giving way to more closely-knit relationships based on mutual trust and reciprocal obligations – reflecting core lean practices -- to unlock value for the whole supply chain.

One emerging supply chain phenomenon that is largely exclusive to the commercial aircraft segment is the disproportionately high growth expectations in the aftermarket logistics part of the supply chain. The main reason for this expectation is the forecasted installed base of commercial aircraft. Most forecasts estimate the installed base at 36,000 aircraft by the year 2023, more than double the 16,000 aircraft that were in service in 2003.[46] Complementing this factor is the trend of outsourcing maintenance services to third party Maintenance and Reserve Organizations. The two

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[45] In the April issue of Airliner World Publication, Boeing's best-practice 737 assembly flow time is indicated to be 11 days.
[46] Presentation by John Dickie, VP Maintenance&Engineering Services, Airbus N.A. Aviation Week MRO Conference 2005. Dallas, Texas.

factors combined indicate that productive maintenance capacity is not sufficient to supply the growing aircraft fleet.

Boeing's supply chains across its business units are quite complex and, more importantly, quite different from one another. The supply chains within the commercial airplanes business unit, however, have many common characteristics. Though some individual suppliers may be different, in general the overall processes and best practices in the commercial and military business segments of Boeing are similar. The remaining part of this chapter will describe the supply-chain practices within the commercial airplanes division of Boeing.

5.1 Operating Model and Supply Chain Network

The operating model and supply chain network for Boeing commercial aircraft is explored here in five main areas. These are Orders by Channel, Order Fulfillment, Facilities, Customers and Suppliers. The descriptions below are applicable to all commercial product lines of the company.

5.1.1 Orders by Channel

The ordering process is a good starting point for the analysis of the commercial aircraft supply chain network. Boeing receives its orders from either leasing companies or airlines. Boeing sales representatives are always in contact with existing and potential customers. Orders from leasing companies and large national and commercial airlines are part of long-term supply agreements. Large airlines conduct their fleet planning periodically and adjust their aircraft needs accordingly. Fleet planning is conducted for anywhere between 2 to 10 years or more into the future. Hence the orders from this channel have different dynamics then orders to smaller airlines. The differences are most observable in price, delivery flexibility and maintenance agreements.

Lessors, on the other hand, also have a high degree of power due to the large amount of aircraft they order. Their asset selection is also a function of the fleet planning of their clients as a whole. Currently, approximately 25% of all orders are from lessors. [47]The primary lessors in the market are ILFC, GECAS, Ansett, and CIT. The large airlines' orders come with financing in place where-as smaller airlines obtain financing from lessors or lease aircraft from them.

5.1.2 Order Fulfillment

Boeing only manufactures aircraft to order. The usual delivery lead-time is anywhere from 12 to 18 months depending on the product. New products take longer to deliver from the time orders are taken as capacity is set-up for the entire supply-chain of the newly designed aircraft. For example, the 787 series was approved by the Boeing board for sale to customers on December 16, 2003.[48] On April 26, 2004, All Nippon Airways became the first customer for the aircraft with 50 firm orders. The airline will begin taking deliveries in 2008.[49]

5.1.3 Facilities

[47] M. Walton, interview, April 4, 2005

[48] URL www.boeing.com/news/releases/2003/q4/nr_031216g.html (visited 2005, March 27)

Boeing has 4 main facilities in the U.S. Three of these facilities are assembly facilities for the different aircraft programs. These are Long Beach, California, which assembles the 717 aircraft, Renton, Washington, which assembles the 737 and the 757 aircraft and Everett, Washington, which assembles the 747, 767 and the 777 aircraft. The fourth main Boeing facility is in Wichita, Kansas. This facility does not perform final assembly of aircraft but manufactures parts and components for all aircraft types but the 717.[50] The 2004 revenues of the Wichita facility were approximately $3 Billion. Boeing's lean efforts in its facilities and regulatory concessions in the Seattle area also encourage many of its 2nd and 3rd tier suppliers to move close these facilities.[51]

5.1.4 Customers

Boeing's customers are airlines and leasing companies. There are about 500 airlines in the world of which approximately 200 buy new aircraft. There are several dozen leasing companies of various sizes. The most dominant ones are GECAS, ILFC, Ansett and CIT.

5.1.5 Suppliers

The large commercial aircraft supply chain is broken down into three main components. These are aerostructures, engines and avionics. This section will explore suppliers in that order.

5.1.5.1 Aerostructures

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[49] URL www.boeing.com/news/releases/2004/q2/nr_040426g.html (visited 2005, April 3)

[50] URL www.boeing.com/commercial/wichita (visited 2005, April 1)

Aerostructures are structural assemblies that make-up the visible frame of an aircraft. Aluminum, titanium and, more recently, composite materials are used in building aerostructures. Aerostructures do not include engines or avionics. These components have separate supply-chains and are integrated into the aircraft after the main components of the aircraft are assembled. Aerostructures are broken down into three categories: fuselages, wings and landing gear. These main categories include various components and sub-components.

- *Fuselages* – Barrel Sections, Nose, Fin, Tail, Rudder, Tailplane, Elevators
- *Wings* – Control Surfaces, winglets
- *Landing Gear* -- Landing Gear

The manufacturing requirements for aerostructures serve as a significant barrier to entry into this industry. Both Boeing and Airbus contract out a portion of their aerostructures needs to suppliers. The winners of these contracts require adequate capital, design and manufacturing expertise, adequate labor force and government approval to produce these parts or subassemblies.

The aerostructures suppliers together with the large commercial aircraft manufacturers constitute one of three supplier tier-systems in the aircraft segment, the other two being engines and avionics. Generally, the higher tier suppliers sell integrated and complex assemblies to the aircraft manufacturers at high prices. Lower tier suppliers either sell simpler sub-assemblies or parts to the aircraft manufacturers or serve as a supplier to the higher-tier suppliers. The recent supply chain trend that delegates more responsibility to the first and second tier suppliers has led to more complex components and less standalone parts arriving at the Boeing or Airbus

[51] M. Walton, interview, April 4, 2005

assembly lines. As a result, the aircraft manufacturers have simpler and faster assembly processes. There are also examples of avionics and aerostructures components arriving pre-integrated to the final assembly locations, serving as an example of the growing scope of system integration activities at the supplier level. The majority of the "make or buy" decisions for Boeing and Airbus are made for aerostructures rather than for engines or avionics. Neither manufacturer has any engine or engine parts production. Boeing has substantial avionics manufacturing capabilities on the military side as well as the commercial side. There are also very strong suppliers in this sub-segment such as Honeywell, Rockwell Collins and Thales SA. Currently, Boeing supplies approximately 50% of the avionics on its commercial aircraft. The remaining 50% is provided by customer-selected suppliers.[52] Airbus, on the other hand, has no avionics production within the Airbus Company but has ties with avionics manufacturers, such as SAAB Aerospace and Thales through a complex web of ownership within the European aerospace industry.

