Developing and Managing Organizational Capabilities to Meet Emerging Customer Needs: Insights from the Joint Strike Fighter Program

By

Hee Sung Moon

B.S. Electrical Engineering (1994), Hanyang University
M.S. Electrical Engineering (1996), Hanyang University

Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Engineering and Management

at the

Massachusetts Institute of Technology

May 2006
[June 2006]

Signature of Author ____________________

Hee Sung Moon
System Design and Management Program
May 2006

Certified by ____________________

Kirkor Bozdogan
Thesis Supervisor
Principal Research Associate, Center for Technology, Policy, and Industrial Development

Certified by ____________________

Patrick Hale
Director
System Design and Management Program

Developing and Managing Organizational Capabilities to Meet Emerging Customer Needs: Insights from the Joint Strike Fighter Program

By

Hee Sung Moon

Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Engineering and Management

Abstract

This research examines the development and management of dynamic organizational capabilities. These capabilities include, among other things, how enterprises generate and integrate knowledge, understand and respond to customer needs, manage technological interdependencies, create interorganizational alliance networks, and solve complex technical problems as they design and build complex engineering systems. Enterprises must meet emerging customer needs by combining, integrating and deploying their organizational capabilities. The Joint Strike Fighter (JSF) program, which represents the largest defense acquisition program in history, provides an excellent natural experiment for an exploration of the link between the technological solutions offered to meet the emerging customer needs *and* dynamic organizational capabilities. This research focuses on the early Concept Demonstration Phase (CDP) of the JSF program, when the two competing teams led by Lockheed Martin and Boeing, respectively, offered their best possible technological solutions in response to a common set of customer requirements. This research examines these competing technological solutions in some detail in order to gain some new insights into the set of organizational capabilities the two competitor teams pulled together in order to win the big JSF contract. An expected contribution of this research, by focusing on the JSF program, is to provide significantly greater "real world" depth to the extant discussion on dynamic organizational capabilities in the context of developing such an extremely complex and technologically advanced engineering system.

Thesis Supervisor: Kirkor Bozdogan
Title: Principal Research Associate, Center for Technology, Policy, and Industrial Development

Acknowledgments

I thank my wife, who loves me; Sun Ki, for her endless support throughout our most difficult time. Dr. Kirkor Bozdogan, my thesis advisor, can not be thanked enough for his guiding, teaching and help during the semester. Pat Hale, SDM director, and Helen Timber, career development director, have helped me to take a great opportunity in this unknown land. Thanks to my sister and brother, Jung Sun and Baek Young, for their support from the heart. My father has taught how to live right and my mother has made the ultimate sacrifice to look after our family. I dedicate this thesis to my parents.

Table of Contents

List of Figures

List of Tables

Nomenclature

Abbreviations

DSP	Digital Signal Processor
PI	Proportional-Integral
M&A	Mergers and Acquisitions
PDP	Product Development Process
JSF	Joint Strike Fighter
DOD	Department of Defense
CDP	Concept Demonstration Phase
DARPA	Defense Advanced Research Projects Agency
MRF	Multi-Role Fighter
ATA	Advanced Tactical Aircraft
A-X/A/F-X	Advanced-Attack/Advanced/Fighter-Attack
BUR	Bottom Up Review
MOD	Ministry of Defense
ASTOVL	Advanced Short Take-Off Vertical Landing
SDLF	Shaft Driven Lift Fan
GCLF	Gas Coupled Lift Fan
CALF	Common Affordable Lightweight Fighter
CTOL	Conventional Take-Off and Landing
JAST	Joint Advanced Strike Technology
JDAM	Joint Direct Attack Munition
SLAM-ER	Standoff Land Attack Missile-Expanded Response
TFX	Tactical Fighter Experimental
PIE	Potential Industry Earnings
UCAV	Unmanned Combat Air Vehicles
LTV	Ling-Temco-Vought
SDD	System Development and Demonstration
OPM	Object-Process Methodology

FCLP	Field Carrier Landing Practice

Chapter 1: Introduction and Motivation

An engineering system typically consists of a set of elements, where each element has a specific function and the system as a whole is designed to perform well-defined functions or missions. The elements making up the system are interrelated by the system architecture. The system as a whole performs its functionality, which is greater than the sum of the functions performed by each of the elements making up the system.

A motor drive is an example of a system. It has many elements, such as power switching devices turning on and off a circuit, a Digital Signal Processor (DSP) control board generating new commands, and I/O interfaces connecting the DSP control board and measuring devices. A motor drive consisting of many parts fulfills a function of controlling the speed of induction motors. In order to rotate a motor at a certain speed, the operator gives a command to a motor drive and the motor starts rotating. Motor speed shows a dynamic response before reaching a steady state response. The dynamic response of a motor drive is a main concern of its designers. To obtain a better dynamic response, the designers could change Proportional-Integral (PI) controller gains or use filters, such as low pass filters and notch filters. In addition, the load changes of a motor affect a dynamic response significantly and designers have to optimize many control parameters depending on the load changes.

An enterprise is another example of a system. It consists of many organizations such as marketing, finance, operation, and engineering. It also performs a function of delivering value to its stakeholders with profits. Like a motor drive, an enterprise can have a variety of goals, such as increasing its market share, winning a contract and capturing new markets by developing new products which meets customer needs. An enterprise usually spends many years to achieve its goals, showing a dynamic response. An enterprise makes strategic decisions as part of its dynamic response to changing market conditions, those which may include changing its marketing strategy, pursuing mergers and acquisitions (M&A), and improving its product development process (PDP). These are manifestations of how an enterprise deploys its dynamic organizational capabilities to shape its near-term as well as long-term performance.

To optimize the dynamic response of a motor drive, engineers can change many control parameters, measure the resulting dynamic response with an oscilloscope which enables the real-time monitoring of the motor drive's dynamic response, and confirm optimized parameters. However, it is almost impossible to measure the real-time dynamic response behavior of an enterprise because of numerous time-varying factors changing at different rates, complex feedback loops, and the presence of many time-lags where the effects of actions taken today are distributed over different time spans in the future. Thus, it is not as easy to optimize the dynamic response behavior of an enterprise as it is in the case of a motor drive allowing the use of an oscilloscope. Thus, in this research, a retrospective approach is adopted, using historical data, to provide some insights into the how companies evolve and deploy dynamic enterprise capabilities.

1.1 Motivation

The Joint Strike Fighter (JSF) program represents a unique opportunity for studying how the two competing contractor teams led by Lockheed Martin and Boeing responded to the same set of emerging customer requirements in terms of the solutions they offered – engineering, technological, organizational – and what this tells us about the way they respectively bundled their capabilities (e.g., engineering, technology, knowledge, problem-solving, system integration, supply chain design and management) in the best way possible to win the JSF contract, by far the largest military acquisition program in history. By closely examining this experience, some lessons can be drawn to inform other enterprises on how best to develop and combine dynamic enterprise capabilities to meet emerging customer needs.

The JSF program provides a natural experiment for such an investigation. It represents an acquisition program where a fighter jet is being developed, for the first time, to meet the needs of multiple US military services – the US Air Force, the US Marine Corps, and the US Navy – as well as those of several international partners. This is radically different from the typical acquisition program in the past where a given military service is the sole customer. Thus, the JSF program provides an excellent window into developing an understanding of how the emerging and often conflicting needs of multiple customers have been or can be managed in an environment where different customers expect more and more capabilities to suit their own needs, where their requirements may change in quite different ways, and where they all expect greater affordability. How the two competing contractor teams have responded to cope with these conflicting customer demands and how they have configured their capabilities as embodied in the design solutions they proposed – particularly in view of the sheer size and complexity of such a program – would offer useful insights and lessons for other enterprises.

1.2 Key Questions

The key questions that this research hopes to address include the following:

- Emerging customer needs: What are the characteristics of emerging or new customer needs? What can we expect in terms of the evolution of customer needs? How can a company deal with continuously changing customer needs?
- Enterprise architecture: What is the most effective enterprise architecture for managing emerging customer needs as well as new challenges? How can we transform enterprise architecture embodying current capabilities and resources to meet evolving customer needs?
- Strategies: Doing everything in house (Boeing) versus strategic alliance (Lockheed-Martin)? Why did the two competing companies choose different strategies and how did these strategies affect their concept demonstration aircraft? What were the major factors affecting their strategies?
- Technology: Simple and proven conventional technology (Boeing) versus complex new technology (Lockheed-Martin)? What are the differences in terms of the architecture of Short-Takeoff/Vertical Landing (STOVL) Systems? What factors affected the respective system architecture decisions?

1.3 Research Methodology

Research will involve one focused case study, the JSF program. Even though this is a defense project, most of the information is in the public-domain and is de-classified. Detailed information about both the proposed prototypes, design specifications, etc.

offered by both companies can be obtained from the www.jsf.mil website. There is also a wealth of documentary material available online that can be used.

In addition, a few of the author's SDM classmates who have been directly involved with the JSF program personally. They were contacted about this research and they expressed a willingness to help as much as they could. A further source that proved quite useful was the PBS program NOVA, which profiled the JSF development process in great detail.

Chapter 2: The Joint Strike Fighter Program

The Joint Strike Fighter was the first fighter which was being developed to meet the needs of three branches of the US military and international partners. The US Air Force, the US Navy and the US Marine Corps are the major end-users. Also, many countries, such as the U.K., Denmark, Netherlands, Norway, Canada and Italy, are participating in the JSF project as international partners. The involvement of multiple end-users and international partners has made the JSF program unique in many ways.

Technology was the main challenge of the JSF program because the requirements from the three military services were so demanding and often conflicting. However, technology was not an only obstacle. The tension between the three military branches and the US Department of Defense (DOD) made this program even more complicated.

The winner of this acquisition program would achieve an enviable monopoly in the fighter market for many decades by supplying the last manned fighter. Lockheed Martin and Boeing, two main competitors on the JSF program, deployed their capabilities in the best way possible during the Concept Demonstration Phase (CDP) in order to win the contract. Both companies tried hard to develop and offer their unique architectures, the X-32 and the X-35, knowing that the loser in this competition would be in danger of being eliminated in the fighter aircraft business. Given such high stakes, a focused investigation of the CDP phase in the JSF program offered an unparalleled opportunity to learn more about the development and bundling of dynamic enterprise capabilities to meet emerging and often conflicting customer needs and requirements.

Dynamic enterprise capabilities or dynamic organizational capabilities have been defined as the ability of organizations "to integrate, build and reconfigure internal and external competences to address rapidly changing environments" [1]. Dynamic capabilities are further defined to "consist of specific strategic and organizational processes like product development, alliancing, and strategic decision making that create value for firms within dynamic markets by manipulating resources into new value-creating strategies" [2]. They are further defined as "stable and learned patterns of collective activity through which the organization systematically generates and modifies its operating routines in pursuit of improved effectiveness [3]. More recent contributions to the literature have emphasized the links among problem-solving, decision-making and aggregate outcomes, as well as the link between the microfoundations of capability and firm-level profitability performance [4].

2.1 The History of the Joint Strike Fighter Program

The JSF program has evolved out of several fighter acquisition programs from the 1980s to early 1990s. Many fighter acquisition programs have been undertaken by the US military services and the Defense Advanced Research Projects Agency (DARPA). Among these projects, some projects were terminated as the result of the Bottom-Up Review of the US DOD in 1993 and other projects were merged into what became the JSF program.

The Multi-Role Fighter (MRF) program was initiated by the US Air Force in 1991 with the expectation that it would replace a large number of F-16s, with a unit flyaway cost in the range of $35 to $50 million and similar size. The US Navy had launched its Advanced Tactical Aircraft (ATA) program in 1983. The goal of the ATA program was to replace the Grumman A-6 with a long range, low observable medium-attack aircraft. The McDonnell-Douglas and General Dynamics team was selected to develop the ATA, designated the A-12 Avenger II. In 1991, the US Navy started the Advanced-Attack/Advanced/Fighter-Attack (A-X/A/F-X) program to develop a high-end carrier-based multi-mission aircraft as a replacement for the A-6 due to the cancellation of the ATA program. The A-X fighter featured day/night/all-weather capability, low observables, long range, two engines, two-crew and advanced avionics. The U.S Air Force also participated in the program, hoping that the new fighter would replace the F-111, the F-15E and the F-117A. However, in September 1993, the Bottom-Up Review (BUR) of the US DOD determined the termination of the MRF and the A-X/A/F-X programs.

In 1983, the US DOD and the U.K. Ministry of Defense (MOD) started the Advanced Short Take-Off Vertical Landing (ASTOVL) Program with the aim of supporting the development of a supersonic STOVL strike fighter. Four concepts were assessed and none of them were found suitable for the lift system. However, the Shaft Driven Lift Fan (SDLF) and the Gas Coupled Lift Fan (GCLF), two evolutions of the above four concepts, had the potential for the real system. After 1991, when the program expired, the fighter companies continued to design a STOVL strike fighter for the US Marine Corps. A further study showed that the replacement of the F-16 could be developed by replacing the STOVL propulsive life system with a fuel tank.

In early 1992, the Common Affordable Lightweight Fighter (CALF) program was launched, aiming to demonstrate an affordable STOVL fighter for the US Marine Corps and a Conventional Take-Off and Landing (CTOL) fighter for the US Air Force. In March 1993, Lockheed and McDonnell-Douglas signed contracts to work on risk reduction in connection with a shaft driven lift fan and a gas driven lift fan, respectively. In March 1994, Boeing was awarded a contract for risk reduction in a direct lift concept. In 1994, Northrop Grumman participated in the CALF program. However, Northrop Grumman and McDonnell-Douglas worked as a team when the CALF program was merged with the Joint Advanced Strike Technology (JAST) program in 1994

In February 1993, the US DOD began Bottom Up Review (BUR) to evaluate five tactical aircraft development programs, the F-22, the F/A-18E/F, the A-X/A/F-X, the ASTOVL and the MRF, because the US DOD could not afford to continue all of these five programs. The US DOD decided to continue the F-22 and the F/A-18E/F and to terminate the A-X/A/F-X and the MRF, and to begin the JAST program as a result of the BUR in September 1993. The JAST program aimed to mature several technologies which could be used for the future aircraft that would replace the A-6, F-14, F-16 and F-111.

