

ANALYSIS OF ENGINEERING MANAGEMENT CHARACTERISTICS EMPLOYED IN  
THE DEFENSE INDUSTRY

By

Sara S. Gutierrez

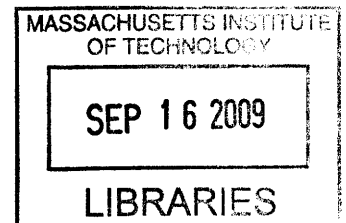
SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING  
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING  
AT THE  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2009

©2009 Sara S. Gutierrez. All rights reserved.

The author hereby grants to MIT permission to reproduce  
and to distribute publicly paper and electronic  
copies of this thesis document in whole or in part  
in any medium now known or hereafter created.



**ARCHIVES**

Signature of Author: \_\_\_\_\_

Department of Mechanical Engineering  
May 8, 2009

Certified by: \_\_\_\_\_

Jung-Hoon Chun  
Professor of Mechanical Engineering  
Thesis Supervisor

Accepted by: \_\_\_\_\_

John H. Lienhard V  
Professor of Mechanical Engineering  
Chairman, Undergraduate Thesis Committee

# ANALYSIS OF ENGINEERING MANAGEMENT CHARACTERISTICS EMPLOYED IN THE DEFENSE INDUSTRY

By

Sara S. Gutierrez

Submitted to the Department of Mechanical Engineering  
On May 8, 2009 in Partial Fulfillment of the  
Requirements for the Degree of Bachelor of Science in  
Mechanical Engineering

## ABSTRACT

An analysis of the engineering management characteristics present in companies in the defense industry was performed. These aspects include the organization characteristics of structure, hierarchy, and standards and procedures, as well as various features of company culture.

This study revealed that the companies that make up most of the defense industry, Raytheon, Lockheed Martin, Boeing, and Northrop Grumman, have very similar organization characteristics. They mostly use a matrix structure to run their businesses. They exhibit group relationships, employ an intermediate degree of centralization, and issue a decreasing span of control with increasing power. Moreover, they follow the Department of Defense Acquisition Model, apply engineering management consistent with military standards, and use Capability Maturity Model Integration.

However, defense companies are set apart by their cultures. Raytheon has the culture that is most conducive to running a successful company. It places a strong emphasis on its Six Sigma management philosophy, which is a major driving force for the whole organization's operations. Its culture also includes a great value placed on training and graduate education, a confident and customer-focused attitude, and a high regard for ethics. This has led it to have a net income per employee of \$23,000 in 2008, the highest out of all four contractors. It also has the highest gross profit margin and revenue growth.

While Lockheed Martin, Boeing, and Northrop Grumman also exhibit positive company culture traits, they do not measure up to Raytheon's. The differences in culture have influenced each company's position in the market.

Thesis Supervisor: Jung-Hoon Chun  
Title: Professor of Mechanical Engineering

## ACKNOWLEDGEMENTS

I feel extremely grateful to have had the chance to complete my undergraduate studies at MIT. The knowledge and skills that I have gained are invaluable, and I am sure they will help me greatly as I continue my career.

I would like to express my sincerest gratitude to my thesis supervisor, Professor Jung-Hoon Chun, for giving me the opportunity to explore this topic and providing me with guidance. I would also like to thank my family for always providing me with words of love and encouragement. Their support has always been instrumental in all of my undertakings.

## TABLE OF CONTENTS

1. Introduction.....	5
2. Engineering Management .....	6
3. Defense Contractors.....	8
4. Organization Characteristics.....	17
5. Culture.....	28
6. Conclusions.....	39
References.....	43

## 1. INTRODUCTION

The United States government depends on certain companies to provide it with the products and services that it needs to keep its citizens safe. The U.S. Department of Defense acquires most of these items from defense contractors, companies that are dedicated to designing and producing the tools that the military requires to do its job.

Defense companies are run somewhat differently than companies in other industries. They must employ different organization characteristics and cultures in order to successfully supply the government with products of the highest quality standards since the whole nation, and especially the soldiers in the field, depend on them for mission success.

This paper will examine those engineering management aspects that defense contractors use in running their organizations to see how they affect their performance in their industry.

## 2. ENGINEERING MANAGEMENT

To be able to analyze the defense industry in terms of engineering management, it is necessary to begin by examining what engineering management entails. The word “engineer” traces its roots back to the Latin word “ingenium,” which can mean natural talent or clever invention.<sup>1</sup> The word management is derived from the Latin “manus” or hand. Management, in the modern sense, has come to mean a process of work involving guiding a group of individuals to achieve defined organizational goals. Therefore, engineering management can be defined as managing engineering to achieve business objectives, which requires skills in understanding engineering in addition to managing business activities of organizations.<sup>2</sup>

Modern management is considered to have begun with the Industrial Revolution in the 18<sup>th</sup> century. The revolution began as Thomas Savery patented the first steam engine. James Watt was able to greatly improve the steam engine in 1769, and it proved to be quite useful in industrial settings. This soon led to railroads and automated factories, and with bigger and more efficient factories, they were able to start producing more and employing many more workers. It was this change in scale of businesses that created the necessity for management.

Fredrick W. Taylor and Henri Fayol are considered to be the fathers of modern management. Taylor became the president of the American Society of Mechanical Engineers in 1906 after a successful career as chief engineer of Midvale Steel Company. He considered a role in management to be about “finding the most appropriate method for performing a job and assigning the right person for each job.”<sup>2</sup> In 1911, he published “The Principles of Scientific Management,” which focuses on finding efficient methods of running organizations by using science rather than the “rule of thumb” methods that were common in those days.<sup>3</sup> Instead of

doing things a certain way because it was the way it had traditionally been done, Taylor theorized that managers should use reasoning to make processes more effective.

Henri Fayol was a mining engineer from France. He hypothesized about general management based on his experiences working as the director of a mining company for 30 years. Fayol published “Administration Industrielle et Générale” or General and Industrial Management in 1916, and his work is still highly regarded.<sup>4</sup> His theory on the main functions of management is used to this day.

Beginning in 1911, when the first conference on scientific management was held, many professional organizations were formed with the purpose of the advancement of management. Moreover, most engineering universities began to offer courses in management. Since then, firms have kept increasing in size and scope, which makes the role of management increasingly important. The aspects of engineering management that are applied by defense contractors to run their organizations will be explored in more detail.