5.1.5.2 Supplier Concentration in North America

The U.S. aerostructures industry segment is dominated by the large presence of Boeing. There are 14 aerostructures manufacturers, including Boeing, in the United States and most of them supply Boeing.[53] The most significant players among these in terms of having greater design responsibilities and producing more complex sub-assemblies are Aerostructures Corp., Vought Aircraft Industries Inc. and Goodrich

[52] (M. Walton, interview, April 4, 2005)

[53] United States International Trade Commission. (2001, June)

Corporation.[54] Consolidation in this industry is the trend for survival, as aircraft manufacturers are opting for more value-added components that decrease manufacturing and assembly costs and lead times at their facilities. A possible merger between Vought and Aerostructures Corp. is expected by industry experts as they are under the ownership of the same fund, the Carlyle Group. As a general rule in the current supplier situation, the greater the complexity of the component, the higher the bargaining power of the aerostructures supplier.

Historically, aerostructures manufacturers have supplied the aircraft manufacturers in their region but due to the weakening of their bargaining power after deregulation in the airline industry and consolidation among aircraft manufacturers, these suppliers are bidding for business from Boeing as well as Airbus. In addition, these companies supply both the military can the civil segment due to their design and manufacturing commonality. They also serve as MROs for their respective components. This business mix helps aerostructures manufacturers battle the price pressures of a two-buyer bargaining situation in the largest market of the aircraft segment.

The U.S. aerostructures industry currently suffers from being the early global leader in the industry. The aging infrastructure in the industry results in losing contracts to newer, cheaper and more efficient facilities in Europe and Asia. Boeing has been especially active in outsourcing aerostructures from Asia. Boeing exercises this policy to obtain an advantage from better technology in Asia along with access to Asian national airlines in exchange for outsourced manufacturing for the aircraft.

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[54] United States International Trade Commission. (2001, June)

Boeing outsources the majority of its aerostructures in North America. It has 13 major suppliers in the U.S. and 11 in Canada. Many of the Canadian aerostructures suppliers are subsidiaries of U.S. owned firms. Some of Boeing's suppliers in North America also supply Airbus. Boeing also has 5 suppliers in Japan, 3 in Korea and 4 in China. The suppliers in Japan handle more complex assemblies then the ones in Korea and China.[55]

5.1.5.3 Engines

There are four suppliers of engines for Boeing commercial aircraft. These are Rolls-Royce, Pratt & Whitney, CFMI and General Electric. The industry practice for selecting engines for aircraft requires the aircraft manufacturer to certify with the regulating bodies one or more engines for an aircraft type. This selection process creates the grounds for competition among the engine manufacturers. Boeing has several engines certified for most of its aircraft.[56] Ideally, the manufacturer does not have to dual source for the costly components such as engines and avionics until the aircraft type's sales are strong. Due to the current competitive realm in the aircraft manufacturing and aviation industries, both large commercial aircraft manufacturers have to present their customers with more than one choice of engines and avionics. The below expected sales for an aircraft type can, however, make dual sourcing a heavy burden on the manufacturer.

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[55] United States International Trade Commission. (2001, June)

[56] URL www.boeing.com/commercial (visited 2005, April 4)

Table 5.1: Engine Suppliers for Boeing Commercial Aircraft

Boeing Commercial Aircraft Engines			
Series	*Manufacturer*		
717	Rolls-Royce		
737	CFM		
747	Pratt & Whitney	Rolls-Royce	General Electric
757	Rolls-Royce	Pratt & Whitney	
767	Pratt & Whitney	General Electric	
777	Pratt & Whitney	Rolls-Royce	General Electric

Manufacturers of regional and business jets that are much smaller in size can testify to the difficulties of dual sourcing. At Embraer, a Brazilian manufacturer of regional, business and military aircraft, one of the important problems encountered in the feasibility planning of regional aircraft with unclear levels of demand is the inability to develop a 2nd source for important components such as avionics, flight management systems and especially engines.[57] Aircraft below 120 seats have this common problem. There are logistical barriers, such as certification requirements, that are both costly and time consuming for the manufacturer. When dual sourcing, Embraer not only has to certify the components from the 2nd source but also has to certify the aircraft and related sub-components to the 2nd source. In other words, different configurations of major components need regulatory certification, a time-consuming and costly process.

5.1.5.4 Avionics

[57] H. Marcondes, interview, March 16, 2005

Boeing has substantial avionics manufacturing capabilities on the military side as well as the commercial side. There are also very strong suppliers in this sub-segment such as Honeywell, Rockwell Collins and Thales SA. Currently, Boeing supplies approximately 50% of the avionics on its commercial aircraft. The remaining 50% is provided by customer selected suppliers. [58]Airbus on the other hand has no avionics production within the Airbus Company but has ties with avionics manufacturers such as SAAB and Thales through a complex web of ownership within the European aerospace industry.

5.2 Supply-Side Business Processes -- Defining Lean Through Lean Enterprise Self-Assessment Tool (LESAT)

The LESAT is a tool developed by the Lean Aerospace Initiative to help aerospace enterprises conduct a self-assessment of the degree of progress they have made in evolving lean enterprises.[59] LESAT is designed as a maturity capability framework, identifying and defining five distinct capability levels. For the pruposes of such self-assessment, LESAT decomposes enterprise processes into three major categories. "Lean Transformation/Leadership", "Life-Cycle Processes" and "Enabling Infrastructure". The LESAT definition of the Lean Transformation Leadership Process reflects the strategic scope of lean processes and practices: "Develop and deploy lean implementation plans throughout the enterprise leading to (1) long-term sustainability, (2) acquiring competitive advantage and (3) satisfaction of stakeholders."

[58] M. Walton, interview, April 4, 2005
[59] Lean Aerospace Initiative. (2001 August) Lean Enterprise Self-Assessment Tool (LESAT) version 1.0.

The first section, Lean Transformation/Leadership, is geared towards performing a paradigm shift within the enterprise away from the existing way of doing business. The level of this shift might differ from one organization to another depending on their level of maturity with respect to the primary activities and major tasks that are required for a lean transformation.