In October 1994, Congress merged the ASTOVL/CALF program into the JAST program because of considerable overlap between the two. The three teams participated in the JAST program. Boeing proposed a direct lift system used for the Harrier as STOVL propulsion system. Lockheed-Martin incorporated the shaft-driven lift fan system. McDonnell-Douglas, teaming with Northrop Grumman and BAE Systems, proposed a system having separate lift engines for the STOVL system with a modified aircraft configuration of the YF-23. The US Marine Corps did not favor the proposal because of the higher expected logistics and life cycle cost caused by the two separate engines.

On 16 November 1996, McDonnell-Douglas was eliminated from the competition. McDonnell-Douglas was then merged into Boeing. Northrop Grumman and BAE Systems changed their teaming arrangement and joined the Lockheed Martin team. In June 1996 the name of the JAST program was changed into the Joint Strike Fighter (JSF) program.

The US DOD chose to move the JSF design study to the CDP and funded two development teams to build two experimental fighters, respectively. In November 1996, Boeing and Lockheed Martin (in a teaming arrangement with Northrop Grumman and BAE Systems) were each awarded contracts to produce two concept demonstrators and test them as the CDP prime contractors. On 18 September 2000, the X-32A CTOL demonstrator the experimental fighter developed by Boeing performed a maiden flight. On 24 October 2000, a maiden flight of X-35A CTOL demonstrator of Lockheed Martin team was executed. The Lockheed Martin X-35 won the JSF competition on 26 October 2001.

2.2 The JSF Enterprise

When we design a new product, we should define the system boundary. With the system boundary, we are able to consider all design factors, such as customer needs, the functions the system will deliver, forms which enable the system to meet customer needs, decomposition of the system, interfaces among subsystems, marketing position, logistics, operation, testing and retirement. More importantly, we can more fully understand the product we want to develop with a clear understanding of the system boundary.

A major objective of this thesis is to understand how dynamic enterprise capabilities are developed and bundled to provide engineering solutions to meet emerging customer needs, focusing on the JSF competition phase. Before starting the study of this topic, I will clarify my study scope by defining the JSF National Enterprise with established definitions.

2.2.1 Definitions and Terms

According to the Black's Law Dictionary, an enterprise is defined as "[o]ne or more persons or organizations that have related activities, unified operation or common control, and a common business purpose." However, the complexity of aerospace industry defies the application of such a simplified definition, particularly in view of the complexity arising from the presence of multi-stakeholders and the dynamic interactions among them.

In addressing the definitional issues related to aerospace enterprises, the Lean Aerospace Initiative (LAI) of Massachusetts Institute of Technology (MIT) has identified three levels of enterprises, program enterprises, multi-program enterprises, and national or international enterprises.

The program enterprise is "a collection of activities that produce a particular product, system, or service that is delivered to the customer and that generates revenue" [10] and it is the basic unit of aerospace business activities. A program enterprise is an enterprise that carries on an acquisition program. Programs involve accountability for cost, schedule and performance of a product, system or service. The F-22 raptor, F/A-18E/F, F-15E, F-16, the Joint Direct Attack Munition (JDAM), the Standoff Land Attack

Missile-Expanded Response (SLAM-ER) are examples of acquisition programs. These examples show that programs vary widely in budget and in schedule.

Multi-program enterprises are defined as "business organizations and government agencies responsible for executing multiple programs." Boeing, Airbus and Lockheed Martin are examples of multi-program enterprises. Multi-program enterprises can be broken down into multi-program business enterprises and multi-program government enterprises.

The collection of all entities contributing to the development and use of aerospace products, including systems and services, can be defined as a national or an international enterprise. This level of enterprise can be characterized as having many stakeholders, such as customers, end-users, manufacturers, and related entities.

2.2.2 The definition of the JSF International Enterprise

In 2006, the JSF program is run by the Joint Strike Fighter Program Office and Lockheed Martin participates as the prime contractor. BAE Systems and Northrop Grumman are members of the Lockheed Martin team as partners. In addition to the US three services, the U.K. government and other international participants are also funding the program. A number of domestic and international suppliers and related entities are involved in the project as stakeholders. Considering the current situation, we can define the JSF enterprise as international aerospace enterprise.

However, during the 1996-2001 CDP phase of the program, the JSF enterprise could be defined differently. To maximize the results of the JSF program, the US DOD awarded the two CDP contracts to the Boeing and Lockheed Martin teams. It was the first attempt to force two experimental fighters to compete against each other before selecting the winner. The two teams were developing two concept demonstrators designated the X-32 and the X-35. Two separate and competing programs were running during the CDP, which means that there were two program enterprises constituting the larger JSF enterprise. Boeing led the X-32 program enterprise to win the bid by developing the X-32 concept demonstrator, teamed with the merged McDonnell Douglas. The X-35 was developed by Lockheed Martin, in a teaming arrangement with Northrop Grumman and BAE Systems. Rolls Royce supplied the very important a lift fan subsystem which was connected to engine with a shaft and driven by an engine. The three branches of US military, the US Air force, the US Navy and the US Marine Corps, identified their requirements as end-users of each joint strike fighter variant by defining their respective needs to replace their aging fighters. The US DOD played a unique role as the customer of the two competing program enterprises and as the main decision maker. It also funded the two experimental demonstrator programs, the X-32 and the X-35. Both program enterprises selected derivatives of the Pratt & Whitney (P&W) F119 engine to power their concept demonstrators. P&W participated in the program as a primary supplier of the engine for both concept demonstrators. In addition to the key domestic players, the U.K. and other international partners also participated in the program, but their roles were limited and rarely affected the decision-making process. During the CDP, a number of suppliers joined the two program enterprises, but their importance was less valued than would be expected during the production phase sometime in the future, because the two program enterprises only developed the two concept demonstrators, respectively.

Considering the above facts, the JSF enterprise during the CDP could be defined basically as a national enterprise consisting of the two program enterprises devoted to the development of the two concept demonstrators, the US DOD (customer), the three US services (end-users), and P&W. Figure 2.1 shows the structure of the JSF international enterprise during the CDP.

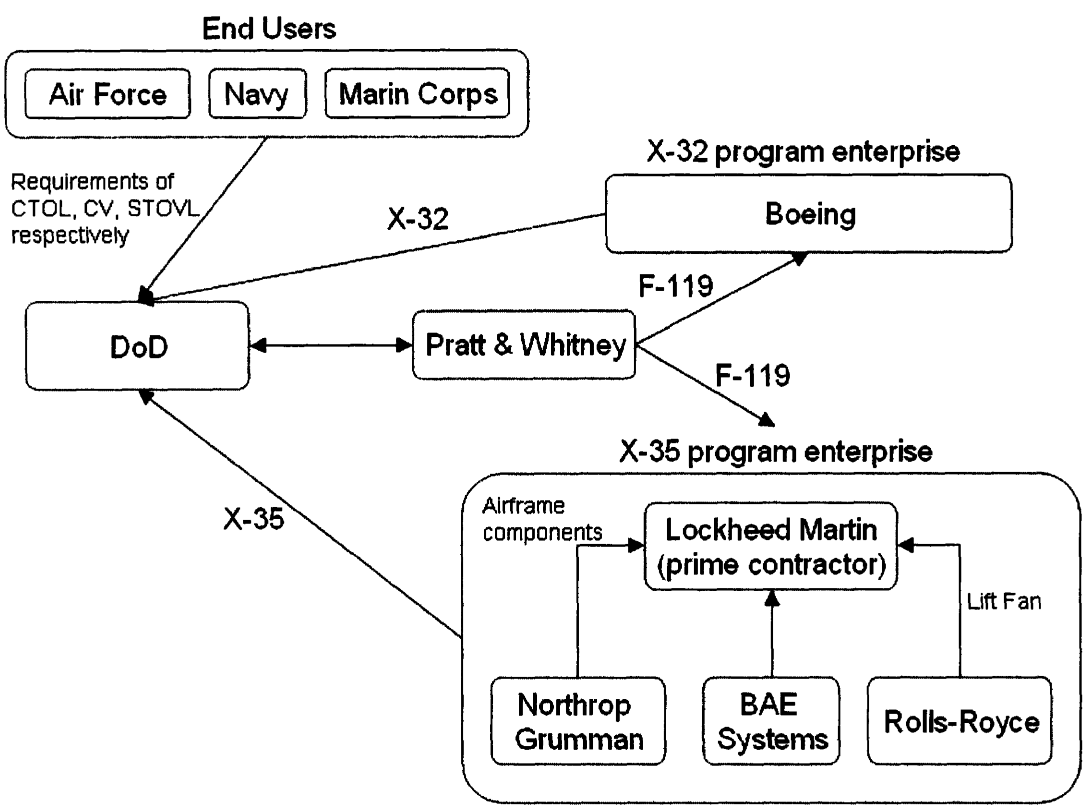

Figure 2.1 – A Depiction of the JSF Enterprise during the CDP

2.2.3 Major Stakeholders Analysis

As shown in Figure 2.1, the JSF Enterprise was comprised of five major stakeholders. This section concentrates on an analysis of these five stakeholders.

The US DOD played multiple roles in this context. First, the US DOD was the main customer whom the X-32 and X-35 program enterprises wanted to satisfy with their concept demonstrators. Unlike usual commercial customers, this customer identified its specific needs and asked manufactures to meet these needs. This customer was understood to place greater value on performance rather than on cost. In addition, the US DOD funded the development of the two concept demonstrators and controlled the schedule and budget. The most important role of the US DOD was as a decision maker determining who would, in the end, produce the last manned fighter.

Boeing had not developed any fighter aircraft by itself since World War II. It has basically served the commercial airplane market with its 7XX series. It needed an expert group having experience of developing fighters. The Phantom Works organization within Boeing led the development of the X-32. It was the major decision-maker of the X-32 program enterprise. It was originally founded by McDonnell-Douglas and it focused on the development of advanced military products and technology. The Phantom Works has been the main research and development unit of The Boeing Company since McDonnell Douglas was merged into Boeing in 1996.

The Skunk Works, the unofficial name given to Lockheed Martin's Advanced Development Programs unit, led the development of the X-35 and the production of three concept demonstrators. Over many decades, it has been the legendary organization responsible for a number of well-known aircraft, such as the U-2, the SR-71, and the F-

117. Its business relationship with the US DOD over the past half century has enabled Lockheed Martin to understand what really its customer, the US DOD wants. Northrop Grumman and BAE Systems are the two additional major companies with strong capabilities in defense aerospace. Northrop has developed the F/A-18C/D and many radar systems and BAE Systems has developed and produced the Harrier, the only STOVL fighter in the world.

Pratt & Whitney was awarded a contract to develop the engine (F119) of the F/A-22 Raptor. It has developed many engines for commercial and military aircraft. The F119 was considered a strong candidate as the engine to power the JSF. During the CDP, P&W supplied its engine to the two program enterprises. Separately, General Electric was also awarded a contact as an alternate engine supplier with the YF120, but neither of the two program enterprises chose the YF120 to power the X planes.

2.3 Goals of the JSF Program

A diverse set of stakeholders participated in the JSF national enterprise during the CDP. The purpose of the JSF program was to develop a new family of strike fighters meeting the needs of the three branches of the US military. However, the various stakeholders had their own respective goals they wanted to achieve through the JSF program. Sometimes these goals were in conflict with those of other stakeholders. More importantly, each stakeholder's goals affected the two concept demonstrators in direct and indirect ways. Therefore, understanding each stakeholder's goal will help us to understand the JSF program during the CDP.

2.3.1 Goals of the US Department of Defense

Developing a new fighter needs a lot of financial resources and the total acquisition cost of a new fighter has steadily increased over the decades. Meanwhile, the US DOD has obviously been quite concerned about the shrinking defense budgets in recent years, particularly since the fall of the Berlin Wall in 1989. This trend is expected to continue. Many old fighters are reaching the end of their design life cycle and are supposed to be replaced with new fighters. Considering the above situation, it could be concluded that affordability has, in recent years, been the first priority of the US DOD. It focuses on the reducing cost of developing, procuring and owning the JSF to maintain an adequate number of fighters in the US military inventory. To achieve this goal, the US DOD has adopted inter-service commonality, in the case of the JSF, to reduce cost, where 70%-80% of the total acquisition cost consists of systems common to all three variants of the aircraft. In addition, total unit cost of the aircraft is expected to be affordable through the scale economies resulting from producing well over 2000 fighters. Based on such an affordability calculus, three more goals are expected to be achieved throughout the JSF program, those of survivability, lethality, and supportability. Survivability implies the reduction of the aircraft's radio frequency/infrared signature and on-board countermeasures to survive in the future battlefield. Lethality can be fulfilled by integration of on- and off-board sensors for current and future precision weapons. Supportability means a reduction of lifecycle logistics and sustainment costs and an increase in the sortie rate to provide more air combat power.

2.3.2 Goals of the Three End-Users

The three services of the US military have different responsibilities in the battlefield. To discharge their different responsibilities, each of the three branches needs a fighter capable of operating in quite different operating contexts. For example, a Navy fighter can take off from a carrier and the Marine Corps needs a fighter that can be operated without a runaway.

The US Air Force wanted a conventional takeoff and landing aircraft (CTOL) variant. It would have a larger internal weapons bay and greater internal fuel capacity with stealth capability. The CTOL variant for the US Air Force would complement the F/A-22A Raptor and replace the F-16 Fighting Falcon and the O/A-10A Thunderbolt.