### 3. DEFENSE CONTRACTORS

Defense contractors are businesses that make products for the Department of Defense (DoD). These products usually include weapons, vehicles, aircraft, ships, and electronic systems. The military depends on these products for national defense and attacks. Defense contractors may also supplement their revenue by using their technology to provide goods to the commercial sector, as well as other countries.

In the United States, the defense industry is highly concentrated. There are four companies that together hold a 94.9% share of the market. These are Raytheon, Lockheed Martin, Boeing, and Northrop Grumman. Therefore, the analysis of the defense industry will be focused on these companies.

#### RAYTHEON

The first company, Raytheon, was founded as the American Appliance Company in 1922 by two roommates, Laurence K. Marshall and Vannevar Bush, along with Charles G. Smith. Bush, a professor at the Massachusetts Institute of Technology, wanted to enter the market with a new refrigerator that would use artificial coolants. However, when this idea failed, they turned their attention to gaseous tubes. These devices were found to enable radios to operate with electricity rather than batteries. Since batteries were very expensive and had a short life span, the new gaseous tubes finally made radios affordable for most American households. This launched the success of the company as well as that of the entire radio industry.

Three years later, American Appliance Company voted to change its name to that of its flagship product, the gaseous rectifier marketed as “Raytheon.” The word was created from the French “rai” or “a beam of light,” and “theon,” which is Greek for “from the gods.”<sup>5</sup>



Raytheon entered the defense industry during World War II when the British military needed to obtain magnetron tubes, which were a key component of radars. The military wanted large quantities of tubes for the radars so that it could detect incoming Nazi aircraft. Raytheon was able to win the contract for the magnetron tubes by presenting the British military with a new design that would allow for better manufacturability and by teaming up with the MIT Radiation Laboratory to supplement its engineering and manufacturing capabilities. By the end of the war, Raytheon had captured 80% of the magnetron tube market and was well on its way to becoming a key defense supplier.<sup>5</sup>

While its research and development department was concentrating on technology that would help the armed forces, Raytheon was able to use its developments to provide households with another major appliance. In 1947, it accidentally discovered a way to heat and cook food when a candy bar in an engineer's pocket melted as he stood in front of a powered magnetron tube. Shortly after, it began selling the "Radarrange," the world's first microwave oven, to commercial establishments.<sup>5</sup> This technology was improved until the result became the household staple that exists today.

Another major step that solidified Raytheon's place in the defense industry was its development of the first missile guidance system capable of hitting a flying target. This started a long string of military contracts that has placed Raytheon as the world's number one missile maker today.<sup>6</sup>

As the company grew, it was able to acquire other businesses that have helped to strengthen its position in the market. The acquisitions include Beechcraft, E-Systems, Texas Instrument Defense Systems and Electronics, and Hughes Aircraft Defense Electronics.

Today, Raytheon Company employs 73,000 people across six business units: Integrated Defense Systems, Intelligence and Information Systems, Network Centric Systems, Space and Airborne Systems, Missile Systems, and Raytheon Technical Services Company. It enjoyed a net income of \$1.7 billion in 2008 with its primary customer being the U.S. government. However, it does continue to be active in the commercial sector, which accounts for 15% of its sales.<sup>6</sup>

## LOCKHEED MARTIN

Lockheed Martin is one of Raytheon's biggest competitors. It is currently the number one military contractor in the world, but the company as it is today is the product of many smaller companies merging together.<sup>7</sup>

Lockheed Aircraft was first founded in 1926 by Allan and Malcolm Loughead, who had previously failed in starting the Alco Hydro-Aeroplane Company. They named Lockheed for the phonetic pronunciation of their last name, and the company's success began a few years later with the creation of the Vega, its first airplane. This plane was later made famous by Amelia Earhart, who used it for her first transatlantic flight. Later, Earhart also flew Lockheed's L-10 Electra on her 1937 attempt to circle the globe, which resulted in her disappearance.

As with Raytheon, Lockheed's involvement with the U.S. government began during World War II when it designed the fighter plane credited with shooting down the most Japanese aircraft. Since then, Lockheed has landed many contracts for airplanes and fighter jets, including the P-80 Shooting Star, which was the first jet to ever shoot down an enemy jet in 1950.<sup>7</sup>

Another main component of Lockheed Martin is the Martin Marietta Company founded in 1961. Martin Marietta is itself a product of a merger between The Martin Company and

American-Marietta Corporation. It specialized in aerospace and materials, until it went through a series of acquisitions that made it the owner of General Electric Aerospace, and General Dynamic Space Systems.<sup>7</sup>

Lockheed and Martin Marietta joined in 1995 to form Lockheed Martin, and they have since acquired Loral Corporation Defense Electronics and System Integration. Today, Lockheed Martin enjoys the benefit of being the primary contractor for the military's two main fighter jets, the F-35 Lightning II and the F-22 Raptor. It is also busy developing NASA's next manned lunar spaceship, Orion, which will replace the space shuttle. Lockheed and NASA hope to use it to take astronauts to the moon, and possibly even Mars.<sup>7</sup>

All of Lockheed's activities account for \$3.2 billion in net income for 2008 and 146,000 employees worldwide.<sup>7</sup>

## BOEING

Boeing is another one of the major defense contractors. It was initially founded as the Pacific Aero Products Company in 1916 by William Boeing in Seattle, Washington. The company started building airliners that year, and it established its own airline soon after. The business thrived against competing airlines, but antitrust rules forced it to split the company. Therefore, the airline was sold off as United Airlines.<sup>8</sup>

During its early years, Boeing started the first international airmail service. It also became a major airplane manufacturer for the military during World War I and World War II. The company continued to develop airliners throughout the 1950s, 1960s, and 1970s, as well as participating in NASA's Apollo program.

In the 1970s, Boeing continued to expand its operations with new information and aerospace sectors. The expansion efforts were renewed in the late 1990s when Boeing acquired Rockwell Aerospace and Defense and McDonnell Douglas, previously a major competitor.<sup>8</sup>

Today, Boeing is concentrating on developing the new 787 Dreamliner, along with other projects. It had a net income of \$2.7 billion in 2008, and it currently employs 162,000 employees.<sup>8</sup> Boeing is now headquartered in Chicago, IL after leaving Seattle in 2001.