There are indications that companies can explore to determine if they are on the right track for a successful transformation to lean. The ones that pertain to Lean Transformation/Leadership are as follows:

- The existence of lean in strategic plans which, in turn, have stakeholder collaboration and understanding customer value as key drivers.
- A clear lean vision championed by a committed senior management team that values lean education throughout the ranks of the enterprise.
- Understanding, measuring and redesigning value streams with "single piece flow" of materials and information supporting a "pull" supply chain.
- An organizational structure that encourages innovation and open communication through tailored employee empowerment and incentive alignment, leading to seamless cross-functional cooperation within the company.
- An appropriate plan and allocation of resources to TTL supporting, among other areas, education and training programs.
- Active management of lean implementation including appropriate measurements against planned goals and reactive actions against deviations from targets.
- A continuous improvement approach that measures and evaluates progress at an enterprise level

The second section of the LESAT examines the business and operational processes of the company for the entire life-cycle of its products. It includes defining customer requirements, designing products and processes, managing supply chains, production, distribution and after-sale support. The lean indicators of this section are as follows:

- Flexible workforce and processes leading to maximum asset and resource utilization in the face of market conditions. Reduced cost, increased quality and faster lead times obtained. Proactive search for new markets using leanness as a competitive advantage.
- Supply-chain stakeholder and customer input in requirements definition process.
- Involving both customers and supply-chain stakeholders in the integrated design of products and processes.
- A strategic and flexible supplier network that complements the company's core competencies. Striving for long-term partnerships and knowledge sharing through well structured and documented relationships.
- A lean production/manufacturing "pull" process. Resulting minimization of waste (space, equipment, labor & capital). Sharing of production expertise throughout the *extended* enterprise.
- Constant coordination between sales/marketing and production for supply-chain information visibility. A lean distribution process and an entire extended enterprise involved in after-sale customer service.

Section 3 of LESAT measures the maturity of the "Enabling Infrastructure" for the transformation to lean. Good examples of enabling supporting functions and their practices are as follows:

- Sound financial information that is ready on demand. A financial system that eliminates counter-lean measurement indicators and incorporates non-financial information as well as financial information for decision making processes.
- Value and coordinate intellectual capital and training at an individual level.
- Flexible, fast and effective information technology systems.
- A "Cleaner, healthier, safer" enterprise
- Common tools and systems used throughout the enterprise, facilitating labor transfer and less variability within the material and information flows in the system.

The indicators described above are strived for in transformation to lean. The overarching theme in all sections that shapes the indicators themselves as well is the emphasis on the extended enterprise. The greater value of lean practices is realized, only when they are implemented throughout the extended enterprise.

5.2.1 The Make vs. Buy Decision and Supplier Selection

The majority of the make vs. buy decisions are made on aerostructures and avionics as Boeing does not possess engine manufacturing capabilities. Boeing has been pursuing a two-prong consolidation policy with regards to its 2^{nd} and 3^{rd} tier partners on the supply side. First, it is de-leveraging itself from component assembly operations and hence reducing the total number of parts that is assembled in its facilities. Second, it is reducing the number of suppliers and selecting more capable ones that can deliver more complex products to the assembly site. The move towards sharing design responsibilities with suppliers along with the first and second tier suppliers gaining systems integration responsibility sees the supply chain eliminate nodes that provide basic parts. Also, lean manufacturing practices serve as selection criteria for supplier selection. Those who can transform their operation to cater to Boeing's lean operational flexibility and efficiency have a bigger chance of continuing their relationship with the manufacturer.

Boeing's make/buy decisions were historically made as "stand alone" judgments at the division level.[60] Also, if an activity was performed in-house in the past, it would continue being performed in-house for the following program and vice versa. Changes would occur only when Boeing in-house teams or suppliers were no longer able to perform. [61]

After the start of the 777 program, Boeing hired Booz, Allen & Hamilton, one of the leading consulting firms, to assist it in structuring a make/buy policy in line with the company's long-term strategy. The policy provided procurement managers with instructions on the criteria to be used as well as the rank at which the judgment should be made. Boeing started to outsource the parts that the policy recommended

[60]Perrons, R. K. (September 1997). Make-buy decisions in the U.S. aircraft industry [Thesis]. p. 44
[61] Perrons (1997) p. 45

throughout its product lines. This policy is periodically reviewed at least every two years for changes in market and supplier conditions.[62]

The principal criteria in the make-buy policy draw upon five main factors: core competencies, costs, capital investment, labor relations and market access[63]. The functions and assemblies that Boeing considers core competencies are performed in-house. The input of suppliers at the design phase is allowed for some of these assemblies but Boeing retains major control over the process as a whole. Boeing is also extremely cost sensitive when outsourcing components. The current practice has Boeing declaring a budget for the component followed by the supplier working with Boeing's in-house team to design the component to exact specifications within the given budget. High capital investment costs for some component manufacturing functions encourage Boeing to outsource those components. This consideration also gives Boeing better flexibility throughout the business cycle in terms of asset utilization and labor, also a major factor due to the heavily unionized nature of the industry. Lastly, the market access factor allows Boeing to sell aircraft to national airlines in countries where the manufacturer has outsourced activities. This phenomenon is most pronounced in Japan and China where Boeing is competing to allocate outsourcing activity for the 787 series in competition with Airbus's efforts to supply components for the A380 as well as the 350 series in the region.[64]

The Boeing Commercial Aircraft Group's Leadership Team has ultimate authority over the make/buy decisions. It is responsible with making sure that make/buy

[62] Perrons (1997) p. 48
[63] Perrons (1997) p. 47
[64] "Airbus is also offering the Chinese aviation industry participation in up to five percent of the proposed A350 programme." Press Release April 22, 2005. www.airbus.com

decisions are aligned with Boeing's long-term policies and strategy. It, along with other teams within the group, also has the right to launch investigations into ongoing practices. The Produce Macro-Process Team within the Boeing Commercial Aircraft Group executes the operations of the make/buy plan, with the help of the Make/Buy Organization for collecting data. A Steering Committee screens the recommendations for its input regarding the macro-level issues such as market access and other political considerations.[65]

5.2.2 Product Development

Product Development is an important area of change for Boeing in the last 10 years. The supplier selection process described in the previous section outlines the emerging trend of increasing shared design of components between Boeing and its suppliers. The latest Boeing products such as the 777 and the 787 along with some of the latest products of Airbus have been platforms where cost and responsibility sharing in design has become commonplace. The 1st tier suppliers, which in some cases have better design capabilities than Boeing itself for their specific components, are providing capital for the design as well as technology. This practice cuts down on design lead time and assembly time since the design of the components are integrated with the design of the parts of the aircraft into which they are assembled. Also, the 1st tier manufacturer does not recover its design and tooling costs until a certain number of aircraft is sold. This way the financial faith of Boeing is correlated to that of its suppliers. Needless to say, the suppliers that want to engage in this risk-reward mechanism need to be financially sound.