Service	U.S. Air Force	U.S. Marine Corps	U.S. Navy
Variants	Conventional Takeoff and Landing (CTOL)	Short Takeoff and Vertical Landing (STOVL)	Carrier-based (CV)
Unit Cost FY94$	$31M	$30~35M	$31~38M
Propulsion	Baseline: Pratt & Whitney F119-PW-100 derivative from F-22 Raptor		
	Alternate Engine: General Electric F120 core		
Payload	4,000 lbs	4,000 lbs	4,000 lbs
Speed	supersonic		
Range (nmi)	450~600	450~550	600
Inventory Objectives	2,036 aircraft	642 aircraft	300 aircraft

Table 2.1 –The JSF Operational/Performance and Cost Requirements

The US Marine Corps wanted a short takeoff and vertical landing (STOVL) variant without any loss of aircraft performance. It would replace the AV-8B Harrier and the F/A-18D Hornet.

The US Navy wanted a carrier takeoff and landing (CV) aircraft featuring increased internal fuel capacity for greater operating range and larger wing tail surfaces for take-off and landing on a carrier. It would complement the F/A-18E/F Super Hornet. Table 2.1 shows the various requirements of the JSF program.

2.3.3 Goals of the Two Program Enterprises

Obviously, the goal of each of the two program enterprises was to win the big contract. A winner would produce the JSF for as long as four decades and could supply possibly more than 4000 aircraft to the three US services and participating international allies, which means that a winner could monopolize the manned fighter market for along time to come since the JSF would be the last manned fighter. However, Boeing and Lockheed Martin approached the challenge of winning the big contract with seemingly different goals in mind.

Boeing was fiercely competing against Airbus for dominance in the commercial airplane market. During much of the past half century, Boeing had literarily monopolized the market, but it was losing its market share due to the entry and successful performance of Airbus in the commercial airplane market. As a way of overcoming this difficulty, Boeing chose to expand its product scope and entered the military fighter market. It concluded that the entry barriers into the military fighter market could be overcome by the technology it had accumulated in the commercial airplane market. When a new entrant comes into an existing market, usually incumbents will react by reducing the price of their products. However, Boeing judged that it could cope well with the low price reaction strategy of the incumbents because cost reduction had been one of its demonstrated specialties in the commercial airplane market. So, Boeing tried to show its advantages in achieving cost reduction through the X-32, and this goal affected Boeing's choice of the system architecture for its X-32 concept demonstrator.

On the other hand, Lockheed Martin was a well-established incumbent in the military fighter market. It had done business with a unique customer, the US DOD, and the three services of the US military for a long time. Drawing upon its unique understanding of the customer needs and requirements, Lockheed Martin tried to reflect its long experience in the development of the X-35 concept demonstrator.

2.4 System Context

The JSF is included in the whole product system to be used in a battlefield. For instance, a mission system links the JSF to a well-defined strategic goal as a supporting tool to achieve that goal. For example, to attack the enemy, the JSF needs weapon systems including air-to-air and air-to-land missiles. Also, in order to maintain its operational effectiveness, the JSF needs skillful mechanics and maintenance processes. Figure 2.2 shows the overall system context of the Joint Strike Fighter.

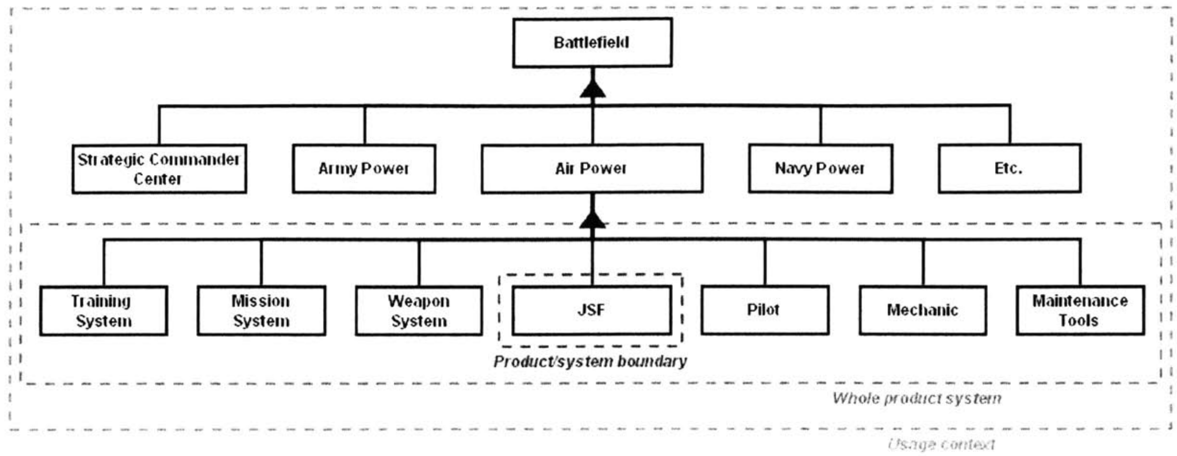

Figure 2.2 – A Context of the Joint Strike Fighter

2.5 Complexity

As technology is being developed and continuously enhanced, the product adopting the latest technology becomes more complex. Most current types of fighter aircraft are equipped with weapons systems, an electro-optical targeting system and a fuel tank. Typically, in the past, various external and structural arrangements were determined first and then other systems were installed in a limited space. In contrast, the JSF is equipped with everything internally to support low observable capacity. The JSF also is designed to ensure unprecedented maintainability and to be manufactured rapidly at low cost. In addition, the JSF team first determined system definition and arrangement, followed by the structural arrangement. These different design and development approaches made the JSF more complex.

In addition to aircraft's technological complexity, the participation of the three end-users added to the complexity of the JSF program. The challenge of meeting the requirements of the three end-users, as well as the affordability and other goals of the US DOD, resulted in unprecedented technological as well organizational complexity for the JSF program. Such increased complexity had to be viewed in the historical context of the many past failures in developing ,military aircraft to meet the needs of several services, like the Tactical Fighter Experimental (TFX) program for the US Navy and the US Air Force in 1960s.

In the very beginning, developing the two experimental fighters had already made the JSF program quite complex. The DOD had to manage two programs at the same time and had to evaluate not only the X-32 and the X-35 but also to compare the two experimental fighters within the strategic and operational context of many considerations.

Chapter 3: Enterprise Capability Analysis

The two JSF program enterprises had developed their concept demonstrators during the CDP. They had worked hard to combine and deploy their resources and capabilities in the best possible way, knowing that winning or losing the JSF development and production contract would decide their fate in a new century as a manned fighter aircraft manufacturer. They had the same requirements they had to fulfill, but their solutions were totally different. What drove them to offer different technological solutions, as well as the supporting organizational architectures, to fulfill the very same needs of the customer? That is, what major lessons or insights can be learned about their respective dynamic organizational capabilities by studying at close-range the technological solutions they offered, namely the X-32 and the X-35?

An enterprise needs a combination of dynamic capabilities to survive and succeed in an evolving market and industry environment, to increase its market share, and ultimately to maximize its profit. There are many enterprise capabilities such as technology, product development, organization, marketing, strategy, operation, manufacturing, etc. Nowadays, all enterprises in the world are trying to develop their capabilities. However, having all the capabilities in place by itself does not guarantee the success of a company. All capabilities must be properly bundled, combined, integrated and interwoven in order to make the best products the customers need and want, including highly complex engineering systems and technology-intensive services.

A certain product is the reflection of all capabilities of a given company. By studying a product, we can capture what capabilities the company has and how these capabilities have been integrated to design, develop and build that product. In this chapter, an attempt is made to develop an improved understanding of the dynamic organizational capabilities of the two program enterprises.

3.1 Industry Analysis

Before studying the enterprise capabilities of the two program enterprises, we need to analyze the aerospace industry, especially the manned fighter industry. Every enterprise is embedded in, and operates within, a particular industry context. A discussion of the industry context sheds light on the common characteristics of the participants of that industry and provides some understanding of their differences as well.

The first step is to provide a definition of the industry. Usually, an industry consists of five forces, potential entrants, suppliers, buyers, substitutes and industry competitors. By identifying the important buyers and suppliers, we can assess the prevalence and extent of buyer or supplier power. By identifying the industry's structure, we can assess the state of the competition. By identifying the boundaries of the industry, we can measure the entry barriers. By confirming the existence of the substitutes for the main product, we can ascertain the nature of the competition, for example via the offering differentiated products versus competition based on cost reduction in producing a mature product. These insights may then offer some clues helpful in forecasting the industry's possible future evolution [6], [7].

Porter's "Five Forces" industry analysis framework is used as an initial guiding framework. More particularly, the "Potential Industry Earnings (PIE) and Four Slices" industry analytical framework developed more recently is deployed for the analysis at hand [7], [13]. In the context of this analysis, PIE is used to measure "[t]he greatest value the incumbents as a group could hope to capture, defining the total value added by the value chain: the value to the final buyers of the goods or services produced less the value of the resources that are used to produce them. We call this value, Potential Industry Earnings (PIE), the possible maximum value an industry can capture. Few substitutes at higher prices, more complements at lower prices, population growth and income growth could add more value to PIE by increasing the demand of the product. Cost reductions by suppliers and incumbents could also add more value to PIE by cutting the opportunity cost of resources used to produce the product. The difference between the two frameworks of industry analysis is that Porter's "Five Forces" model focuses on whether incumbents will be able to capture the value they create, while the "PIE and four slices" framework distinguishes value creation from value capture and identifies broader issues of value creation beyond substitutes.

However, in real life, it is impossible for an industry to capture all of this value. Usually, suppliers can capture some portion of PIE by providing subsystems and materials at a higher price than the opportunity cost of the resources used to produce them. Buyers can capture some PIE by paying a price less than the maximum they are willing to pay. Competition among incumbents can decrease PIE due to a price war, which is a usual result of fierce competition. Finally, new entrants can capture some PIE. We can capture the current snapshot of an industry by applying PIE and four slices framework of industry analysis.

Most incumbents in the manned fighter aircraft industry have operated since World War II, and have manufactured many types of fighters from the P-51 Mustang to the F/A-22 Raptor. They have accumulated a lot of experience-based knowledge and accumulated learning from the many fighter development programs in which they have been engaged, where the lessons they have learned can be used to drive down the development and production costs, as the "learning effects" literature emphasizes. The PIE of the manned fighter aircraft industry may have increased in certain instances due to these learning effects. The three US military services have installed multiple weapons systems, such as JDAM, GBU-24 and ARAM, and various supporting systems, including training systems, maintenance systems and logistic systems in order to keep manned fighters operating in a battlefield. These installed complementary systems may have led to PIE increases in the manned fighter aircraft industry.

However, there are many factors affecting PIE negatively. First, the emergence of the Unmanned Combat Air Vehicles (UCAV) is the biggest threat the manned fighter industry is facing. Whenever operating manned fighters in a battlefield, the US military services have to bear the burden of human pilot loss. The problem of POW costs the US a lot politically and psychologically, as we can see from the result of the Vietnam War. UCAV can solve these problems and have other advantages. UCAV do not need human pilots, which means they do not need human sustaining systems consisting of a significant portion of the cost of manned fighter systems. UCAV can be produced in smaller sizes and can be offered at lower prices to the US DOD, in part due to the absence of human sustaining systems. UCAV can conduct rapid maneuvers which can cause a human pilot unconsciousness. These rapid maneuvers can provide a number of advantages to the US military services. Most importantly, a shrinking budget has most likely helped to reduce PIE in the aggregate for the industry as whole, due to the cancellation of a number of acquisition programs and a sharp reduction in purchase quantities of acquisition systems, such as in the case of the F/A-22. Figure 3.1 shows the PIE in the manned fighter aircraft industry.

Entry barriers in the manned fighter aircraft industry are quite high in terms of technology and technical know-how. A manned fighter is the arguably the most complex and technologically-sophisticated product that can be produced by any industry, requiring

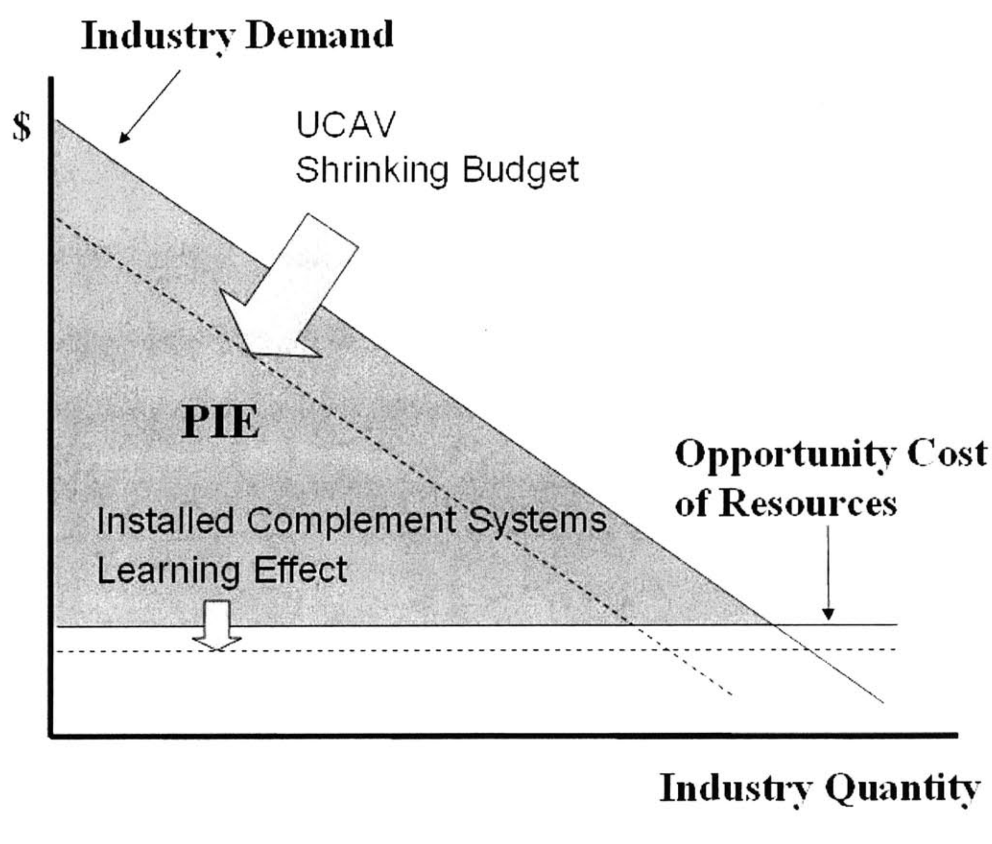

Figure 3.1 – Potential Industry Earnings of the Manned Fighter Aircraft Industry

a command of a wide array of technologies, production processes, organizational structures, and supplier networks. As already discussed above, all players in this industry have operated over a long period time and have developed unique resources and capabilities that are difficult to imitate. For these reasons, the entry barriers are very high for the manned fighter aircraft industry.