## NORTHROP GRUMMAN

By the time Jack Northrop founded Northrop Aircraft in 1939, he had already co-founded Lockheed Aircraft and designed its first plane, the Vega. Northrop began its operations in Hawthorne, CA, and it started producing aircraft for the military during World War II.<sup>9</sup>

Northrop's most successful ventures include the P-61 Black Widow fighter, the first aircraft designed specifically to be used with radar technology. In the 1950s, the company focused on designing and producing the F-89 Scorpion, the first fighter to be equipped with nuclear weapons, and the SM-62 Snark nuclear missile. However, during the next decade, it decided to shift its focus to obtaining a larger number of smaller subcontracts rather than having a few risky main contracts. To accomplish this, Northrop acquired Page Communications Engineers and Hallicrafters Company.<sup>10</sup>

In 1994, Northrop acquired the Grumman Corporation and changed its name to Northrop Grumman. Grumman was founded in 1929, and won its first contract three months later. It began its work for the military right away with that first contract, which was for a U.S. Navy fighter.

The company started many other ventures soon after. It began building commercial aircraft in 1936 with the Grumman Goose, an eight-seat twin-engine plane designed for

commuter businessmen in the Long Island area. In 1962, the company received the main contract for the Apollo Lunar Module from NASA. The company can also be credited with the Grumman Long Life vehicle, introduced in 1986. This vehicle was designed specifically for the United States Postal Service, and it is what most people know today as the mail truck.<sup>9</sup>

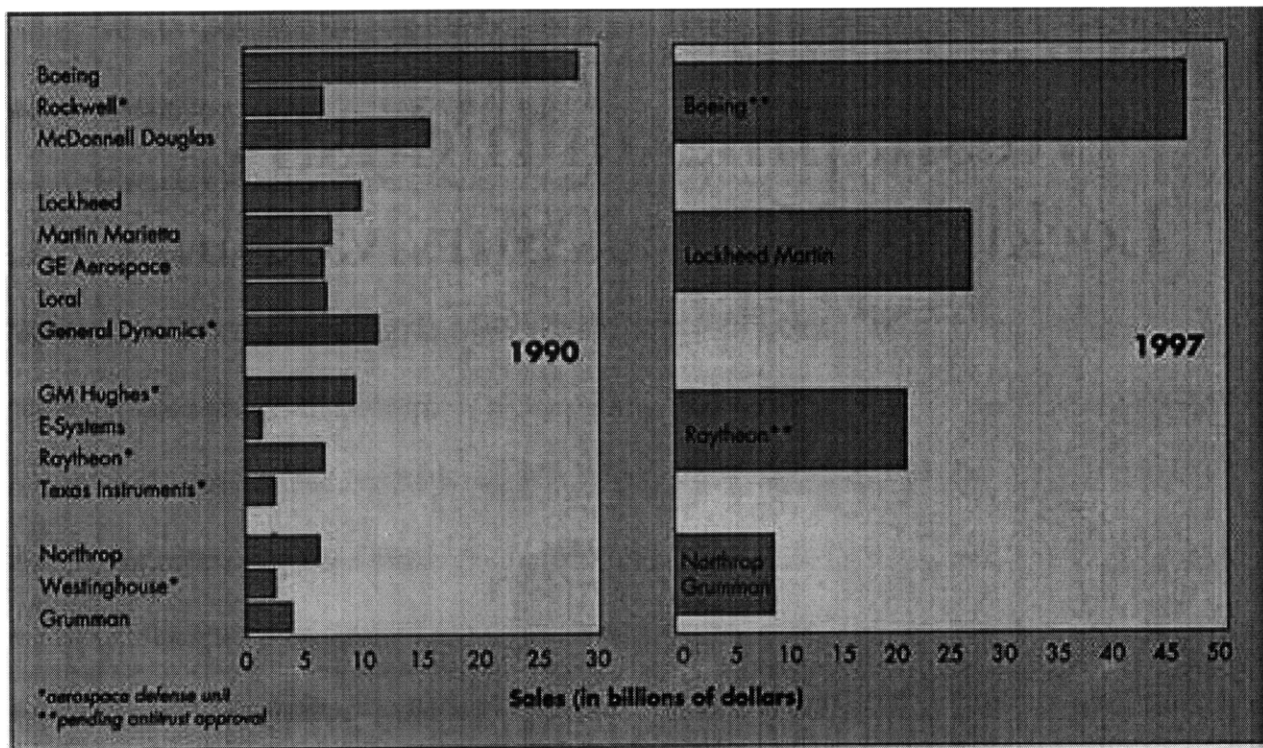
After the formation of Northrop Grumman, the company agreed to be purchased by Lockheed Martin for \$12 billion in 1998. However, the U.S. government blocked the acquisition due to a lack of competition in the defense industry. Northrop Grumman then began a restructuring effort, and acquired California Microwave Information Systems, Ryan Aeronautical, Comptek Research, Carlyle Federal Data, Litton Industries, Aerojet-General Electronics and Information Systems, Newport News, and TRW, as well as selling off Northrop's underperforming businesses.

As a result, Northrop Grumman is the world's number three military contractor and the number one shipbuilder. It currently has over 123,000 employees, and its 2007 net income of \$1.8 billion is mostly due to government business, which accounts for 90% of its sales.<sup>9</sup>

## MERGERS AND ACQUISITIONS

Overall, the defense industry has been greatly consolidated to reach its current state, mainly comprising the four previous companies. The consolidation, which occurred mostly in the 1990s, can be attributed to several reasons. First, the end of the Cold War in 1991 was followed by a significant decrease in military spending.<sup>11</sup> This affected the whole industry, which heavily relies on the government for sales. In 1993, U.S. Defense Secretary Les Aspin personally invited the heads of fifteen defense companies for dinner at the Pentagon. Over dinner, he announced to them that in a short time, less than half of the companies would be

needed. The meeting became known as “The Last Supper,” after Norman Augustine, Lockheed Martin CEO, referred to it as such in an interview a few days later.<sup>12</sup> Soon after, many of the smaller companies became part of today’s four major contractors.