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[65] Perrons (1997) p.54-55

This supply-chain practice is also prominent in other aircraft segments. At Embraer, the difference between the older 145 aircraft and the newer 170 aircraft is that the supplier risk-sharing relationship has extended from 4 suppliers to 16 suppliers. Also, in the earlier series of aircraft, the suppliers only participated in the risk-sharing during the design phase. In the later series of aircraft have the supplier partners sharing market risk as well as financing the development and design phase of the aircraft.[66]

The need for capital is surely a driver for sharing the design and development costs with suppliers. However, the real supply-chain related driver is in the ability to reduce development cycle times through risk-sharing at the design level. Such risk-sharing including and beyond the design level enables the aircraft manufacturer to set high level requirements. It also allows it to receive support from suppliers for sales of aircraft as well as aftermarket support. This enables the entire supply-chain to reduce the life-cycle cost of ownership for the customer. (Marcondes, 2005)

5.3 Inside Business Processes

Product portfolio management, capacity planning and production & inventory planning are the key inside business processes at Boeing. They have to be flexible and adaptive to market needs. Due to the highly cyclical nature of the airline industry, however, they are not flexible enough to cost effectively satisfy demand

5.3.1 Product Portfolio Management

Boeing currently has six commercial aircraft products. These are the 717, 737, 767, 777 and 747 in order of capacity excluding the 787 aircraft which will be delivered

[66] H. Marcondes, interview, March 16, 2005

starting in 2008. These products lines are mostly standard within themselves in terms of performance and structure. There is a high degree of customization, however, in interior configuration and partially in avionics. Boeing used to have more than a hundred combinations of interior designs that it offered to airlines. (P. Belobaba, class discussion, 2005) It recently reduced this offering so there is much more commonality in aircraft that are currently being delivered. The lower number of offerings makes the second-hand trading of the aircraft much more convenient as most operators can operate these configurations.

Boeing has always had a range of aircraft that covered the linear capacity and range combinations. (See figure 1 chapter 3) Recently, it decided to exit the regional jet market by announcing the termination of the 717 line. It also has not responded to the Airbus A380 aircraft with a very large aircraft of its own. The new 787 line emphasizes high density regional aviation as well as long-range non-stop services between non-hub cities. The 787-3 has no matching product from Airbus but the 787-8 and 787-9 are similar in range and capacity to the flexible A340 family.

Both large airlines and leasing companies influence Boeing's product portfolio. Both buyers make purchases based on long-term fleet planning decisions. Since these customers make-up a majority of Boeing's backlog, Boeing can see demand trends well into the future. Hence, as the customers determine air traffic patterns and decide on what type of capacity they need, Boeing adjusts its product portfolio accordingly. This adjustment is a slow process, however, since technologically and economically, Boeing needs to continue an aircraft line a minimum amount of years.

5.3.2 Facility and Capacity Planning

Facility and Capacity Planning is done before during and after the launch of the aircraft lines. The initial demand and advance orders shape the initial tooling and facilities. In the large commercial aircraft industry, capacity is never enough to accommodate the demand of the peak years immediately. A backlog builds up in the profitable years for the airlines and vice versa.

After capacity is determined in an assembly facility, the work process is adjusted depending on takt time, a measure representing available production time divided by customer demand. [67] Lean manufacturing is an enabler of adjusting takt time according to demand since assembly is continuous rather than in batches.

5.3.3 Lean and Other Process Technologies

Boeing has recently implemented two new process technologies in its handling of production, materials handling and inventory. One practice was lean manufacturing. Lean manufacturing enabled Boeing to change around the assembly floor from a batch assembly structure to a continuous structure. (M. Walton, interview, April 4, 2005) As a result, Boeing became more adaptable to demand swings and more importantly less impeded by wasted work and inventory. The work-in-process quality control aspect of lean manufacturing also is capable of reducing rework time though no information on this metric was available.

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[67] Murman, E. (2002)

Currently single-line assembly is employed in both 737 and 777 product lines. This is supplemented visual controls, support staff and inventory "supermarkets" right on the assembly floor.[68]

The lean practices employed at Boeing for the 737 fuselage sheds more light on the effectiveness of this technology at the program level. A Lean Effects on Aerospace Programs (LEAP) case study describes, in detail, the implementation of lean practices at Boeing's Wichita facility following the tremendous increase in demand for the 737 program after the introduction of its Next Generation (NG) aircraft.[69]

The popularity of the 737 NG aircraft served as a motivator for the implementation of lean practices. The Wichita facility needed to increase production from the previous rate of 10 aircraft per month to 28 per month. This drastic ramp up of production led to several lean practices being implemented at the same time. Boeing had already started working on lean practices for several years. They utilized the Shinijutsu Consultancy, a lean management consulting company, to adapt the Toyota Production System to Boeing. The training of the work force on lean principles was regarded as very highly important for the lean initiatives to be successful.

The highlights of the lean production acceleration program were[70]:

- A 737 Value Chain team that was lean savvy championed the lean initiative project within the company.
- Integrated Production Teams made up of Engineering, Manufacturing, Quality and Supplier personnel were assigned to specific assembly sections.

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[68] Philip E. Cook., Sytems & Equipment, Boeing Commercial Airplanes, interview, May 10, 2005

[69] Ferdowski,B & Haggerty, A. (2002, March 1) Lean effects on aerospace programs (LEAP) project. 737 fuselage case study report [Case Study Report].

[70] Ferdowski (2002) p.8

- The tooling and design of the factory enabled flexible "mixed-model" production. Supplies of parts were delivered to the point of use on the Assembly area daily.
- Single-piece flow design through new machinery and "Chuka-Chuka" lines
- Alcoa, Boeing's major supplier at Wichita, provided more ready to use parts such as aluminum products cut to size.

The results of the program were very impressive. The work-in-process airframes were reduced from 6 to 1. Factory flow time was reduced by 21%. From 1998 to 2000, labor hours per unit were reduced by approximately 50% and unit cost was reduced by 25%. Repair and rework was reduced by 50% in both volume and cost, showing a significant improvement in quality.

The other effective production technology that that was implemented was DCAC/MRM which stands for Define and Control Airplane Configuration and Manufacturing Resource Management.[71] This practice essentially breaks down orders into three categories or "Tailored Business Streams". The aircraft with basic configurations are and the repeat configurations are directed straight to production. The third batch representing the aircraft with new and unique options are processed through the engineering design and manufacturing planning functions. In turn, the materials necessary for the assembly of the different business streams are different and handled separately. Finally, the orders and materials are routed to facilities where the manufacturing systems are a close fit for the productions of the aircraft on order. Hence

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[71] URL www.boeing.com/commercial/initiatives/dcacmrm/dcac_summary.html (visited 2005, March 28)

every aircraft does not have to go through the entire line of manufacturing systems and material handling as well as inventory handling is streamlined.