Suppliers in this industry are also very specialized due to the high technology content of their products and services, which must be designed and produced to extremely exacting requirements and quality specifications. Unlike the case in many industries in the commercial sector, it is also very difficult to switch suppliers due to extremely high re-qualification costs and asset-specificity involving high investment costs that are not transferable. Today, the manned fighter aircraft industry faces increasing competition due to the shrinking of market demand stemming from the sharp reductions in the defense acquisition budget.

As already discussed in the previous chapter, the main customer in this industry, the US DOD, shapes the face of the industry by virtue of its immense buying power. The US DOD is the only buyer that can plan and manage new fighter development programs after the Cold War. Some fighters, like the F-20, have been developed by an individual enterprise, Northrop, regardless of any involvement or commitment by the US DOD. However, none of them have survived. The sheer power and institutional weight of the buyer in this industry is much stronger than any buyers in any other industry.

3.2 R&D Experience of the Major Participants

The most important enterprise capability shaping the competition in this industry has been the previous technological innovation, as well as the design, development and production experience of the incumbent enterprises, including their ability to design and manage their supplier networks. The technical and performance requirements associated with military aircraft are so demanding and tough that it truly represents the most complex system in existence, consisting of multi-layer subsystems and complicated connections among the various subsystems. It is hard for an enterprise to develop the abilities to design and build such a complex system. These abilities have been accumulated through the past experience of developing military aircraft. To develop this theme further, provided below is a discussion of the R&D experiences of the major current and past participants in the industry, including Lockheed Martin, Northrop Grumman, Boeing, and McDonnell-Douglas.

The R&D experience of the major participants from 1970s to the 1990s can be seen in Figure 3.2. Many agile supersonic jets have been developed during this period, such as those including the F-16 Fighting Falcon, the F/A-18 Hornet, and the F-20 Tigershark. Lockheed Martin, in particular, has pioneered during this era, developing the first stealth fighter, the F-117 Nighthawk. Northrop Grumman has developed the first stealth bomber, the B-2 Spirit, using wing body architecture.

The Boeing X-32 concept demonstration aircraft was directly affected by the R&D experience of Boeing and McDonnell-Douglas in this era. Boeing has mainly developed its B-7XX series commercial airplanes. Before the prototype YF-22, Boeing did not have an experience comparable of other incumbents in developing a fixed wing fighter. Even the YF-22 was not developed solely by Boeing. It has participated in the development of the YF-22 as a team member with Lockheed Martin. As shown in Figure 3.3, Boeing has been engaged in fewer fighter aircraft development projects than other major participants during the period 1977 to 1996. This fact serves to demonstrate that Boeing did not possess the well-honed dynamic capabilities to develop a fighter by itself. This lack of the experience could give an answer to the question as to why Boeing decided to merge with McDonnell-Douglas. It wanted to compensate its weakness with the R&D experience and related military aircraft development and production capabilities of McDonnell-Douglas.

RAND MR939-6.1

		1975	1980	1985	1990
Boeing	(M)	AGM-86 (ALCM)		A-6F YF-22*	F-22*
	(C)	757 767			777
GD	(M)	F-16 CCV F-16	AFTI F-16 F-16XL	A-12* YF-22*	NF-16D VISTA
		BGM-109A/B, G (SLCM/GLSM)			F-22*
Grumman	(M)	EF-111	X-29A		E-8 JSTARS
Lockheed	(M)	XST	F-117 TR-1	YF-22*	F-22*
McDonnell	(M)	F/A-18*	C-17	A-12*	F/A-18E/F
		AV-8B		F-15S/MTD	
			T-45	F-18 HARV YF-23*	
	(C)	MD-80		MD-11	MD-90
Northrop	(M)	F/A-18*	F-20	B-2 AGM-137 (TSSAM)	
			Tacit Blue	YF-23*	
Republic	(M)		T-46		
Rockwell	(M)	HiMat	B-1B	X-31*	

*Collaborative program with other contractor(s).

SOURCE: RAND database.

(M) = military; (C) = commercial, bold = fighters, bombers, and related programs; underlined = missiles; normal = X-planes, commercial aircraft, and miscellaneous.

NOTE: Aircraft placement approximates beginning of full-scale development.

Figure 3.2 – Selected Major Fixed-Wing and Cruise Missile Programs, 1975-1990
Source: RAND MR939-6.1

Prior to the merger of Boeing and McDonnell-Douglas, McDonnell-Douglas was one of main providers of fighter aircraft. McDonnell-Douglas has, in fact, developed many successful fighters including the F/A-18 and the AV-8B Harrier II, and has produced the F-15 Eagle. The AV-8B is the only fighter having STOVL capabilities among current fighters. It also has developed experimental planes, modifying the F-15 and the F/A-18. In addition, it has proposed the prototype YF-23, with Northrop, which is reminiscent of the F-15. McDonnell-Douglas had strong experience in developing military fighters and, judging from the perspective of history, represented a right solution to help buttress possible weaknesses in Boeing's capabilities in the fighter aircraft area.

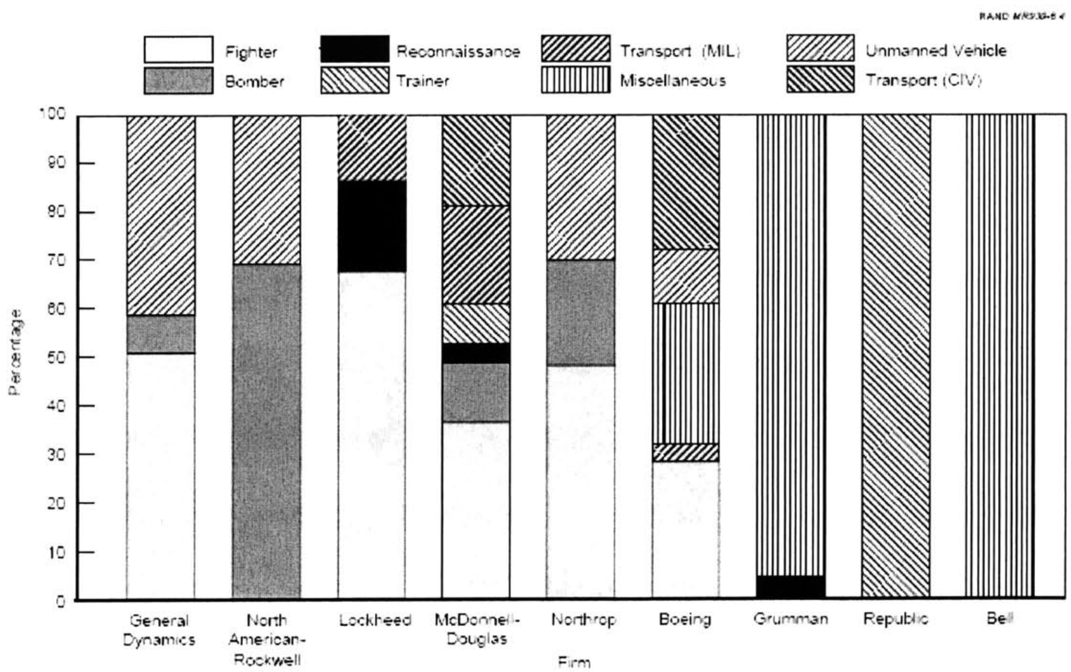

Figure 3.3 – Breakdown by Firm of Share of Experience by Types of Aircraft Relative to Firm's Total Experience from 1977 to 1996
Source: RAND MR939-6.4

Lockheed Martin developed the F-117, proposed the YF-22 working together with Boeing, and was awarded the F-22 contract. Both the F-117 and the F-22 Raptor have full stealth capabilities. Before the era in question, the Skunk Works operations of Lockheed had developed a series of highly successful secret and challenging aircraft, such as the U-2 and the SR-71 Blackbird. Figure 3.3 shows Lockheed Martin's experience in developing fighter aircraft.

Northrop Grumman, one of team members of the Lockheed Martin team on the Joint Strike Fighter program, teamed up with McDonnell-Douglas to develop the F/A-18 Hornet. Before the JSF program, both companies (McDonnell-Douglas and Northrop) had worked together. Northrop had unique experience in developing the F-20 without funding through the US DOD acquisition program. Northrop had cancelled the $1.2 billion project due to no buyers. The F-20 project proved that an independently developed fighter by a company could not survive in the military fighter aircraft market. Northrop also developed the B-2 bomber having full stealth capabilities and long range of operation. Northrop has developed the YF-23 with McDonnell Douglas.

The US Marine Corps has required STOVL capabilities to replace the AV-8B Harrier II. Boeing had researched a direct lift system since the CALF program. It subsequently merged with McDonnell-Douglas, which had developed the AV-8B, using a direct lift system. The X-32 program enterprise had sufficiently well-developed technology to develop the direct lift system.

On the other hand, Lockheed Martin and Northrop did not have the experience in developing a STOVL fighter. However, BAE Systems, another team member, had developed the Harrier and the Sea Harrier, the first STOVL fighter. BAE Systems had experience with the original technology for the direct lift system.

Survivability, one of main requirements of the JSF program, could be achieved with stealth technology. Lockheed Martin was the originator of stealth technology, having developed the F-117. Northrop Grumman also had developed stealth technology, applying it to the B-2. The Lockheed Martin team had sufficient technological capabilities to develop a semi stealth fighter, the Joint Strike Fighter.

However, Boeing did not have similar experience in developing stealth technology, for which it would pay a price in the CDP. For example, when deciding on a post tail design, Boeing could not precisely evaluate the stealth signatures of two designs, the two post tail and the four post tail. It chose the two post tail, on the grounds that it had a smaller stealth signature.

The two program enterprises have also developed innovative simulation technology during the CDP. Lockheed Martin developed full mission simulation capabilities for the X-35 variants, verifying operational concepts and system requirements. Boeing was able to remove many mistakes before it built or flew the X-32 concept demonstration aircraft, using simulation technology as well as 3D modeling software.

The legacy of each company has affected the development of its respective aircraft. For instance, the design of the Lockheed Martin X-35 was clearly derived from that of the F-22 Raptor developed earlier by Lockheed Martin, intended as the next generation fighter replacing the F-15. The aerodynamic configuration was very similar because of the application of stealth technology.

3.3 Mergers and Acquisitions (M&A)

An enterprise can typically use M&A for two basic purposes. First, it can achieve economies of scale or economies of scope through M&A. We can easily find many examples of these in the consumer and commercial industry. Recently, Procter & Gamble acquired Gillette for economies of scope and the Big Three in the automotive industry acquired many small brands for the economies of scale and economies of scope. Second, an enterprise can merge with others for the technologies they have. Usually, a big company can buy smaller ventures to acquire new technologies developed by them. Technology driven industry like the biotechnology industry and the pharmaceuticals industry are good examples of the latter.

M&A is an efficient tool for enterprises to enhance their capabilities, especially their technologies, in the aerospace industry. As mentioned above, the fighter aircraft represents an extremely complex system embodying innovative and cutting-edge technologies driven by the rather demanding requirements of the customer. There are two ways for enterprises to catch up with the rapid evolution of technology. First, enterprises can develop the technology in-house. However, the scope of technology is so broad and deeply specialized that an enterprise cannot develop all the technologies it wants to have at its disposal. In addition, it takes long time for an enterprise to develop new technology. If an enterprise invests its resources to develop new technology, it would, of course, be useless in the event that its competitors have already succeeded in advancing their technology base further and faster. Second, when needing new technology, an enterprise can acquire other companies having that technology. This method is a more immediate and efficient way than previous one. We can find many examples in the aerospace industry.