*Figure 1.<sup>13</sup> Consolidation of the defense industry in the 1990s. The bar graph on the left represents the sales of the several contractors in 1990. The graph on the right represents the sales of the four major companies in 1997 after they merged or acquired the companies that they are grouped with on the left.*

Moreover, because of the nature of this industry and the products that the companies manufacture, they benefit from consolidating due to economies of scale. Economies of scale occur when the unit cost of a product decreases as the company produces a greater quantity of that product. For example, if several small companies are all producing missiles, they must all

pay for factories, equipment, workers, materials, etc. However, if all of those small companies join together and work as one larger company, they can produce all of the missiles ordered with one set of factories, equipment, workers, etc. This brings down the cost of each missile because the cost of production can be divided by the entire number of missiles produced. A lower cost per unit means that the company makes a larger profit. Therefore, there is an incentive to consolidate the companies.

Economies of scale are also part of the reason why defense companies have acquired companies that had previously not been involved in defense. They are continuously looking for ways to increase their revenue by expanding their products into the commercial sector. If they acquire a company with experience in a commercial area of interest, they are able to apply the technology that they have developed to fulfill a government contract in a commercial product for that industry. The resulting increase in total production leads to economies of scale and larger profits.

Both of these factors have led to a great reduction in the number of companies in this industry. As is evident in Figure 1, defense sales are now highly concentrated among Raytheon, Lockheed Martin, Boeing, and Northrop Grumman. The consolidations have greatly reduced competition since there are many fewer companies submitting bids for government contracts. Also, in the past few years, it has become common for these companies to agree to cooperate and work jointly on a project. Therefore, defense companies have been able to survive despite the smaller government budget and tough economic times.

Because of the dominance of Raytheon, Lockheed Martin, Boeing and Northrop Grumman in the defense industry, the analysis of engineering management, which comprises

organization characteristics and culture, can be limited to those four companies while still representing the whole industry.



## 4. ORGANIZATION CHARACTERISTICS

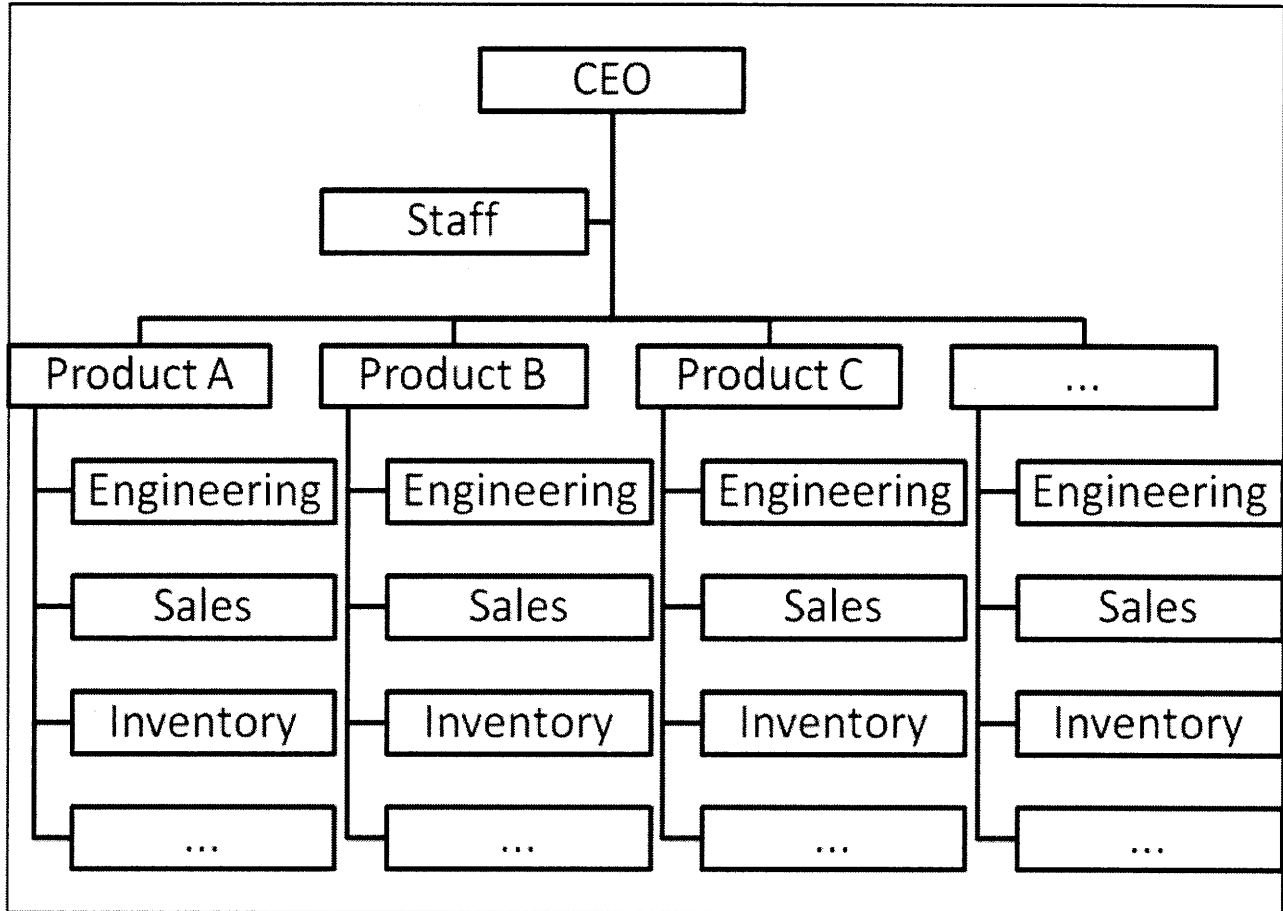
The first element of engineering management to be analyzed is the organization characteristics of defense contractors. Organization in this sense refers to the framework that the companies use in order to operate functionally so that they can accomplish their goals effectively.

### STRUCTURE

Managers of a firm always begin by defining the work that is to be done. This means setting the type and the scope of work that will be performed by a certain group. The next step is dividing the work into units and assigning responsibility for what has to be accomplished. This leads to the creation of an organizational structure that greatly influences how the company functions.