One example of the improvements in manufacturing can be seen on the 737 line in Renton, Washington. The assembly time for a 737 has decreased more than 50% to 11 days and inventory has concurrently declined 59%[72].

5.4 Customer-Side Business Processes

In light of the structural and technical complexity of an aircraft, the competing products offered by Boeing and Airbus are quite similar to one another. Therefore, the purchasing decision of a customer often reflects the customer-side sales and support capabilities of the two manufacturers. The important customer-side elements in the industry are customer management, sales & order management and after-market logistics support.

5.4.1 Customer Management

Boeing has two main customer groups that are segmented within themselves. The airlines, the larger of the two groups, are divided into four main groups. These are large commercial airlines, national airlines, large low-cost airlines, and small to medium airlines. Each segment has varying degree of negotiating power against Boeing in price, delivery flexibility, maintenance terms and some other airlines specific items. The large airlines as well as national airlines are powerful enough to influence Boeing's design development for future aircraft. Negotiating power for an airline in all fields decreases as the size of its fleet decreases. The same structure is in place for the other customer group, the leasing companies. The larger ones such as ILFC and GECAS have power similar to that of larger airlines.

5.4.2 Demand Planning & Forecasting

The main driver of aircraft orders is airline profitability (M. Walton, interview, April 4, 2005) The main driver of airline profitability is air traffic which is a factor of the global economy. Boeing forecasts air-traffic for passengers and cargo every year as does Airbus. The forecasts run 20 years into the future for both companies. (See Appendix 6) Boeing advertises this forecast through publications as well as presentations and seminars throughout the year.

Forecasting down the supply chain is also important for Boeing. For most suppliers that deal directly with raw materials suppliers, Boeing tries to produce accurate forecasts that would enable the component suppliers to be more informative to the raw materials suppliers.[73] This in turn, reduces order lead time in an area where bottlenecks occur as all manufacturing industries compete with the aircraft industry for resources.

5.4.3 Sales & Order Management

The sales decisions at Boeing are made by a "Sales Operations" Committee. This committee decides on the number of aircraft that are available for delivery at predetermined times. This committee has members from three functional groups:

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[72] Airliners World. (2005, March). p 26.
[73] Philip E. Cook., Sytems & Equipment, Boeing Commercial Airplanes, interview, May 10, 2005

"Marketing", "Sales" and "Contracts". These members work with the input from the manufacturing division along with capacity, sold aircraft and build rate information to quote customers for deliveries. [74]

Order quoting in the industry also involves complex negotiations regarding price, delivery time, delivery flexibility and aftermarket services. Usually, the customer initiates the process by contacting the regional sales division of Boeing. The order is then taken back to a "Program Management" division depending on the type of aircraft in the order. An outcome is never reached without negotiations. The usual order quoting negotiations end with Boeing receiving a basket of firm orders and varying degrees of options. Options have to be confirmed 18 to 24 months before delivery of aircraft or the options are partially or fully canceled[75]. On the other hand, there are penalties for Boeing in case of missed deadlines.

Order fulfillment is done according to the schedule derived from the various order negotiations. There are opportunities for airlines in need to purchase rights to buy aircraft from other airlines or lessors who are higher-up in the delivery schedule. The lead-time for aircraft varies by type. On average smaller aircraft have a 9 to 12 month delivery lead-time and large aircraft have approximately an 18 month lead time. When completed and flight tested, aircraft are delivered either at the Boeing facility or at the customer's preferred airport.

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[74] Thomas Crabtree, Regional Director Marketing, Boeing Commercial Airplanes, interview, May 4, 2005

[75] Crabtree, interview, May 4, 2005

5.4.4 After-market Logistics & Support

The aircraft aftermarket logistics support is an area with very serious competitive and operational implications for Boeing. This segment is forecasted to have revenues that are 1.5 to 2 times that of the aircraft manufacturing industry in the next 15 years.[76] This ratio will increase as the installed base of aircraft increases with healthy trends in air travel and air cargo transportation.

This area is treated as a separate business unit within the commercial airplanes business unit. The aircraft that Boeing sells have a maintenance warranty that covers maintenance costs several years after purchase. Boeing has 9 service centers around the world with 3 of them offering avionics maintenance services. (appendix G)

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[76] United States International Trade Commission. (2001, June).

A large majority of Boeing's customers' needs are met by either in-house maintenance facilities or through maintenance and repair organizations that offer third-party services. These facilities are certified by the related civil aviation organizations for maintenance service capabilities for each aircraft type. The Federal Aviation Administration (FAA) is the regulating civil aviation body in the U.S. and its certification is recognized by many other countries in the Americas. The European Aviation Safety Agency is the European counterpart of the FAA and is recognized by many national civil aviation agencies outside of the European Union as well.

The recent competition in aircraft sales has prompted both Boeing and Airbus to include life-cycle maintenance agreement for their aircraft. Hence, both companies are trying to increase their service reach through maintenance partnerships with original equipment manufacturers and third-party maintenance and repair organizations.

6 Strategy and the Operating Model

Boeing has been steadily loosing market share to Airbus since the early 1970s, when Airbus was created in Europe. There are many factors affecting this trend but not all of them are reversible in the context of the company's supply chain management practices[77]. In order to understand Boeing's competitive position against Airbus, it is helpful to also examine the Boeing's strategy, operating model as well as how functional activities fit together to deliver greater value.

6.1 Strategy

In *"What is strategy?"* Michael Porter describes strategy as "the creation of a unique and valuable position, involving a different set of activities".[78] With this definition in mind, Boeing's strategy has been providing a full range of aircraft to all airlines who can afford to buy them. The strategy also included timing the launch of new aircraft at the right time in order to increase installed base of aircraft in different product categories.

Boeing may have enjoyed a relative competitive advantage with respect to Embraer and Bombardier at the lower-end of its product family in terms of seating capacity, but this will likely dissipate with the announced ending of the Boeing 717 production line in 2006.

Meanwhile, Boeing's previous competitive advantage in the very large commercial aircraft market segment is obviously being challenged by Airbus with the

[77] Piepenbrock, T.F. (2004 June). Enterprise design for dynamic complexity: Architecting & engineering organizations using system & structural dynamics [Thesis].

introduction into service of the A380. However, the expected introduction of the Boeing 787, which is designed to complement the Boeing 777, may well redefine marketplace competitive dynamics by providing Boeing a unique advantage in the shorter-distance point-to-point air transportation market segment.