The manned fighter aircraft industry has been very dynamic because of many M&A since the CALF program. Northrop bought a 49% stake within Ling-Temco-Vought (LTV) in 1992, which had developed the Corsair II aircraft. In March 1993 Lockheed purchased the General Dynamics (GD) Fort Worth fighter division from GD. In February 1994, a merger between Lockheed and Boeing was discussed but it did not happen. However, Northrop and BAE Systems had joined McDonnell-Douglas to work together on the CALF program, because of the merger discussion between the two big enterprises, Boeing and Lockheed. In April 1994, Northrop bought Grumman and

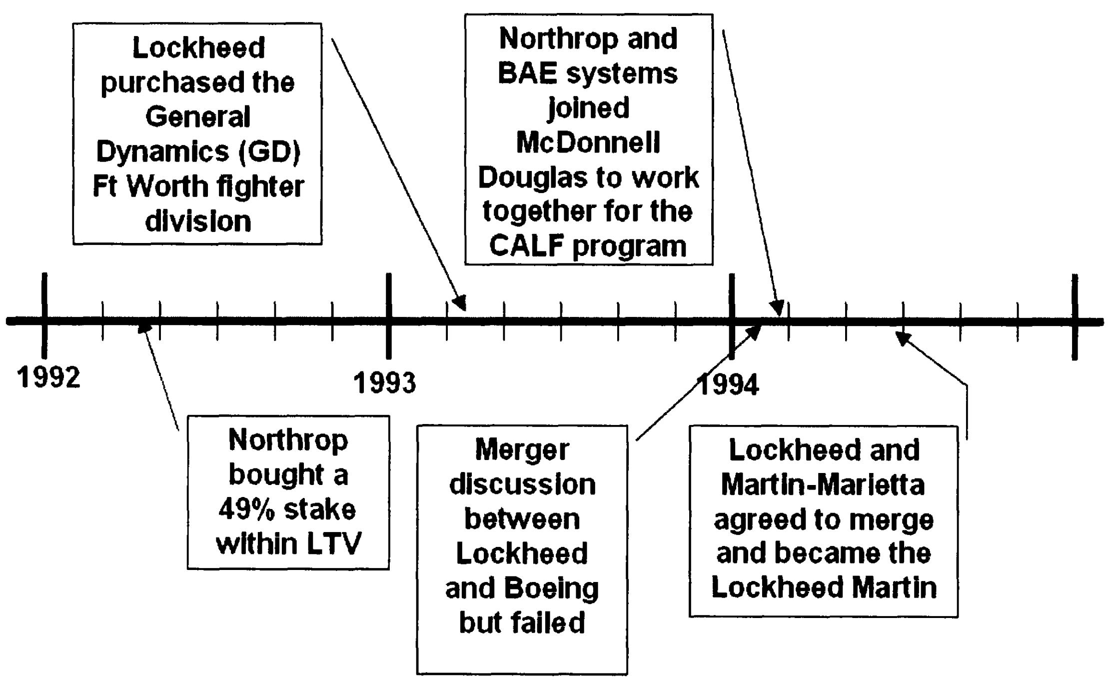

Figure 3.4 – M&A in the Military Aerospace Industry between 1992 and 1994

became the Northrop Grumman. It purchased the rest of LTV stocks in 1994. In June 1994, Lockheed and Martin-Marietta agreed to merge and became the Lockheed Martin. Figure 3.4 shows M&A in the military aerospace industry between 1992 and 1994.

3.4 Risk Management

The risk management capability of an enterprise is as important as other capabilities. Depending on its risk management capability, an enterprise can overcome its difficulties or go out of business. The risk management capability includes how to minimize the risk of applying innovative but unproven technology and how to cope with unexpected events.

During the CDP, the two program enterprises demonstrated the capability of technical risk management. Both enterprises have tried to maintain the balance between unproven technology and proved architecture or between proven technology and unprecedented airframe.

The Lockheed Martin team chose a shaft driven lift fan system to meet the STOVL capabilities of the US Marine Corps. The shaft driven lift fan (SDLF) system was a very new concept and no one had proven its usefulness in reality. The SDLF was a very risky business decision. To compensate for this technical risk, Lockheed Martin used the airframe design of the F-22. Lockheed Martin managed the risk of the unproven system with proved airframe design during the CDP.

On the other hand, Boeing adopted an opposite approach. It chose a direct lift system to meet the STOVL requirements. This system has been proven much earlier through its real application on the Harrier. This system has proven its value in many battlefields. Boeing chose the delta wing and the two post tail, with the proven simple direct lift system. The two post tail was a new concept against the four post tail. It could reduce the whole weight of the X-32. Boeing thus gained the advantage of long operational range with a thick delta wing containing much fuel.

While demonstrating its capability to manage the aircraft's technical risk, Boeing failed to deal with an unexpected event. Boeing experienced the largest white-collar strike in the US history during the CDP. About twenty thousands employees participated in the strike and more than one hundred people working on the X-32 program joined the strike. The strike lasted for forty days and the progress of the X-32 program was stopped during the strike. Boeing lost the lead in making rapid progress on the development of the X-32 due to the loss of several weeks in a tight schedule.

Chapter 4: A Comparative Review of the Two Concept Demonstrator Aircraft Proposals

Many experimental planes designated X planes have taken to the sky to develop and to demonstrate new technology since World War II. Among them, some experimental planes have made huge impacts on the aerospace industry. For example, the Bell X-1 broke the sound barrier and flew faster than the speed of sound on October 14, 1947. Until the JSF program, X planes have been designed and tested for future technology and product development possibilities.

The Boeing X-32 and the Lockheed Martin X-35 were the first X planes to compete against each other, as well as to demonstrate the superiority of their designs in order to win the next big contract for System Development and Demonstration (SDD). The two program enterprises had designed, developed and tested their solutions, the X-32 and the X-35, over four years. The two competitors had put their best possible combination of resources and capabilities to win the contract, representing the biggest military acquisition contract in history. The two program enterprises had made business and technical decisions based on their enterprise capabilities. The two concept demonstrators in fact reflected every facet, depth and breadth of their respective enterprises capabilities.

This chapter will present a comparative review and discussion of the details of the two concept demonstrators. The two program enterprises provided their unique solutions to the same customer, the US DOD. Obviously, particularly in retrospect, the huge differences between the two concept demonstrators can be seen, even thought they were developed to meet the same customer needs. The capabilities of the two program enterprises have resulted in these two quite different solutions. By studying these two solutions side by side and by focusing on their differences we can hope to say something useful about the nature of the organizational capabilities of the two competing program enterprises, each comprising of a different team of companies. This can be done by tracing the links between the technological solutions offered and the organizational capabilities that enabled the realization of these two different technological solutions, the,X-32 and the X-35.

4.1 Introduction of the X-32 and the X-35

The goal of the JSF program was to develop a low-cost, multi-role fighter for the three US military services. The two program enterprises were required to build their concept demonstrators during the CDP.

Boeing assembled two concept demonstration aircraft, the X-32A CTOL concept demonstrator for the US Air Force and the US Navy, and the X-32B STOVL concept demonstrator for the US Marine Corps at its plant in Palmdale, California. Unlike the Lockheed Martin concept demonstration aircraft, X-35A and X-35C, the X-32A needed no airframe changes to demonstrate a CV capability for the US Navy and a CTOL capability for the US Air Force, performing both roles.

On 18 September 2000, the X-32A completed its maiden flight from Palmdale to Edwards Air Force Base in California. The X-32A made 66 flights, demonstrating CTOL as well as CV capabilities during the four months of testing. On 29 March 2001, the X-

32B aircraft made its first flight. The X-32B made 78 flights, demonstrating STOVL and hovering capabilities by using a direct lift system. Table 4.1 shows the specifications for the X-32 concept demonstrators.

Meanwhile, the Lockheed Martin team had assembled two concept demonstrators, the X-35A for the US Air Force and X-35C for the US Navy during the CDP, and converted X-35A into X-35B for the US Marine Corps after testing the CTOL capabilities of X-35A. All variants were developed at the Lockheed Martin's plant in Palmdale, California. The X-35C had a larger wing than the X-35A for low-speed

Specifications	
First flight:	X-32A, Sept. 18, 2000; X-32B, March 29, 2001
Military model numbers:	X-32A and X-32B
Classification:	Concept demonstration aircraft
Span:	X-32A, 36 feet; X-32B, 30 feet
Length:	X-32A, 45 feet; X-32B, 43 feet 8.6 inches
Takeoff weight:	50,000 pounds
Speed:	Supersonic
Service ceiling:	50,000 feet
Range:	600 to 850 nautical-mile-radius (internal fuel only)
Power:	One Pratt & Whitney JSF119-614 turbofan producing thrust in excess of 42,000 pounds
Accommodation:	One pilot

Table 4.1 – Specification of the Boeing X-32 concept demonstrator aircraft, X-32A and X-32B, Source: Boeing website

handling qualities and carrier approach. It also had the addition of ailerons and a strengthened structure to absorb high impact when landing on a carrier, which required a bigger wing.

On 24 October 2000, the X-35A with a CTOL capability made its first flight from Palmdale to Edwards Air Force Base. The X-35A for the US Air Force completed its test with all requirements achieved on 22 November 2000 and returned to Palmdale to be converted into the X-32B for the US Marine Corps. Lockheed Martin had installed a shaft driven lift fan system in the X-35A structure for six months. On 24 May 2001, the X-35B made its maiden flight. On 16 December 2000, the X-35C for the US Navy completed its first flight. Table 4.2 shows the specifications for the X-35 concept demonstrator aircraft.

When comparing the two sets of specifications for the two concept demonstrators, especially wing span and length, we can easily notice that the X-32 variants were smaller than the X-35 variants. However, in spite of its smaller size, the X-32 could strike a target further away than the X-35 variants due to their thick delta wing design.

One of important requirements of the JSF program was the STOVL capability. To fulfill this requirement, the two program enterprises chose different systems, a direct lift system and a shaft driven lift fan system, respectively. Obviously, these two different systems were in response to the different power specifications of the two concept demonstration aircraft. The X-35B had a Pratt & Whitney F119-PW turbofan derivative and a Rolls-Royce lift fan producing 18,000lb trust, two power sources providing better flight capabilities during the vertical landing operation.

First flight:	X-35A, Oct. 24, 2000; X-32B, May 24, 2001; X-35C, Dec. 16, 2000
Military model numbers:	X-35A, X-35B and X-35C
Classification:	Concept demonstration aircraft
Span:	X-32A/B, 33 feet; X-32C, 40 feet
Length:	X-35A/B/C, 50 feet 11 inches
Takeoff weight:	50,000 pounds
Speed:	Maximum level speed Mach 1.4+ at altitude
Service ceiling:	50,000 + feet
Range:	540 nm (622 miles) for USMC, 600 nm (691 miles) for US Navy
Power:	One Pratt & Whitney F119-PW turbofan derivative, designated SE611, of 42,000 lb. (186.9 kN) st. with afterburning plus Rolls-Royce lift fan (X-35B only) of 18,000 lb (80 kN) thrust. (F119-PW-611C for CV/CTOL and F119-PW-611S for STOVL variant).
Accommodation:	One pilot

Table 4.2 – Specification of the Boeing X-35 concept demonstrator aircraft, X-35A, X-32B and X-35C, Source: Lockheed Martin website

4.2 System Architecture

Requirements of vertical landing and transition between hovering and conventional flight were decisive factors in the choice of a winner. To meet these requirements, the two program enterprises developed their own unique systems. Boeing assembled the X-32B with a direct lift system. On the other hand, the Lockheed Martin team converted the X-35A into X35B having a shaft driven lift fan system.

The starting point in new product development is system architecture. Architecture is composed of function, concept and form. A product should deliver functions derived from customer needs. Function must meet customer needs. Sometimes, function satisfying customer hidden needs achieves unprecedented success. System architects create concepts involving a principle of operation in order to map function to form. Among many concepts, an enterprise chooses one that is based on all aspects of its organizational capabilities and the current business situation. The concept must enable a system to execute all required functions. Form is the holistic sum of the elements related through structure and is embodied by concept. Form of a system can be varied according to concepts enterprises create [8].

Then, what determines system architecture? System architects must take many influences into consideration. These influences include upstream influences and downstream influences on system architecture. Upstream influences consist of such factors as regulation, customers, corporate marketing strategy, competitive environment, and technology. Customers affect system architecture with their needs. Regulation might prevent an enterprise from producing a product violating existing laws. An enterprise should know what technology it currently has, because at any given time it serves not future customers but one or more current customers with a product it may be developing right now. How best to deal with all upstream influences depends on enterprise capabilities. The system architect must fully understand the enterprise's capabilities.

Implementation, operating cost, operators, evolution and design are typical examples of downstream influences on system architecture. Even if an enterprise creates an innovative system architecture, it would be useless if it cannot implement or execute the system architecture. An aerospace enterprise typically invests significant resources to produce new products. It wants these new products to serve the customer as long as they can and it also wants to expand the life cycle of existing products, for example through the development of derivate products using the same platforms, since new product development requires serious commitment of the enterprise's financial and other resources. When creating the system architecture, system architects should consider the future evolution of the product or system being designed and developed. Obviously, an enterprise must have the requisite capabilities to deal with these downstream influences in order to succeed in the marketplace.

The Lockheed Martin team and Boeing have developed two different kinds of system architecture to meet STOVL requirements. The JSF program was an ultimate example showing how enterprise capabilities of the two competitors have affected their system architecture and how their system architecture has affected the JSF competition.

4.2.1 System Architecture of the Boeing X-32

Boeing has served the commercial airplane market with its various product lines since World War II. One of the main concerns of commercial airlines has been the cost of acquiring and operating airliners. Over time, Boeing has developed its organizational capabilities enabling it to produce innovative products and reduce cost in order to survive and succeed in an increasingly competitive global market environment. The emphasis on affordability in the JSF program has been recognized as a great opportunity by Boeing to demonstrate its capabilities to produce an affordable solution. During the CDP, Boeing definitely tried to develop the X-32 reflecting its cost-saving capabilities.

Boeing started research on a direct lift system in March 1994, when it was awarded a contract to conduct risk reduction in the direct lift system for the CALF program. Before Boeing, Lockheed Martin conducted risk reduction in a shaft driven lift fan system and McDonnell Douglas did risk reduction in a gas driven lift fan system.

The direct lift system has been used in the AV-8B Harrier for the US Marine Corps and the Harrier and the BAE Sea Harrier for the UK Royal Air Force and Royal Navy for many decades. This system has proved its practical use in battlefields including The Falklands War and the First and Second Gulf Wars. The direct lift system is one of the simplest approaches to STOVL flight and the only system operated in a battlefield.

The concept of the Boeing direct lift system is that it changes the direction of the jet propulsion with lift nozzles and a jet screen system in order to deliver the function of vertical landing and hovering. A system architect uses Object-Process Methodology (OPM) to represent a complex system. OPM can help us to capture function, concept and form of a system. Figure 4.1 show the OPM of the direct lift system.