There are several types of organizational structures, but the main structure employed by defense companies is the matrix structure. A matrix structure is a hybrid of a product structure and a functional structure.

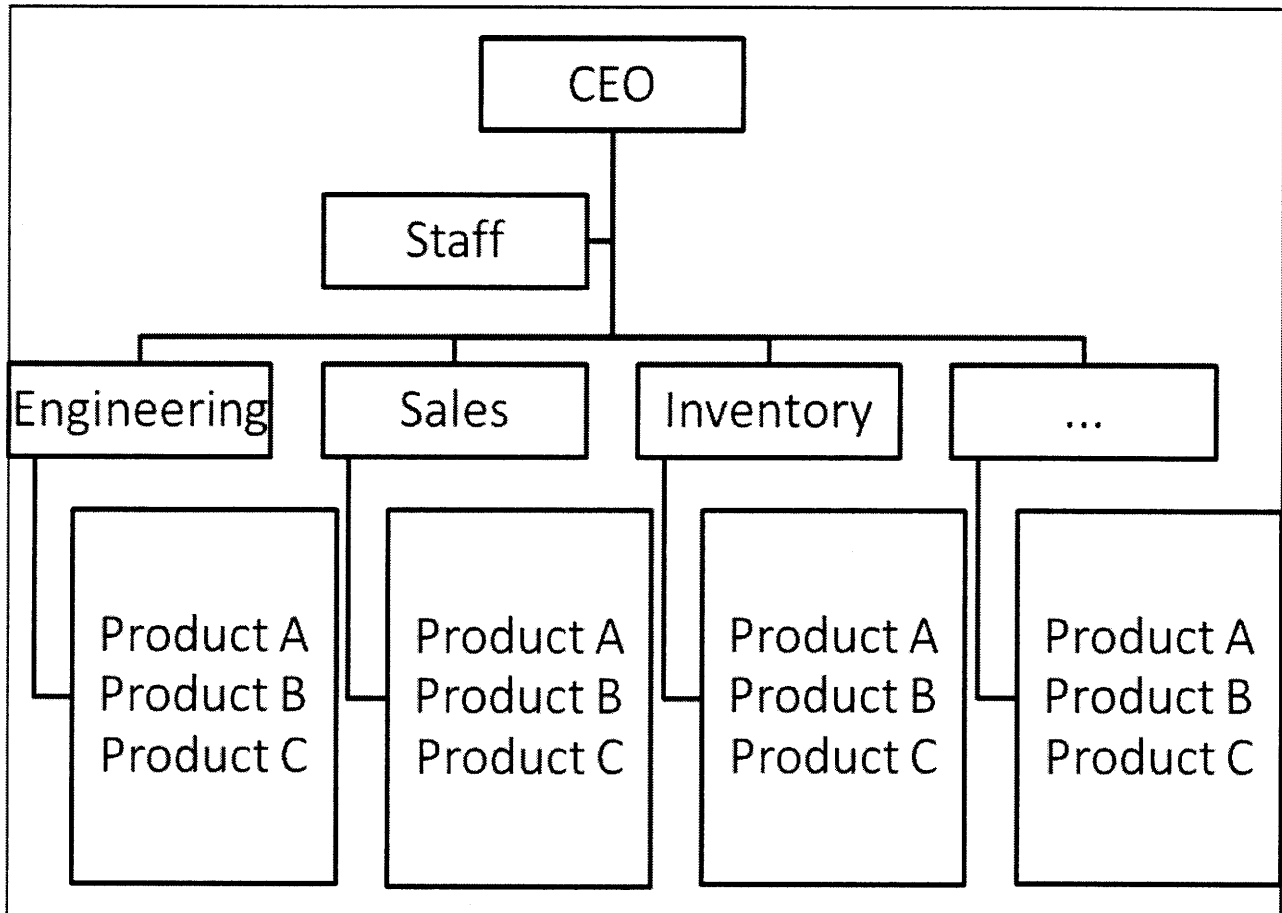
In a product structure, work is divided according to the company's products or services. Each division is given the responsibility for the production and sale of that product. The divisions contain personnel of all the different capabilities that are necessary to carry out the goals for that product.



*Figure 2. Representation of product structure. Most people are assigned to work on a specific project by performing tasks related to their capabilities, and they report to a project manager who is responsible for overseeing that unit.*

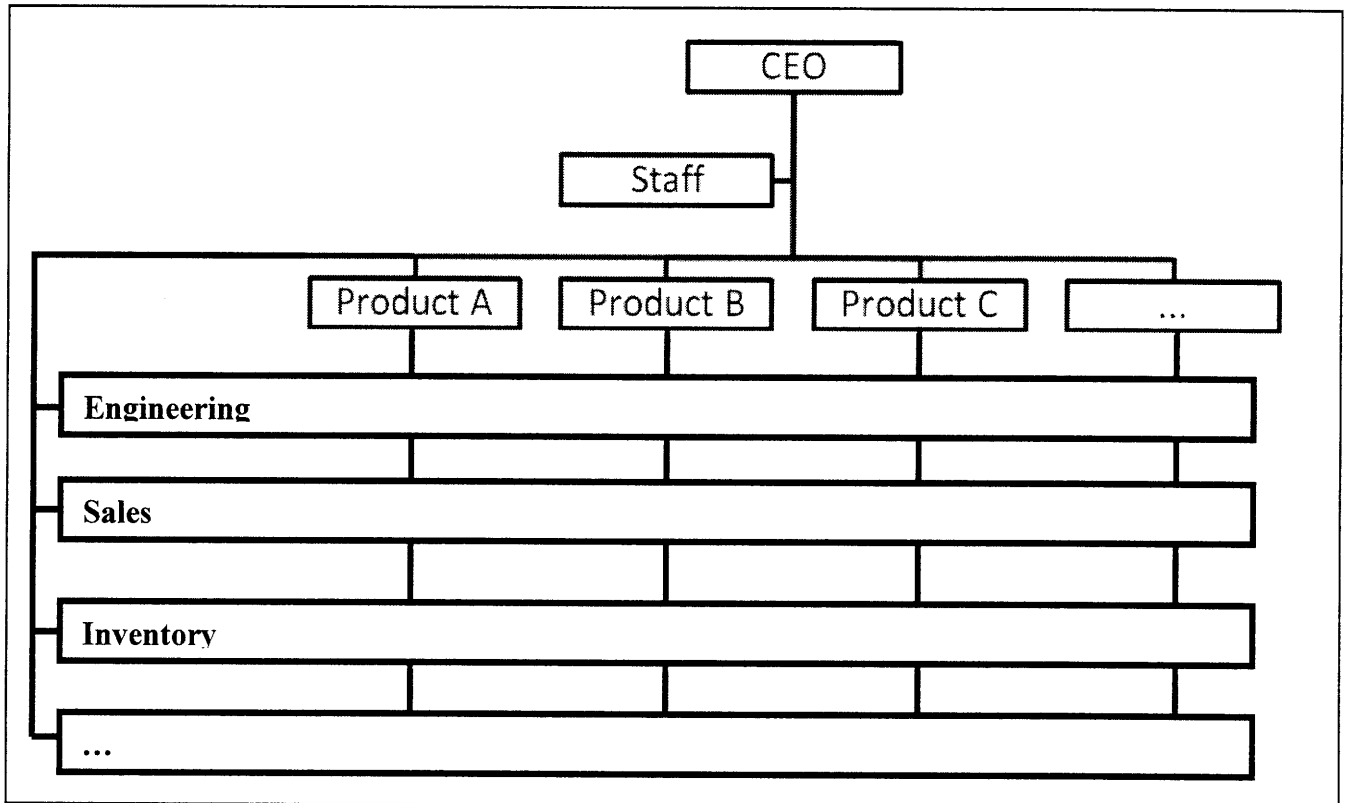
As shown in Figure 2, the employees in a certain group perform work related to a specific project, and they report to a project manager who is responsible for the performance of that product.