The assertions in the last two paragraphs can be tested by revisiting Porter's qualifications for having a strategic competitive advantage. Porter states that a company's competitive advantage is only sustainable if it can either deliver greater value to its customers vis-à-vis its competitor, or deliver the same value at a lower cost.[79]

Looking at both qualifications simultaneously is possible since "greater value" in the context of airlines is based mainly on lifecycle-cost. Both Boeing and Airbus are trying to deliver better operating cost structures along with lower acquisition costs to airlines. Producing fuel-efficient and maintainable aircraft are two key factors in delivering lower operating cost structures. Both Boeing and Airbus practice this quite well. The lower acquisition cost is deliverable by cutting prices. An important point to make regarding lower acquisition cost is that it can be delivered much easier as the number of aircraft sold within a program increases. This is due to the very high design and tooling costs at the start of a new aircraft program. Hence price cuts tend to dictate the "value" delivered to the customer.

Given the lack of significant differentiation between Boeing and Airbus products in terms of value described in the last paragraph, the deciding factors for an airline are a combination of order lead time, politics and aftermarket support contracts. Order lead

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[78] Porter, M. (1996 November, December) What is strategy? Harvard Business Review pp. 61-79.
[79] Porter, (1996)

time depends on the backlog of the individual program supply chain. Politics is an exogenous factor to both Boeing and Airbus as it is handled by governments. Strong aftermarket support is a new area for both Airbus and Boeing and though Airbus is working faster than Boeing, neither company has yet to establish a better support network over the other.

In conclusion, given very similar set of suppliers and common best-practices, the strategic advantage of Boeing vs. Airbus or vice versa varies by product category, time and any other exogenous factors that might be in consideration at the time of sale.

6.2 Operating Model

Boeing's supply chain operating model supports its strategy, from the design stage to the aftermarket support of aircraft. At the design stage, Boeing includes first and second-tier suppliers in its design and development processes, reducing both the cost and design lead time of components. The part and component design is also geared towards maintainability, an important part of delivering better operating cost to the airlines. Both activities help enhance price flexibility. In addition, by including these suppliers in a risk/reward sharing structure, Boeing is able to break-even earlier on its aircraft programs, leading to more flexibility in price negotiations. At the manufacturing stage, Boeing is able to ramp-up or decrease production according to the pull signals in its supply chain. This helps the company quote decreased order lead- times when it competes on availability of aircraft. In the aftermarket, Boeing started expanding its relationships with maintenance and reserve organizations around the world in order to be able to deliver the promised "life-cycle costs" to the customer after the sale of aircraft. Boeing is outsourcing this capability in order to be able to offer aftermarket services more quickly.

6.3 The Balance Among Operational Objectives

A review of the importance given to different metrics within Boeing's operations shows consistency between the strategy and operational objectives of the company. The three key operational metrics that are employed in the measurement of the supply chain are cost, quality and schedule.[80] There is a balance between these metrics with respect to their fit to the strategy of the company. Aftermarket performance of aircraft, which can be a burden to Boeing within the manufacturing warranty period, are a measure of quality as well as the amount of rework to be done after the initial assembly. The cost metric is a function of the manufacturing costs as well as negotiations in procurement processes. Lastly, the schedule metric measures the on-time delivery of aircraft to customers. In the ongoing product lines, this is a function of the efficiency and speed of the whole supply chain's procurement, manufacturing, and assembly lead times.[81]

6.4 The Strategic Fit of Tailored Business Practices

Porter describes three types of strategic fit for activities.[82] The first-order fit involves simple consistency between each activity and the overall strategy. The second-order fit involves the different activities reinforcing one another. The third-order fit has some activities eliminating the need for other activities, optimizing the operating

[80] Philip E. Cook., Sytems & Equipment, Boeing Commercial Airplanes, interview, May 10, 2005
[81] Philip E. Cook, interview, May, 10, 2005

model in the process. The most desirable fit is the third-order fit. It is least imitable by competitors thus leading to a longer lasting competitive advantage.

Some of the lean practices at Boeing are third-order fits with respect to the overall strategy. On the assembly line, the work-in process quality control that is performed as the aircraft are being assembled eliminates a significant portion of the rework before flight testing. This is a significant issue as only 3 out of 10 aircraft come out of the assembly line exact to customer specifications.[83] This in turn, saves both time and money for the delivery of the aircraft. At the design stage, having suppliers design integrated components instead of stand-alone parts saves time at the assembly line by eliminating many of the fastening and assembly functions. This greatly enhances assembly time as was the case in the 737 program which experienced more than 50% reduction in assembly time since such practices were put in place in 1999.[84] Another related third-order fit is the delegation of systems-integration tasks to suppliers which eliminates a portion of the systems integration tasks on the assembly line. This practice does not just pass down the systems-integration tasks up the supply chain but reallocates them where they are less complex relative to the assembly line. Lastly, by offering less-customization on its aircraft, Boeing eliminated certain interior customization related engineering function and achieved more efficient materials handling, inventory management and speedier manufacturing.[85] This was the result of

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[82] Porter, (1996)
[83] Comments by Dr. Wolfgang Kortas, Senior Director MRO Support Management Customer Services Aibus. Aviation Week MRO Conference. (2005, April 19-21), Dallas, TX

[84] Airliners, (2005, April)
[85] This concept is taken further in the 787 series according to a recent Wall Street Journal Article "Streamlined Plane Making

Boeing's "Define and Control Airplane Configuration/Manufacturing Resource Management" that was initiated in 1994.

6.5 Conclusion

After analyzing the information that helped form this paper, it has become apparent that this study catches both the aircraft and the airline industries in the middle of a massive transformation period. Although many advances have been made in individual areas at Boeing and Airbus, as well as at the regional and business aircraft makers, the aerospace supplier networks taken as a whole still have a lot of room for further improvement. A recent Wall Street Journal article called "Streamlined Plane Making" is a testament to this, quoting both Boeing and Airbus executives promising 6 month manufacturing times for aircraft from scratch and 3 day final assembly times.[86] The article also identifies the two manufacturers as copying Toyota's manufacturing practices which are the source of lean manufacturing practices.[87] These advancements will be more pronounced in the future, as they are increasingly complemented by similar improvements more widely in other parts of the global large commercial aircraft supplier networks. Spurred by intensifying international competition, it is expected that the journey towards the creation of lean extended enterprises will, if anything, accelerate in the future.

[86] Michaels, D.M. & Lunsford J.L. (2005, April 1) Streamlined Plane Making. The Wall Street Journal p.B1
[87] Womack, (1991)

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APPENDIX A - US Census Bureau NAICS (North American Industry Classification System) codes and definitions for the aerospace industry (duplicated from the US Census Bureau website)

3364 Aerospace Product and Parts Manufacturing

This industry comprises establishments primarily engaged in one or more of the following: (1) manufacturing complete aircraft, missiles, or space vehicles; (2) manufacturing aerospace engines, propulsion units, auxiliary equipment or parts; (3) developing and making prototypes of aerospace products; (4) aircraft conversion (i.e., major modifications to systems); and (5) complete aircraft or propulsion systems overhaul and rebuilding (i.e., periodic restoration of aircraft to original design specifications).