The direct lift system provides propulsion for both conventional flight and vertical landing. It achieves a vertical landing capability by redirecting engine thrust downward through the lift nozzles. The lift nozzles are located on the center of gravity of the X-32B for the best performance, providing most of the downward thrust when the X-32B performs hover flight and vertical landing. To locate the lift nozzles on the center of the X-32B, Boeing has located the engine, a F119 derivative engine, in the front part of the fuselage, with the lift nozzles immediately behind it, and then a long exhaust duct leading back to the afterburner and a pitch-axis thrust vectoring exhaust nozzle at the rear. For vertical flight, the exhaust nozzle is closed, diverting the flow through the lift nozzles.

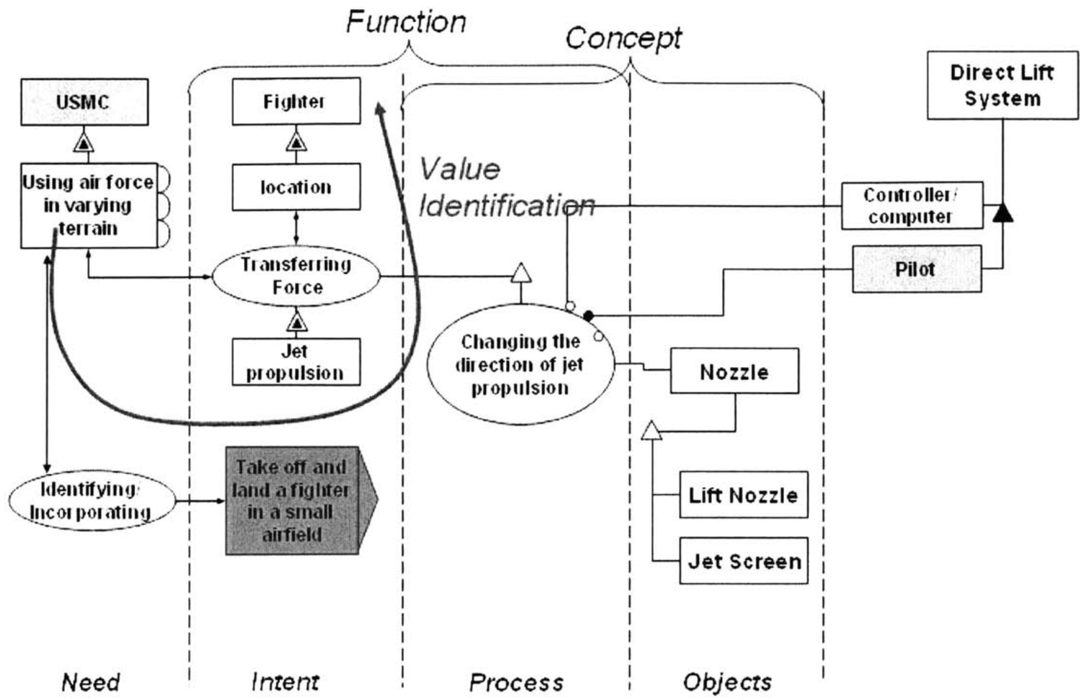

Figure 4.1 – OPM of the Direct Lift System on the Boeing X-32B

One of features of the X-32B is a jet screen system located in front of the lift nozzles. It provides additional thrust in vertical flight mode. The direct lift system gives the stability of vertical flight with three thrusts provided through the lift nozzles and the rectangular opening of the jet screen system. However, compared with a shaft driven lift fan system, the direct lift system provides less thrust in vertical flight mode. Figure 4.2 shows the Boeing direct lift system.

"The Boeing JSF concept combines the world's most powerful fighter engine with a simple and low-risk direct-lift system design," said Frank Statkus, Boeing vice president and JSF program manager. From his comment, we can capture one of reasons why Boeing chose the direct lift system. Boeing was certain that the direct lift system was the simple and low risk solution for the X-32B. Once again, the emphasis on affordability led Boeing to offer a simple solution enabling minimum structural changes among the three aircraft variants. Boeing also demonstrated its cost-saving capability through the simple structure of the X-32. The direct lift system also affected the design of the X-32 concept demonstration aircraft. The F119 derivative turbofan engine must be installed on the center of the X-32 and a huge air intake must be needed to provide enough amount of air to the engine in vertical flight mode. Choosing the direct lift system resulted in the infamous appearance of the X-32.

In spite of its strengths and its reflecting a perfect fit with Boeing's organizational capabilities as a cost-efficient manufacturer, the direct lift system has an inherent weakness. Hot gas ingestion is a very common incident in the operation of Harriers. Engine inlet ingestion of exhaust gases or air heated by exhaust gasses can occur in vertical flight mode. Hot gas ingestion may cause increased inlet gas temperatures as well as flow distortion. Inlet gas temperatures higher than the engine's maximum rated temperature will cause thrust loss. If entering the engine's air intake, the hot exhaust can cause compressor stall, which can cause a fighter to descend at a rapid

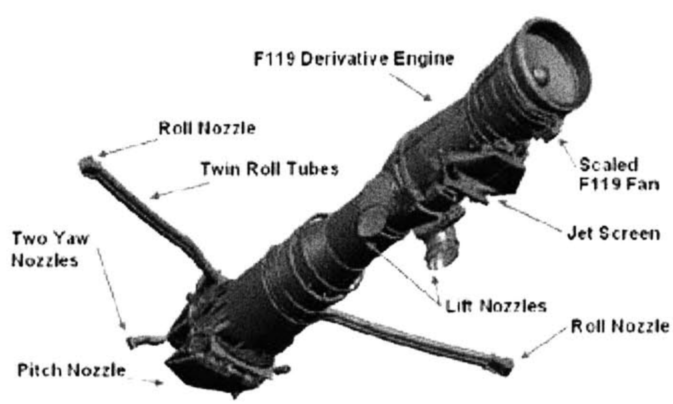

Figure 4.2 – The Boeing Direct Lift System of the X-32B for STOVL Capabilities, Source: Military Analysis Network website

rate, and can lead to an accident.

To prevent hot gas ingestion, Boeing added a jet screen system providing some vertical thrust in vertical flight mode. The main purpose of the jet screen system was to prevent the engine from choking by screening the engine inlet with cooler air.

In addition to the direct lift, Boeing chose a delta wing as another design choice to utilize its enterprise capabilities and maximize its cost-saving capability. A delta wing has been used for a couple of aircraft since the 1960s. A delta wing was used for the SR-71 Blackbird, the fastest military aircraft, because it was more appropriate for supersonic speeds. It was also used for the space shuttle because it provided better lift. The choice of the delta wing brought two additional advantages. First, the delta wing was structurally simple. Boeing could save total development budget with the simple structure of the delta wing. To maximize the advantage of simple structure and design of the delta wing, Boeing made a one-piece wing and attached it to a fuselage. Second, the Boeing X-32 variants could fly further than the X-35 because they could contain much more fuel due to the thick delta wing. However, the delta wing had a weakness. It had a worse turning capability. The Typhoon and the Rafale can overcome this weakness by adding canards in front of a delta wing. However, the X-32 variants did not have canards.

4.2.2 System Architecture of the Lockheed Martin X-35

The Lockheed Martin team consisted of Lockheed Martin, Northrop Grumman, and BAE Systems. Each team member has been a big player in the military aerospace market for more than half a century. The military aerospace market possesses several characteristics that are different from those of the commercial airplane market. The only customer, the US DOD, plays multiple roles as a customer, decision maker and provider of financial resources. The US DOD wants to maintain military superiority over the enemy. It has traditionally preferred higher performance rather greater cost efficiency. This was very much in evidence during the many decades of the Cold War. However, the US DOD has been faced with a shrinking defense budget immediately after the end of the Cold War. Nevertheless, it has wanted to acquire a fighter having the best performance within the constraints of the defense acquisition budget.

The long history of the three companies in the military aerospace market has enabled them to deeply understand who their customer is and what the customer wants. Based on these facts, the Lockheed Martin team has tried to deliver the best performance during the CDP. This market also rewards the offering of new products, particularly those resulting in better performance through the application of innovative technology. So many times in the past this market has been the primary ground where innovative technology has made its debut as a real product.

The Advanced Short Takeoff Vertical Landing (ASTOVL) Program assessed four concepts for the development of a supersonic STOVL strike fighter in the early 1980s. Among the four concepts, the Shaft Driven Lift Fan (SDLF) and the Gas Coupled Lift Fan (GCLP) showed the most promise. Figure 4.3 and Figure 4.4 show the SDLF and the GCLP, respectively. The Common Affordable Lightweight Fighter (CALF) Program succeeded the ASTOVL program. Lockheed Martin was awarded a contract to conduct risk reduction in connection with the SDLF system.

The STOVL variant of the JSF program should fulfill three requirements in terms of a STOVL capability. The fighter should have enough vertical thrust to float itself. In

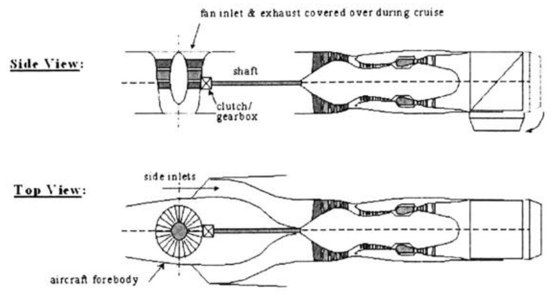

Figure 4.3 – Shaft Driven Lift Fan
Source: JSF: A DARPA Perspective

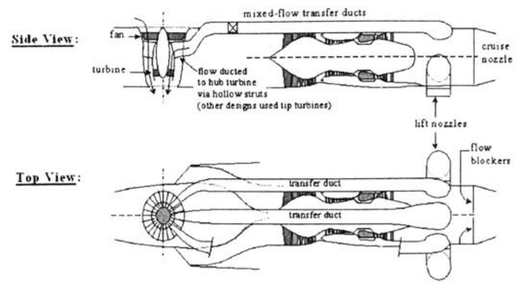

Figure 4.4 – Gas Coupled Lift Fan
Source: JSF: A DARPA Perspective

addition, it should provide good controllability at zero airspeed, as well as transition between conventional flight and vertical flight mode. To meet these requirements, the Lockheed Martin team developed the SDLF system.

The concept of the SDLF system is that it changes the direction of the jet propulsion with a three bearing swivel nozzle and provides additional vertical thrust with a lift fan driven by a shaft connected to the F119 derivative turbofan engine. The OPM of the SDLF system can be seen in Figure 4.5.

Lockheed Martin developed the SDLF system using a vertically installed lift fan. This system has two main sources of vertical thrust, a column of cool air from the lift fan and engine exhaust through the three bearing swivel nozzle. Rolls-Royce produced the lift fan providing thrust in vertical flight mode. The Rolls-Royce lift fan is installed behind a cockpit and is connected to a two-stage low pressure turbine on the engine by a drive shaft. The lift fan generates a column of cool air in the vertical mode. It produces nearly 20,000 pounds of lifting thrust.

The three bearing swivel nozzle on the main engine provides another vertical thrust in the vertical mode. Rolls-Royce also provided the three bearing swivel nozzle.

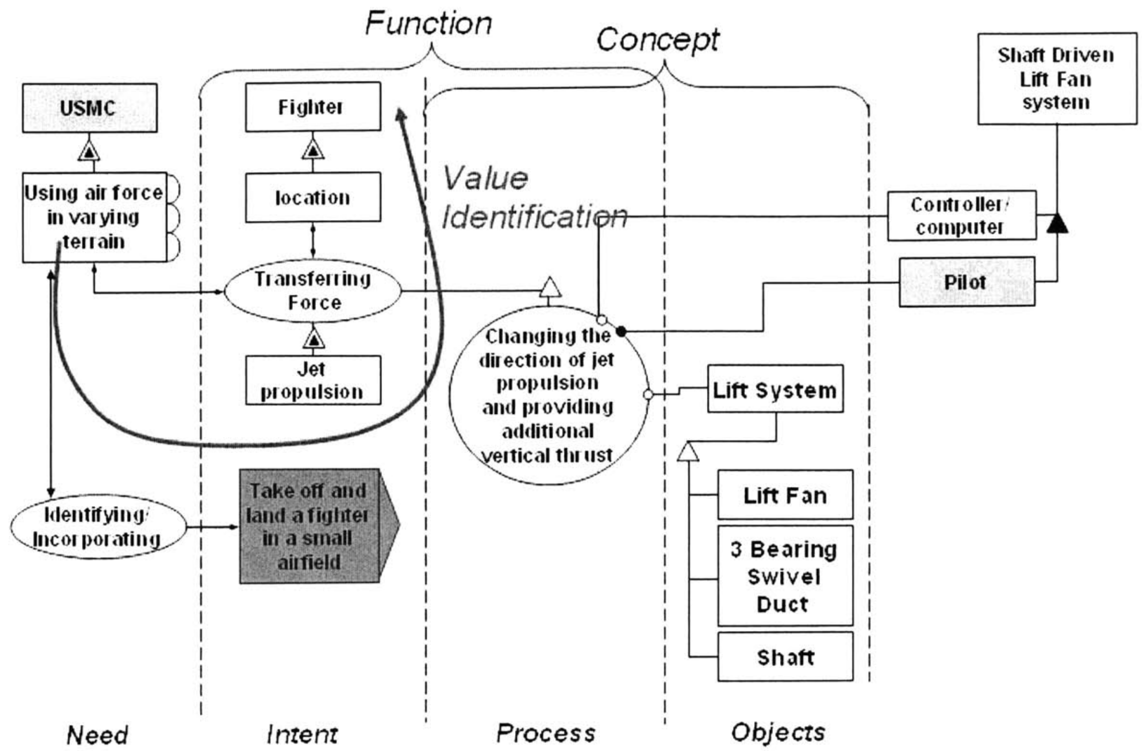

Figure 4.5 – OPM of the Shaft Driven lift Fan System on the Lockheed Martin X-35B

The three bearing swivel nozzle can swivel 110 degrees downward from the horizontal, providing vertical thrust and yaw control. The SDLF system can be seen in Figure 4.6.