On the other hand, a functional organization defines units by the type of tasks that they perform. Each unit possesses a certain skill that it uses to achieve the organization's goals, such as making and selling certain products or services.



*Figure 3. Representation of a functional organization. Each division performs a certain function with the goal of supporting the company's goals. Employees report to their function supervisor, who is responsible for people with similar expertise or capabilities.*

Combining both product and functional structures yields a matrix structure. Matrix structures divide an organization by both projects and functions, so employees are responsible for using their specific skills to work on an assigned project. Employees are anchored to their functional department, and their function managers “lend” them out to project managers. The employees then report to both the project and the function manager.



*Figure 4. Layout of a matrix organization. There are two types of units, functional and product. Employees work in their function to support a product. They report to both a project manager and a function manager.*

Matrix structures were first developed and implemented in the 1950s by defense and aerospace companies.<sup>2</sup> As the complexity of the products that they were designing and producing increased, they looked to this new structure to be able to distribute work and responsibilities to employees effectively.

Using a matrix structure is beneficial to defense companies for several reasons. It increases the accountability that each person has for the work he has to complete for a project, as opposed to what may be experienced in a functional structure. It also helps to increase the pace of work flow, since the members of a project group can better coordinate with each other. In

addition, function managers can manage people more easily, since their subordinates have very similar capabilities which they themselves possess or understand. These benefits have led Raytheon, Boeing, and Northrop Grumman to all use matrix structures to run their company efficiently.

## HIERARCHY

Although an organizational chart may show the assigned connections between people, hierarchy is something that cannot be assigned as easily on paper. There are several characteristics of hierarchy that must be looked at in order to fully define the organization.

The first characteristic that must be examined is the types of relationships that exist between employees. One of the ways that relationships can be shaped is referred to as line relationships. A line relationship describes the way authority is passed down from one person to another. In this relationship, one person at the bottom of the chart is managed completely by one person above him, and that person is managed completely by another person above him, and so forth.<sup>2</sup>

Another way that relationships can exist in an organization is in the form of group relationships. In this case, multiple people working together as a group report to a single manager. The manager is also grouped with other managers that report to someone who is responsible for managing them. In these relationships, however, the groups at the bottom of the organizational chart are usually much larger than those at the top.<sup>2</sup>

The companies in the defense industry operate with group relationships, although these relationships are often complex due to the matrix structures of the companies. Since most employees report to both function and project managers, their superiors may feel an unintended

struggle over who was the most control. For example, in a case where an engineer's skills are needed on a different project, the function manager may choose to reassign the engineer to fill that need. However, the project manager may have wished to keep him because getting someone else to replace him will disrupt project operations as the replacement becomes acquainted with the project. Another example can be made with the relationship between a project manager and his chief engineer. It is common that the chief engineer will surpass the manager in knowledge of the project's technical aspects and become more apt to make the decisions that the project manager has the authority to make. In this case, the project manager may feel like his authority is not being respected.

Another aspect of hierarchy that must be analyzed is the degree of centralization. This refers to looking at the extent to which the upper and lower management share the power to make decisions. In highly centralized organizations, the upper management is given most of the authority. By contrast, in decentralized organizations, authority is passed down and delegated to lower levels of management.<sup>2</sup>

In the defense industry, most of the authority for each project rests with the chief engineer and the project manager. Because the products being made by the companies are often very complex, there is a high degree of technical knowledge that is needed to make major decisions about them. Therefore, the decisions are often made by the chief engineer working on that specific product, or the project manager. While they may report to department managers who report to division managers who report to vice-presidents, and so forth, it is unlikely that the higher managers would know enough technical background on the product to make key design or production decisions.

Since defense companies operate with group relationships, it is also important to look at the final characteristic of hierarchy, which is the span of control that managers have. Span of control, in this case, refers to the number of people that a manager has authority over.<sup>2</sup> As was mentioned earlier, usually a manager with a lower position in an organization has a greater number of people for whom he is responsible. This is very true for the defense contractors since there are typically many employees that are needed to design and produce their products. Large groups work together to be able to make deliverables of the highest quality for the military.

Lockheed Martin has even developed a model to determine the ideal span of control that managers should be given. It assigns a weight to each of the following criteria:

- The degree of coordination required
- The organizational help available to superiors
- The locations of individuals reporting to a superior
- The degree of direction and control required by subordinate individuals
- The type of department or unit management
- The nature of work performed
- The importance of planning and functions of superiors or organizational units, their complexity and time requirements
- The similarity of functions carried out by subordinate individuals.<sup>2</sup>

After evaluating these factors, the company then assigns what it considers to be the most effective number of supervisors and subordinates.