336411 Aircraft Manufacturing

This U.S. industry comprises establishments primarily engaged in one or more of the following: (1) manufacturing or assembling complete aircraft; (2) developing and making aircraft prototypes; (3) aircraft conversion (i.e., major modifications to systems); and (4) complete aircraft overhaul and rebuilding (i.e., periodic restoration of aircraft to original design specifications).

336412 Aircraft Engine and Engine Parts Manufacturing

This U.S. industry comprises establishments primarily engaged in one or more of the following: (1) manufacturing aircraft engines and engine parts; (2) developing and making prototypes of aircraft engines and engine parts; (3) aircraft propulsion system conversion (i.e., major modifications to systems); and (4) aircraft propulsion systems overhaul and rebuilding (i.e., periodic restoration of aircraft propulsion system to original design specifications).

336413 Other Aircraft Parts and Auxiliary Equipment Manufacturing

This U.S. industry comprises establishment primarily engaged in (1) manufacturing aircraft parts or auxiliary equipment (except engines and aircraft fluid power subassemblies) and/or (2) developing and making prototypes of aircraft parts and auxiliary equipment. Auxiliary equipment includes such items as crop dusting apparatus, armament racks, in-flight refueling equipment, and external fuel tanks.

336414 Guided Missile and Space Vehicle Manufacturing

This U.S. industry comprises establishments primarily engaged in (1) manufacturing complete guided missiles and space vehicles and/or (2) developing and making prototypes of guided missile or space vehicles.

336415 Guided Missile and Space Vehicle Propulsion Unit and Propulsion Unit Parts Manufacturing

This U.S. industry comprises establishments primarily engaged in (1) manufacturing guided missile and/or space vehicle propulsion units and propulsion unit parts and/or (2) developing and making prototypes of guided missile and space vehicle propulsion units and propulsion unit parts.

336419 Other Guided Missile and Space Vehicle Parts and Auxiliary Equipment Manufacturing

This U.S. Industry comprises establishments primarily engaged in (1) manufacturing guided missile and space vehicle parts and auxiliary equipment (except guided missile and space vehicle propulsion units and propulsion unit parts) and/or (2) developing and making prototypes of guided missile and space vehicle parts and auxiliary equipment.

APPENDIX B: AECMA Product Segment Descriptions (Duplication from AECMA 2002 report)

PRODUCT SEGMENTS

AIRCRAFT

- Complete systems of and/or airframes for aeroplanes, helicopters and gliders, ground installations, their subsystems and parts, spares and maintenance
- Piston engines, turboprops, turbojets, jet engines, their subsystems and parts, spares and maintenance, for installation in aircraft systems
- Finished products, subsystems and parts, spares and maintenance, also for test and ground-training equipment, for installation in aircraft systems
- Service Providers, Consultants, etc.

MISSILES

- Complete systems of and/or airframes for missiles, ground installations, their subsystems and parts, spares and maintenance
- Engines, their subsystems and parts, spares and maintenance, for installation in missile systems
- Finished products, subsystems and parts, spares and maintenance, also for test and ground-training equipment, for installation in missile systems
- Service Providers, Consultants, etc.

SPACE

- Complete systems of and/or airframes for space vehicles, satellites, launchers, ground installations, their subsystems and parts, spares and maintenance
- Propulsion devices, their subsystems and parts, spares and maintenance, for installation in space vehicles, satellites, launchers
- Finished products, subsystems and parts, spares and maintenance, also for test and ground-training equipment, for installation in space vehicles, satellites, launchers
- Service Providers, Consultants, etc.

APPENDIX C: Sector Descriptions (Duplication from AECMA 2002 report)

SECTORS

SYSTEMS & FRAMES

• Complete systems of and/or airframes for aeroplanes, helicopters and gliders, ground installations, their subsystems and parts, spares and maintenance
• Complete systems of and/or airframes for missiles, ground installations, their subsystems and parts, spares and maintenance
• Complete systems of and/or airframes for space vehicles, satellites, launchers, ground installations, their subsystems and parts, spares and maintenance

ENGINES

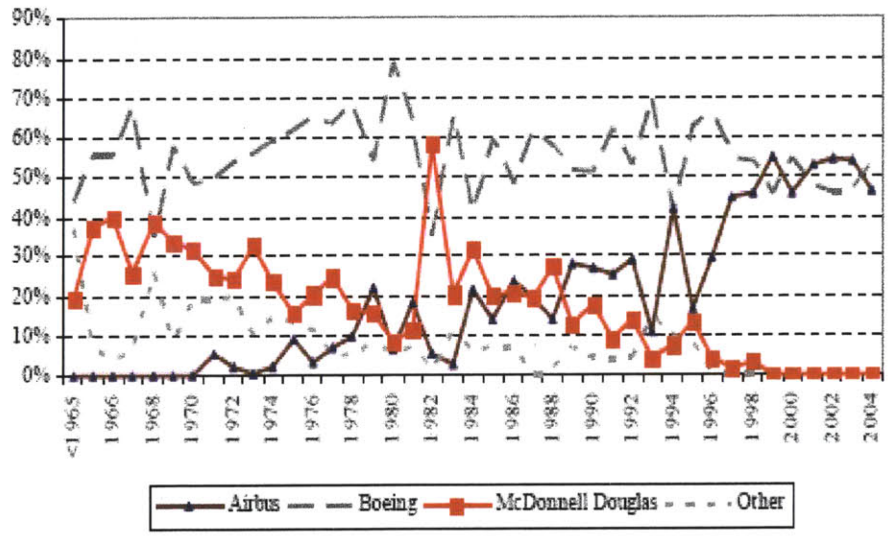
• Piston engines, turboprops, turbojets, jet engines, their subsystems and parts, spares and maintenance, for installation in aircraft systems
• Engines, their subsystems and parts, spares and maintenance, for installation in missile systems
• Propulsion devices, their subsystems and parts, spares and maintenance, for installation in space vehicles, satellites, launchers

EQUIPMENT

• Finished products, subsystems and parts, spares and maintenance, also for test and ground-training equipment, for installation in aircraft systems
• Finished products, subsystems and parts, spares and maintenance, also for test and ground-training equipment, for installation in missile systems
• Finished products, subsystems and parts, spares and maintenance, also for test and ground-training equipment, for installation in space vehicles, satellites, launchers

APPENDIX D: Large Commercial Aircraft Market Share Breakdown (From Morgan Stanley Global Aerospace and Defense Monthly Handbook September 2004)

Figure 30: Large Aircraft Order Market Share by Manufacturer, 1965-2004 YTD



Source: Jet Information, company reports.