Lockheed Martin expected that the SDLF system could overcome hot gas ingestion, an unsolved weakness of the direct lift system used for the Harrier and the X-32B. When driving the lift fan, the engine consumes some power and it can reduce exhaust temperatures significantly compared to the direct lift system. Cool air from the lift fan and low exhaust temperatures can solve the hot gas ingestion in the vertical mode.

In spite of solving hot gas ingestion, the SDFL has some weaknesses, however. Compared with the Boeing direct lift system, the SDFL increased the complexity of the

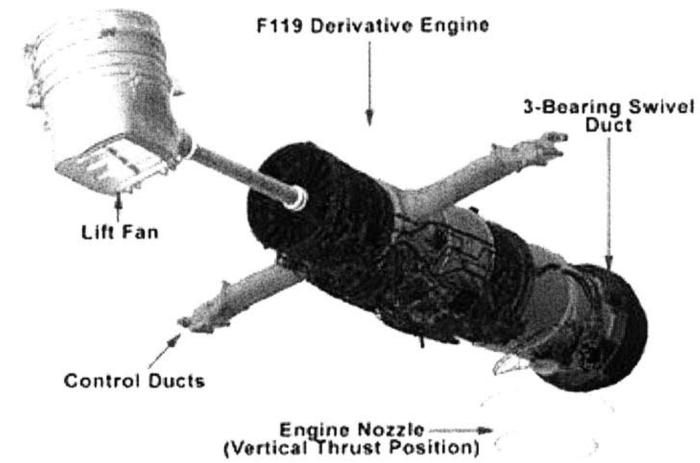

Figure 4.6 – The Lockheed Martin Shaft Driven Lift Fan System of the X-35B for STOVL Capabilities
Source: Military Analysis Network website

system. This complexity affects the X-35 in many ways. Usually, greater complexity increases the cost of assembly. Interfaces between subsystems could cause problems

when subsystems are highly integrated. Installing the lift fan increases the weight of the X-35, which is typically the key variable determining the total development cost of the fighter. In addition, the greater complexity of the SDLF system could negatively affect supportability in a battlefield. In conclusion, the SDLF system could deliver better performance, but is perhaps a riskier choice than the direct lift system.

4.3 Production Methods for the Two Concept Demonstration Aircraft

Boeing and Lockheed Martin developed their concept demonstration aircraft with different interpretation of the customer needs. Boeing considered that the program cost was the key determinant of the JSF contract. On the other hand, Lockheed Martin placed an emphasis on cutting-edge technology and performance. This initial interpretation on the part of each enterprise subsequently led them to develop different systems which they considered to represent the best fit to their respective capabilities. Boeing and Lockheed Martin also produced their concept demonstrators in different ways based on their respective capabilities.

Boeing considered the production of the X-32 variants as a great opportunity to show its capability in producing affordable aircraft. While developing the X-32 variants at Palmdale, Boeing not only assembled the X-32 but also tested its manufacturing techniques in order to bring about significant cost reduction. Boeing assembled its X-32 hundreds times by using assembly simulation before it assembled the real parts, thus correcting mistakes which would be made in real production processes. Boeing used a laser-guided part positioning technique to position every component precisely. This helped the assembly team to reduce assembly time by removing the wait time in the assembly process. All pieces were designed precisely by using three dimensional modeling and they fit together without any errors.

Boeing used its philosophy, "design anywhere, build anywhere." For instance, a delta wing of the X-32 variants was made over a thousand miles away at Boeing's main facilities in Seattle. It was transferred to Boeing's Palmdale facility by using a transport plane. Boeing spent only six hours to attach its delta wing to the fuselage. It was an unprecedented advance in the assembly process for a fighter. A front end of the X-32 was another good example of Boeing's philosophy. It included the cockpit and all of its electronic systems. It was made at a former McDonnell-Douglas facility in St. Louis. The merger of Boeing and McDonnell-Douglas took place just after the beginning of the CDP.

According to Boeing, it has taken only 52 weeks to assemble its first X-32 with 58 people. Due to the techniques it used during the CDP, Boeing has assembled the X-32 concept demonstration aircraft with only 50% of planned staffing levels and work hours. With a design fit to its enterprise capabilities and production techniques maximized its capabilities, Boeing was sure that it could meet the cost requirements of the US DOD and could win the JSF competition.

While Boeing applied its cost-saving manufacturing techniques, Lockheed Martin has built its X-35 in the same way as it built its past prototypes at its Palmdale plant. It assembled the X-35 piece-by-piece by hand. It could not assemble its X-35 at the same speed as Boeing did. However, Lockheed Martin did spend much time and financial resources on the production process. Still, it was barely able to compete with Boeing in terms putting in place a production process providing the needed cost savings. In addition, Lockheed Martin suffered from the delay of one part. To save cost, Lockheed Martin had tried to reduce the number of parts in the X-35. As a result of reducing parts count, it ended up with one complicated part, bulkhead 270. This would connect the cockpit and the fuselage. It was made of titanium, due to the strength and lightness of this material, and had a complicated shape. No one knew how long it would take to have it carved from hard metal, titanium. Finally, it turned out that the bulkhead 270 was not delivered at the planned time and it halted the whole assembly process. Lockheed Martin could not proceed without the part. It then spent five months to complete the carving the bulkhead 270, running its machine tool for 24 hours a day. Lockheed Martin also suffered from some budget management problems during the CDP. It overran the allocated budget by

$100 million. The conventional assembly method used by Lockheed Martin would be one of the causes of the overrun.

Even thought Boeing's loss of forty days delay resulted from a serious strike, Boeing made its first flight of the X-32 a month faster than did Lockheed Martin. This would demonstrate the efficiency of the cost-saving manufacturing method used by Boeing.

4.4 Corporate Strategy

During the CDP, the two program enterprises used different corporate strategies depending on their enterprise capabilities and chose a different system architecture for their concept demonstration aircraft. The two enterprises also chose a different set of factors as their marketing point. Boeing focused on the affordability of the X-32, using a simple architecture and cost-saving assembly techniques. Lockheed Martin put the greater stress on innovative technology and performance, using a new and complex system architecture for the X-35. Obviously, each program enterprise had developed and deployed its own unique system that each thought was the most appropriate not only in terms of delivering the best value to the customer but also in light of its own organizational capabilities. As the two different architectures reflected differences in the organizational capabilities of the two companies and their teaming partners, the corporate strategies of the two program enterprises were, as well, driven by their enterprise capabilities and their system architectures.

Boeing has chosen "doing everything in house" as its corporate strategy. Boeing has been a dominant player in the commercial airplane market for more than half a century. It has developed its successful B-7XX series and marketed them with considerable success. When developing its B-747, Boeing had to stake its survival on the success of the B-747. Gradually, it outsourced more and more of the series of commercial aircraft it built, often by entering into close partnering alliances with other companies internationally. However, during the JSF competition, Boeing probably tried to do virtually everything by itself. This may have prevented or reduced the likelihood of fresh ideas from other alliance companies.

What made Boeing's overall strategy possible were the very enterprise capabilities it had accumulated over time and subsequently buttressed through the acquisition of McDonnell-Douglas. Boeing had not developed military aircraft since World War II. However, it had participated in the development of the YF-22 and had been selected as one of contractors. From the YF-22 program, Boeing could gain the experience of developing military aircraft. By engineering its merger with McDonnell-Douglas right after the start of the CDP, Boeing definitely positioned itself to benefit from the considerable experience enjoyed by McConnell-Douglas in developing military aircraft. Most particularly, McDonnell-Douglas had developed the AV-8B Harrier serving for the US Marine Corps. The aircraft used the direct lift system for the STOVL requirement, the system suggested by Boeing for the X-32B STOVL variant. Boeing did not need to enter into a strategic alliance at the time, since it had a simple design and every type of technology needed for the JSF competition.

Boeing's corporate strategy had some advantages compared with the strategic alliance approach that Lockheed Martin chose. By avoiding complicated business relationships that alliances might have involved, Boeing could make quick decisions and share information more efficiently. However, there were clear weaknesses in this corporate strategy. The military aerospace industry is highly specialized. Even though Boeing was a big company, it could not be in complete command of the technical know-how involving all subsystems used in military aircraft. In addition, if the X-32 failed to win the contract, Boeing itself would assume the entire responsibility. In short, Boeing chose a more risky strategy compared to that adopted by Lockheed Martin, in terms of risk-sharing and knowledge-sharing with other companies.

Lockheed Martin chose a strategic alliance with Northrop Grumman and BAE Systems during the JSF competition phase. In the military aerospace industry, strategic alliances had become increasingly important since the 1970s. Usually, the development of military aircraft has required a high level of technological competence and management capabilities involving the coming together of multiple companies specializing in particular areas in order to maximize overall performance. The F-18A/B, YF-22, YF-23 and F-22 Raptor were representative results of strategic alliances. Northrop had teamed up with McDonnell-Douglas to develop the F-18 Hornet. The two companies had developed their YF-23 to compete with the YF-22. Boeing and Lockheed Martin have worked together to develop the YF-22 and have been awarded the contract for the F-22 Raptor.

The complex architecture of the X-35B STOVL system also forced Lockheed Martin to create a strategic alliance, since this would enable it to make good on the system architecture that it considered would best meet the customer needs. Lockheed Martin focused on the complex STOVL system. This system was so complex that it could not complete the development of the X-35 without a strategic alliance with Northrop

Grumman and BAE Systems. Northrop Grumman brought to the team capabilities in such areas as tactical aircraft integration, carrier suitability, stealth technologies, avionics systems integration, sensors, and advanced commercial aircraft manufacturing. BAE Systems provided its experience with the direct lift technology of the Harrier and Sea Harrier. Lockheed Martin itself would bring to the table its own expertise and experience with stealth technology and the shaft driven lift fan system, along with its other business, program management and related capabilities. In addition, the team would share the overall project risk if it were to fail to win the competition.

While creating a strategic alliance would bring better performance and would help share the overall risk, it also has its own weaknesses. Typically, many teams develop their subsystems and the prime contractor integrates them to develop the overall system or product. Integrating subsystems is a difficult task because of the complex interfaces among the various subsystems and unexpected interaction effects. Another difficulty is that sharing the workload with various teaming partners might cause schedule delays and may lead to budget overruns if the prime contractor does not have enough authority to control work share. This problem is one of main reasons why the F/A-22 program has suffered a schedule delay of over fifty months and has overrun the planned budget. On the other hand, the F/A-18E/F program has had a demonstrated record in developing and managing a successful worksharing agreement based on the specialized capabilities of the parties involved, and has largely escaped the type of problem just mentioned.

4.5 Test Flights of the Two Concept Demonstration Aircraft

The testing of the two concept demonstration aircraft proved to be a decisive factor in the subsequent selection of the winner. Before the testing process, Boeing seemed to be ahead of the Lockheed Martin team. It had reduced assembly costs by as much as 75 percent by using cost-saving manufacturing techniques and with its simple system architecture. However, during the test, the situation was radically changed. The commonality concept was proved in the course of the design of the two demonstration aircraft as well as during assembly, thus meeting one of the requirements mandated by the customer. Meeting the other two major requirements, low speed/carrier approach handling qualities and STOVL capabilities, as well, remained to be proven during the test of the two concept demonstration aircraft. The discussion below focuses on what exactly happened in this respect, how Lockheed Martin tried to catch up with Boeing in terms of the project schedule, and how each test affected the selection of the winner.

4.5.1 History of Flight Tests of the Two Concept Demonstration Aircraft

On 18 September 2000, the Boeing X-32A made its first fight, entering into a flight test program of five months at Edwards Air Force Base. The flight test consisted of about fifty test flights. The flight test program evaluated flying qualities and performance of CTOL and CV variants.

On 15 November 2000, the X-32A began field carrier landing practice (FCLP) tests. The tests were conducted on a simulated carrier deck outlined on a runway at

Edwards Air Force Base to validate the aircraft's low speed and carrier approach handling qualities. Unlike Lockheed Martin, Boeing used the X-32A for testing both of its proposed CTOL and CV variants. This was meant to demonstrate that its proposed design, the X-32A, could satisfy the requirements of the two military services, the US Air Force and the US Navy, without any changes. On 18 December 2000, it completed the CV flight tests, fulfilling all requirements.

On 29 March 2001, the X-32B made its maiden flight. Many tests were conducted to assess the STOVL capabilities of the X-32B. On 24 June, the X-32B completed the transformation between a conventional flight mode and vertical flight mode. The X-32B made its final flight, achieving a maximum speed of 1.05 Mach on July 28, 2001.

A month after the X-32A first flight, the X-35A made its first fight on 24 October, 2000. The X-35A completed the CTOL flight tests, satisfying all requirements on 22 November, 2000. Right after the X-35A completed its tests, Lockheed Martin started its conversion into the X-35B, installing the lift fan developed by Rolls-Royce.

Unlike Boeing, Lockheed Martin began the CV flight tests with the X-35C on 16 December, 2000. To meet the low speed/carrier approach handling requirements, the X-35C had a larger wing and control surfaces than the X-35A. In addition, the X-35C was assembled with a special structure to absorb the landing impact on a carrier.

On 12 May 2001, Lockheed Martin completed the conversion to the X-35B by installing the shaft driven lift fan system. It made its first vertical takeoff and vertical landing on 23 June, 2001. On 23 June 2001, the X-35B made its last test flight, making a strong impression of its performance.

On 26 October 2001, the US DOD announced that the Lockheed Martin team was awarded the JSF contract.

4.5.2 Test Flights of the X-32 Variants

The most difficult requirement of the JSF program was the STOVL capabilities. Boeing had chosen the direct lift system as its best solution to meet the STOVL requirements.

At its first attempt of vertical landing, the controller of the X-32B detected trouble, raising some concern. The engine had ingested hot gas from the lift nozzles. Except for the alarm of the controller, its first vertical landing seemed to be successful. However, just a week later, the X-35B revealed its own weakness when hot gas ingestion was detected during another vertical landing. Hot gas ingestion caused a pop stall of the engine. To prevent hot gas ingestion, Boeing augmented its direct lift system with a jet screen to prevent the engine from choking, accomplished by screening the engine inlet with cooler air. However, this did not always work as expected. Even though Boeing completed all STOVL test flights, thus meeting the US DOD requirements, this incident affected the selection of the winner negatively because the Boeing direct lift system still had the possibility of hot gas ingestion.

Another negative effect was that Boeing had removed some exterior parts to lighten the weight of the X-32B, assuming that its final proposal would be 1500lbs lighter than the X-32B. The US DOD had accepted the proposed change externally, but the assumption made did not materialize, quite likely hurting Boeing's performance.

4.5.3 Test Flights of the X-35 Variants

Compared with the test flights of the Boeing concept demonstrators, those of Lockheed Martin represented a major turning point in the CDP. During the test flights, Lockheed Martin proved that its product not only met but also exceeded all customer requirements.

Lockheed Martin built three variants by converting the X-35A into the X-35B for the required test flight for the latter. All three end-users could be confident that Lockheed Martin could deliver each variant tailored to the unique needs of each service branch. Lockheed Martin could thus demonstrate that it knew well the need for the differences among the three variants and that it could deliver them to meet the unique set of requirements of each customer.

The X-35B STOVL system worked perfectly. The shaft driven lift fan system proved that it could overcome the weakness of the direct lift system. The concept of the shaft driven lift fan system brought the best STOVL capabilities with better control quality in vertical flight mode.

As the final selection decision approached, Lockheed Martin wanted to make a strong impression on the customer. At its final flight, the X-35B made history when it took off in less than 500 feet, then went supersonic and made a vertical landing. This flight was a great triumph in aircraft history, showing the superiority of the X-35B

Chapter 5: Conclusions

On 26 October 2001, the US DOD awarded the Lockheed Martin team the System Development and Demonstration (SDD) contract based on a four-month review of the results during the CDP. The winner, the Lockheed Martin team, signed the $18.98 billion SDD contract, the biggest defense contract in US history. During the flight testing process, both types of concept demonstration aircraft proposed by Boeing and Lockheed-Martin had fulfilled all government requirements or exceeded them. There is no official document about why the US DOD chose the Lockheed Martin team for the SDD contract. However, we can infer what drove the US DOD to make that decision through the discussion presented in the previous chapters. This discussion attempted to provide some insights into how the management of the organizational capabilities of the two program enterprises may have affected the selection of the winner.

5.1 The Choice of the US Defense of Department

At the beginning of the CDP, the two program enterprises responded differently in meeting the same Government requirements. Boeing concluded that the decisive factor of the JSF program would be the affordability of its proposed solution by maximizing commonality among the proposed variants. During the CDP, Boeing made its decision based on this interpretation of the customer needs. Boeing was certain that it would be the winner because it had sufficient capabilities, acquired over many decades of developing commercial aircraft, which would enable it to achieve the important objective of affordability. On the other hand, the objective of the Lockheed Martin team was to deliver better performance within the possible price range. This interpretation of the customer needs was based on its close business relationships with the customer over many decades.

The two program enterprises differently positioned their products, the concept demonstration aircraft. The product positioning of the two competitors can be seen in Figure 5.1. Boeing developed the X-32 concept demonstration aircraft, fulfilling the performance requirements with a lower price tag, while Lockheed Martin proposed its

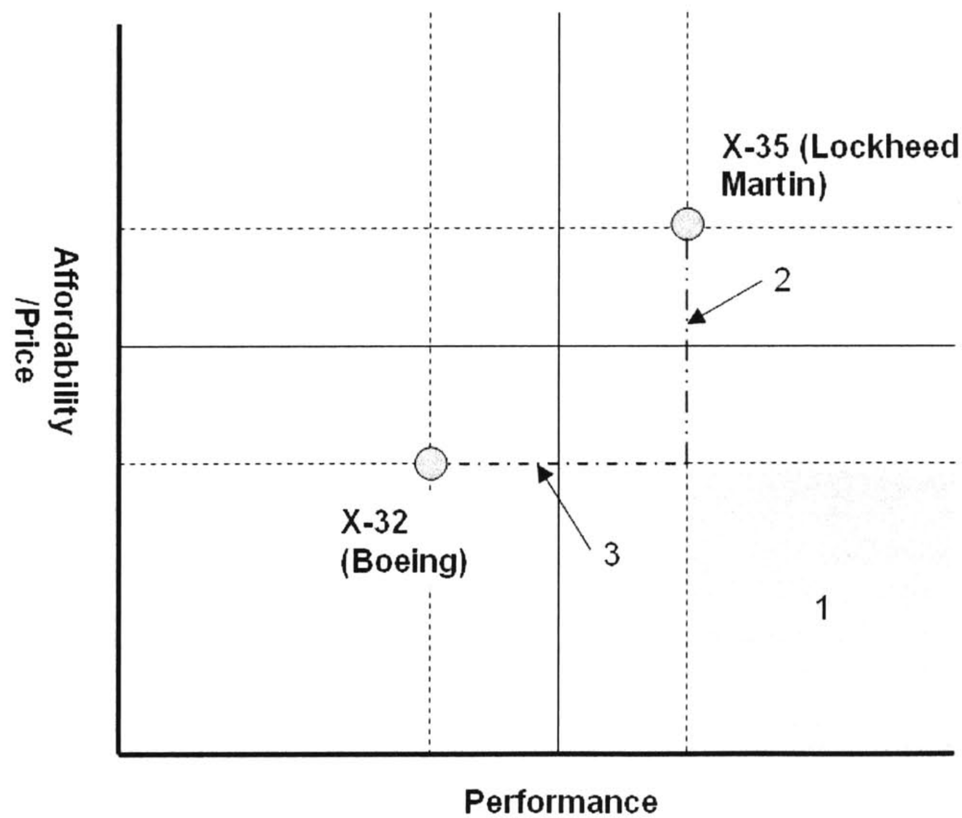

Figure 5.1 – Product Positioning of the Two Program Enterprises

own solution, the X-35, having the better STOVL performance at a somewhat higher price. A product in the area 1 would have been the best one for the US DOD, offering a low price and very high performance. The product positioning resulted from the enterprise capabilities of the two competitors. However, in reality it is virtually impossible for enterprises to provide the product falling into area 1. What would be the next best choice for the US DOD? Considering the success of previous military aircraft acquisition programs, particularly during the long Cold War period, it is quite apparent that the US DOD has typically placed greater value on performance rather than on cost. This would suggest that a product located on line 2 would be the second best choice for the US DOD, one delivering better performance within the budget range. The product on line 3 would be the third choice.

Basically, Boeing failed to win the contract because of the following reasons. First, its STOVL system, the direct lift system, had exposed its weakness during the CDP. Even though Boeing installed a jet screen to prevent hot gas ingestion, the direct lift system did not overcome the problem. Second, there were many changes in its final proposal, those including the change of tail post design and wing design. These changes could have forced the US DOD to doubt the on-time delivery of the JSF. Third, Boeing removed the intake cowl during the STOVL tests, insisting that its final proposal would be lighter than the X-32. Third, Boeing tested the same concept demonstration aircraft, the X-32A, to verify its CTOL and CV capabilities. However, the US Air Force and the US Navy had insisted that they needed different types of aircraft to complete their unique mission responsibilities long into the future. Except for the F-4 Phantom, the two service branches had never before used same aircraft. In addition, many pilots were found to make a mockery of the X-32 because of its unique shape resulting from the selection of the direct lift system. There is an old saying in aircraft design, "if it looks right, it flies right!"

In contrast, the Lockheed Martin team proved the superiority of the shaft driven lift fan system during the test and Lockheed Martin and Northrop Grumman had the better stealth technology than did Boeing. In addition, the X-35 looked like a fighter, quite reminiscent of the F-22 Raptor.

In conclusion, it can be inferred from the preceding discussion that the two program enterprises offered two very different types of demonstrators revealing their respective underlying organizational capabilities during the CDP. They selected the best affordable technological solution, embodied in the system architecture of the two proposed aircraft designs, based on their enterprise capabilities. Their strategic approaches to winning the big JSF contract, for example through entering into alliances with other companies as well as their M&A activities, also reflected how they viewed their organizational capabilities and they thought must be done to expand and integrate their organizational capabilities to meet emerging customer needs. The JSF program has thus provided an excellent natural experiment for an exploration of the link between product development performance and organizational capabilities.

5.2 Recommendations for Further Research

This research has focused the development of the JSF concept demonstration aircraft. It has reviewed the various aspects of the initial product development process including the design, assembly, and test phases of the JSF prior to the initiation of the System Development and Demonstration (SDD) phase. The discussion has tried to show the linkages between enterprise capabilities and the proposed technological solutions by examining the interplay between the two in some detail.

Many enterprise capabilities were discussed in this research, but these capabilities are only the tip of an iceberg. Many opportunities are waiting for further research. In addition, this research has been limited to one unique industry, the military aerospace industry. Depending on the industry, an enterprise should develop the right capabilities, as well as the right combination of such capabilities, to serve the customer well and succeed in the marketplace.

Simulation and 3-D modeling technology represent an important opportunity for further study. These technologies can bring huge financial benefits to the aerospace industry by helping to reduce the product development cycle time to meet the fast changing customer needs. Research focusing on the application of these technologies in performing specific tasks will be of value to most manufacturing enterprises. Another opportunity is to examine further how members of a strategic alliance can maximize their potential by efficiently sharing information and knowledge across multiple organizational boundaries. Due to the complexity of a product and the difficulties associated with emerging new technologies, more and more enterprises will form strategic alliances. The success of these alliances will depend on the efficient sharing of information and knowledge through networked relationships. The research of this area will be of value to many enterprises.

The only way for an enterprise to survive in the current dynamic business environment is to enhance its dynamic organizational capabilities. Further research in this area can help enterprises not only to perform well today but also to prepare well for the future.

Bibliography

[1] Teece, David J., Gary Pisano and Amy Shuen (1997). "Dynamic Capabilities and Strategic Management," *Strategic Management Journal*, Vol. 18, No 7, pp. 509-533.

[2] Eisenhardt, Kathleen M. and Martin, Jeffrey A. (2000). "Dynamic Capabilities: What Are They?", *Strategic Management Journal,* Vol. 21, Issue 10-11, pp. 1105- 1121.

[3] Zollo, Maurizio and Sidney Winter (2002). "Deliberate learning and the Evolution of Dynamic Capabilities," *Organization Science,* Vol. 13, No 3, pp. 339-351.

[4] Jacobides, Michael G. (2006). "The Architecture and Design of Organizational Capabilities," *Industrial and Corporate Change*, Vol. 15, No 1, pp. 151-171.

[5] Nickerson, Jack A., Todd R. Zenger (2004). "A Knowledge-Based Theory of the Firm-The Problem-Solving Perspective," *Organization Science*, Vol. 15, No. 6, pp. 617–632.

[6] Porter, Michael E. (1980). Competitive Advantage, *Harvard Business School Press*, Cambridge, MA.

[7] Saloner, Garth, Andrea Shepard, and Joel Podolny (2001). Strategic Management, John Willey & Sons, Inc.

[8] Crawley, Edward F. (2004). System Architecture Presentations. ESD.34J Class Notes, Department of Aeronautics & Astronautics.

[9] Pindyck, Robert S. and Rubinfeld, Daniel L. (2001). Microeconomics, Prentice-Hall.

[10] Murman, Earll, et al. (2002). Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, Palgrave.

[11] Womack, James P. and Jones, Daniel T. (2003). Lean Thinking, Free Press.

[12] Kotler, Philip (2003). Marketing Management, Prentice-Hall.

[13] Sørensen, Jesper (2005). Strategic Management Presentations. 15.900 Class Notes, Massachusetts Institute of Technology, Sloan School of Management.

[14] Ulrich, Karl and Steven Eppinger (2000). Product Design and Development, McGraw-Hill Inc.

[15] Bolkcom, Christopher (2003). "Joint Strike Fighter (JSF) Program: Background, Status, and Issues," Report for Congress.

[16] Struth, Robert G. (2000). "Systems Engineering and the Joint Strike Fighter: The Flagship Program for Acquisition Reform," RAND Corporation.

[17] Lorell, Mark (2003). "The U.S. Combat Aircraft Industry," RAND Corporation.

[18] Birkler, John, et al. (2003). "Competition and Innovation in the U.S. Fixed Wing Military Aircraft Industry," RAND Corporation.

[19] Greenfield, Victoria A. and Persselin, David M. (2002). "An Economic Framework for Evaluating Military Aircraft Replacement," RAND Corporation.

[20] Fox, Bernard, Michael Boito, John C. Graser, and Obaid Younossi (2004). "Test and Evaluation Trends and Costs for Aircraft and Guided Weapons," RAND Corporation.

[21] Younossi, Obaid, David E. Stem, Mark A. Lorell, and Frances M. Lussier (2005). "Lessons Learned from the F/A–22 and F/A–18E/F Development Programs," RAND Corporation.

[22] United States General Accounting Office (2000). "Joint Strike Fighter Acquisition Development Schedule Should Be Changed to Reduce Risks"

[23] Greenfield, Victoria A. and David Persselin (2002). "An Economic Framework for Evaluating Military Aircraft Replacement," RAND Corporation.

[24] Lorell, Mark A. and Levaux, Hugh P. (1998). "The Cutting Edge: A Half Century of U.S. Fighter Aircraft R&D," RAND Corporation.

[25] Glazner, Christopher G. (2005). "Enterprise Integration Strategies Across Virtual Extended Enterprise Networks: A Case Study of the F-35 Joint Strike Fighter Program Enterprise," Master thesis, Massachusetts Institute of Technology, Engineering Systems Division.