APPENDIX E: Leading Global Defense Contractors: Defense Revenues as % of Total Revenues (From Standard & Poor's Aerospace & Defense Industry Survey October, 2004)

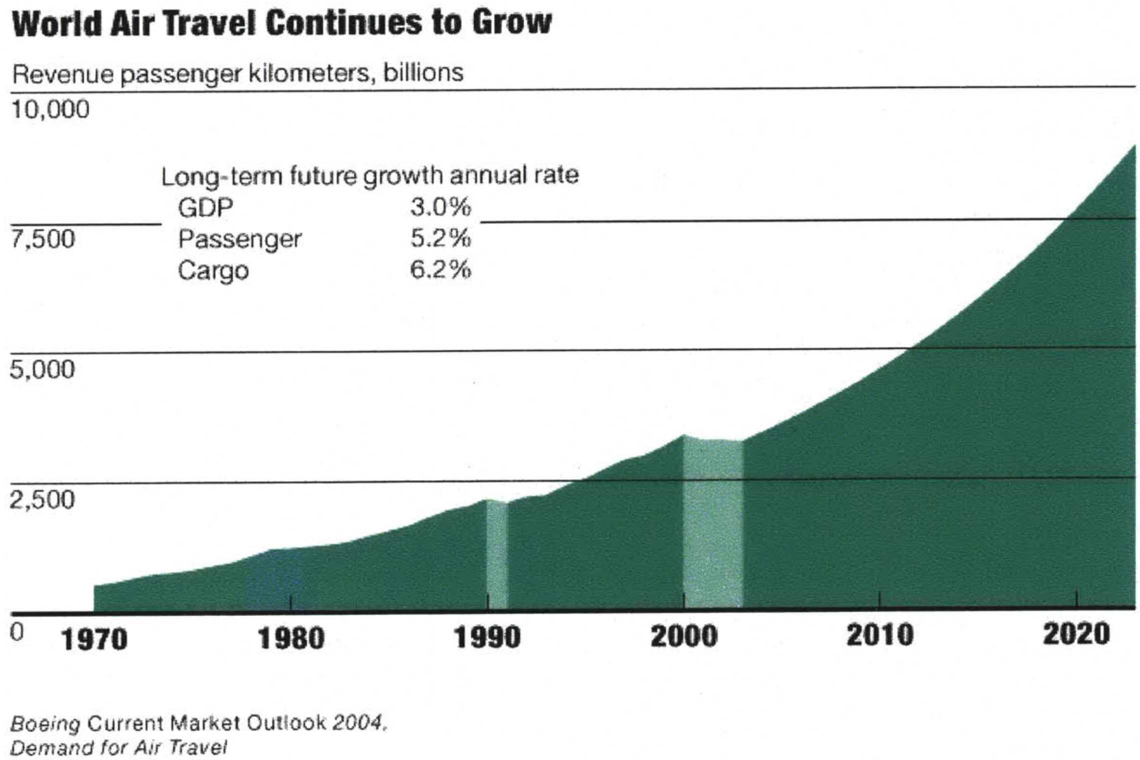
LEADING GLOBAL DEFENSE CONTRACTORS

(Ranked by defense revenues, in millions of dollars)

		2003 REVENUES (MIL. $)		
COMPANY	COUNTRY	DEFENSE	TOTAL	DEFENSE AS % OF TOTAL
1. Lockheed Martin	US	30,097	31,824	94.6
2. Boeing	US	27,360	50,500	54.2
3. Northrop Grumman	US	18,700	26,200	71.4
4. BAE Systems	UK	17,159	22,359	76.7
5. Raytheon	US	16,896	18,100	93.3
6. General Dynamics	US	12,782	16,617	76.9
7. Thales	France	8,476	13,310	63.7
8. EADS	France	8,037	37,797	21.3
9. Finmeccanica	Italy	5,896	10,857	54.3
10. United Technologies	US	5,300	31,034	17.1
11. L-3 Communications	US	4,369	5,062	86.3
12. Honeywell	US	4,200	23,100	18.2
13. Computer Sciences	US	3,818	14,800	25.8
14. Science Applications International	US	3,735	6,720	55.6
15. General Electric Co.	US	3,100	134,200	2.3
16. Halliburton	US	2,700	16,271	16.6
17. Mitsubishi Heavy Industries	Japan	2,667	22,474	11.9
18. Rolls-Royce PLC	UK	2,490	9,960	25.0
19. Alliant Techsystems	US	2,102	2,366	88.8
20. DCN	France	2,085	2,085	100.0
21. United Defense Industries	US	2,053	2,053	100.0
22. Rheinmetall Group	Germany	2,014	5,334	37.8
23. Dassault Aviation SA	France	2,009	4,144	48.5
24. SNECMA Group	France	1,846	8,037	23.0
25. ITT Industries	US	1,791	5,627	31.8
26. Smiths Industries PLC	UK	1,778	4,235	42.0
27. Textron	US	1,600	9,859	16.2
28. GKN Group	UK	1,534	7,669	20.0
29. Aviation Holding Company Sukhol	Russia	1,425	1,500	95.0
30. Saab AB	Sweden	1,380	1,725	80.0
31. Sagem	France	1,360	3,993	34.1
32. Booz Allen Hamilton	US	1,355	2,700	50.2
33. Israel Aircraft	Israel	1,308	1,868	70.0
34. Goodrich	US	1,300	4,383	29.7
35. Rockwell Collins	US	1,270	2,542	50.0
36. URS	US	1,230	3,200	38.4
37. QinetiQ	UK	1,161	1,380	84.2
38. Titan Corp.	US	1,113	1,800	61.8
39. ThyssenKrupp Werften	Germany	1,110	6,153	18.0
40. Harris Corp.	US	1,100	2,093	52.6
41. Kawasaki Heavy Industries	Japan	1,097	10,986	10.0
42. Washington Group International	US	1,048	2,501	41.9
43. DRS Technologies	US	940	1,001	93.9
44. Anteon Corp.	US	927	1,042	89.0
45. GIAT Industries	France	915	915	100.0
46. Bechtel Group	US	910	16,300	5.6
47. Singapore Technologies Engineering	Singapore	904	1,655	54.6
48. Mitsubishi Electric	Japan	899	31,338	2.9
49. VT Group	UK	858	1,225	70.0
50. Elbit Systems	Israel	848	898	94.4

Source: *Defense News.*

Appendix F: Boeing's Current Market Outlook from 2004 to 2023 for passenger and cargo traffic. (From Boeing.com)



Appendix G: Boeing's global aftermarket logistics and maintenance network

Appendix H: Boeing's U.S. aftermarket logistics and maintenance network