## STANDARDS AND PROCEDURES

One of the most prevalent organization characteristics of defense companies is the special standards and procedures that they follow due to the military's reliance on them for products that will lead to mission success. Soldiers on the field depend on their systems for safety and survival, and the products must work when they engage in combat. To ensure that these results are achieved and that its equipment and its systems are of the highest quality, the military has developed procedures for these companies to follow. In order for them to receive government contracts, companies must demonstrate that they are capable of following those procedures, and that they will do so throughout the duration of the project.

The Department of Defense uses a series of stages in order to acquire new products and ensure their quality. The DoD Acquisition Model can be described with these phases:

- Concept and technology development
- Systems development and demonstration
- Production and deployment
- Operations and support.<sup>1</sup>

The first stage involves contractors developing new ideas and the technology necessary to achieve them. Then, they develop the system and present it for approval. Once it is approved, the system goes into production and it is delivered to the customer. When the system is put in use, the DoD depends on the contractor for support, which may include technical assistance, repairs, or making adaptations for different needs.

When the DoD is choosing which products to acquire, and which company to award a contract to, it evaluates five main categories. These are:

- Achievement of interoperability



- Rapid and effective transition from science and technology to products
- Rapid and effective transition from acquisition to deployment and fielding
- Integrated and effective operational support
- Effective management.<sup>1</sup>

This means that the DoD looks for the degree to which the product will work with its existing systems, and with those of the allied nations. It also evaluates how quickly and smoothly it would be able to complete the acquisition process. Moreover, it anticipates the quality of support that it would receive from a certain contractor. Finally, it assesses the management that the project would have since the utmost quality of project management is necessary in order to achieve all other characteristics.

The Department of Defense also develops military standards. These standards are made with the purpose of ensuring the quality and compatibility of military equipment. In 1969, the DoD drafted the first engineering management standard to be used by companies serving the military. The document, named Mil-Std-499 Engineering Management, was “developed to assist Government and contractor personnel in defining the system engineering effort in support of defense acquisition programs.”<sup>13</sup>

Engineering management military standards require contractors to go through a process of:

- Requirements analysis
- Functional analysis
- Synthesis
- Systems analysis and control.<sup>13</sup>

The first step, requirements analysis, consists of analyzing the customer's needs and objectives to determine what the product's essential characteristics will be. Next, a functional analysis calls for defining the functional architecture of the product and determining the design constraints of the project. During synthesis, solutions are designed in order to fulfill all of the performance and functional requirements. Lastly, during systems analysis and control, progress is evaluated and decisions are made by analyzing all of the alternatives. Management must ensure that the effectiveness of the system will satisfy the customer requirements and that any risk is minimized.

By requiring contractors to follow up-to-date engineering management military standards, the DoD ensures that the products it acquires will have been developed properly so that they are reliable and achieve mission success. When the standards are followed correctly, great emphasis is placed on planning. This reduces or eliminates risk, which is one of the primary goals of the DoD. Contractors must always strive to adhere to these standards.

Another process that the Department of Defense values is Capability Maturity Model Integration, or CMMI. This process was developed in 1997 at the Carnegie Mellon Software Engineering Institute with the sponsorship of the Office of the Secretary of Defense. This process is the result of an update to the previous Capability Maturity Model, or CMM. The CMM had been initially developed to help the DoD determine government contractors' ability to fulfill a software project so that it could award contracts to the best contractor. The CMM was expanded and improved so that the new CMMI gives organizations a model for process improvement.<sup>14</sup> By improving their development processes, defense contractors consequently improve the products or services that they provide.

The maturity level of an organization that uses CMMI can be appraised and rated on a scale from 1 to 5. These levels are:

1. Initial
2. Managed
3. Defined
4. Qualitatively Managed
5. Optimizing.

Defense companies strive to achieve Level 5, which shows the military that the organization is committed to continuous improvement and innovation. Currently Raytheon, Lockheed Martin, Boeing, and Northrop Grumman all have divisions appraised at levels 2 through 5.<sup>14</sup>

Overall, the organization characteristics that the four major defense contractors exhibit are very similar to each other. However, to more fully examine engineering management in the industry, it is also necessary to study the cultures that the contractors create in their companies.

## 5. CULTURE

While the core companies of the defense industry, Raytheon, Lockheed Martin, Boeing, and Northrop Grumman, have comparable organization characteristics, they have very unique cultures that set them apart from each other.

### RAYTHEON

At Raytheon, the biggest engineering management factor that contributes to the company's success is its Raytheon Six Sigma process, which is deeply rooted at the core of the company. Six Sigma has come to stand for a management system used to achieve quality products and processes. Even though the original term " $6\sigma$ " is a statistical term that describes a manufacturing process that yields only 3.4 defects for every million opportunities, or basically, a defect-free process, the term has been expanded to this engineering management tool.

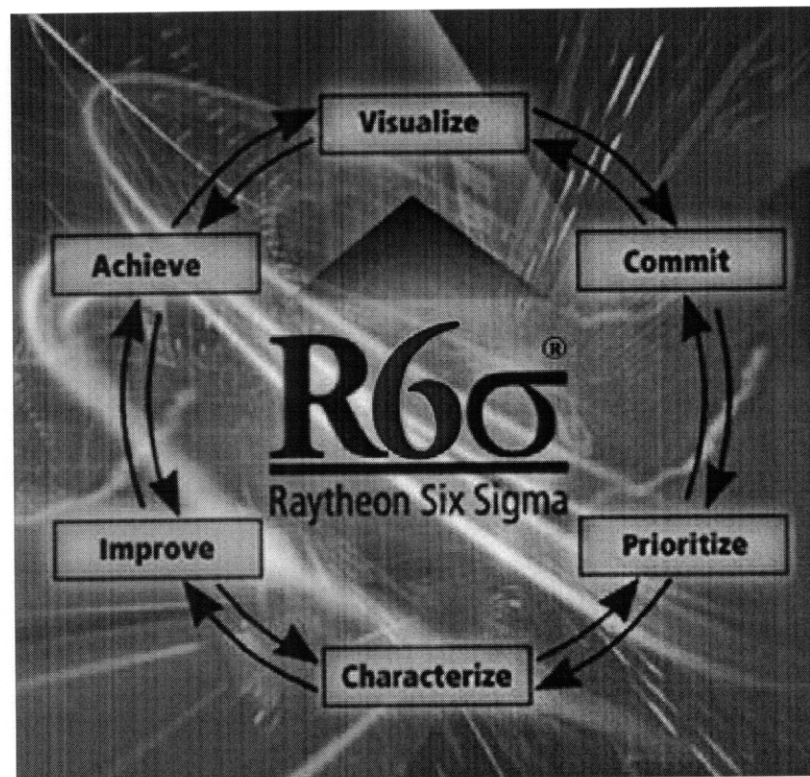
Six Sigma first appeared in 1974 when Robert Galvin, who was CEO of Motorola at the time, introduced the Six Sigma Quality Program to his company. His process called for using problem-solving to achieve zero defects not only in products, but in processes and management as well. The program was developed by Motorola employee Mikel Harry, and it consisted of the four steps:

- Measure
- Analyze
- Improve
- Control.

This Six Sigma program had enormous success, and when Mikel Harry moved to AlliedSignal in 1993, he implemented it there.<sup>15</sup>

Several years later, in 1998, Daniel Burnham, Vice Chairman of the Board of Directors at AlliedSignal moved to Raytheon to become COO and CEO shortly after. After having seen Six Sigma achieve great success at Allied, Burnham was intent on introducing it into Raytheon.<sup>16</sup> However, Burnham's vision for Six Sigma was that it should be centered around a new company culture so that Six Sigma would drive the whole business to grow and increase productivity.

Raytheon established its own version of Six Sigma, called Raytheon Six Sigma (R6σ), which was developed partly by Raytheon's Chief Learning Officer, Don Rochi.



*Figure 5.<sup>17</sup> The six steps of the Raytheon Six Sigma process. The company considers it to be one of the driving forces behind the company.*

The process consists of six steps: “Visualize” or imagining the future, “Commit” or committing to change, “Prioritize” or determining improvement priorities, “Characterize” or defining existing process and plan improvements, “Improve” or designing and implementing improvements, and “Achieve” or celebrating achievements and building for tomorrow.<sup>16</sup>

Raytheon offers employees R6 $\sigma$  certification for three different levels. The first one is “Qualified Specialist,” which involves 16 hours of classroom training, participating in an R6 $\sigma$  project, and approval from a coach. The next level of “Certified Expert” involves additional expert training, completing an R6 $\sigma$  project, and demonstrating proficiency to a certification board. Certified Experts are called on to lead projects in their functions and to train other employees on R6 $\sigma$ . The top level is “Master Expert,” which is achieved after further extensive training. Master Experts work full-time as R6 $\sigma$  leaders by training employees, planning projects, and mentoring others through the Six Sigma process.

Today, Raytheon Six Sigma is embedded in the company as a philosophy that managers use throughout the whole organization. This has resulted in savings of more than \$2 billion in just the first five years since its installment.<sup>18</sup> Because of the magnitude of success that it has brought the company, Raytheon places great emphasis in meeting its goal of having every employee trained as a R6 $\sigma$  Qualified Specialist and encourages employees to do so by rewarding them with a \$100 gift card when they complete the training. This even includes Human Resource staff, who have found valuable cost savings in their department as well.

Along with Six Sigma, Raytheon places great emphasis on education. The company’s philosophy is that it has to invest a considerable amount of money in education so that it causes an immediate impact on the organization.<sup>19</sup> Consequently, more educated employees will generate bigger profits, and there will be a significant return on the education investment. As a

result, the company offers many courses for employees to enroll in when the need arises. With a supervisor's approval, employees sign up for classroom or e-learning courses that will help with their project by choosing from an extensive catalogue. The trainers are employees who are experts in a topic, and the courses are taught during work hours. The funding for employees' pay during training is provided for by their functional department.

Raytheon management also recognizes that engineers have special training needs. For example, because engineers may have not received as much education in communication as other disciplines, the company offers classes such as peer review technique.<sup>20</sup> This gives employees the ability to critique someone else's designs or code without making him feel personally attacked.

As with training, Raytheon recognizes the value of graduate education. Employees who benefit from a graduate program can receive funds to complete a degree. In some cases, Raytheon will pay an employee's full tuition and expenses while he attends school full-time, or in other cases, the company will reimburse an employee's tuition while he attends school and continues working at the company part-time.

In addition to Six Sigma and education, Raytheon's culture includes its unique attitude. The top members of management of the company who are responsible for making and meeting goals tend to have a very confident outlook. This creates a good working environment for the engineers who create solutions for their businesses every day. By having faith in their team, the managers transfer to their employees a drive to succeed in any situation.

This attitude has its drawbacks though. When Daniel Burnham joined the company as CEO, he said that "one of the attractive aspects of this company is the can-do attitude, but it fundamentally blinded people."<sup>21</sup> With this comment, he referred to the managers who are

strongly tied to their projections. Once they commit to their five-year goals, they are very reluctant to back down from them or to report any problems that may keep them from reaching them. This tendency is very risky for the company as a whole since it can lead to big shortfalls in yearly earnings and to dissatisfied investors.

Along with its can-do characteristic, Raytheon's attitude includes a strong customer focus. In recent years, Raytheon's management has adopted new measures that recognize that its biggest customer is the Department of Defense and that its top priority is mission assurance. Therefore, it has determined that it must make changes to ensure customer satisfaction.

One of the major changes involved was shifting to an integrated supply chain. Managers are focusing on integrating their supply base with their engineering groups as early on in the project as possible. As opposed to a traditional supply chain, in which the cheapest supplier who can produce at the same quality and at the same schedule is selected to provide a project's necessities, Raytheon's new focus is selecting the suppliers with the best quality and best performance. This reduces rework and ensures mission success. One of the steps it is taking to ensure this is holding more supplier conferences in which the company presents its needs and expectations.<sup>22</sup> By doing this, Raytheon hopes to make suppliers an extension of itself, working to deliver the best products to the DoD.

Lastly, Raytheon's culture is ingrained with the highest regard for ethics. Mandatory training programs are carried out each year, and employees are told to refer to the Raytheon Ethics Committee for any questions or anonymous reports. As a result, Raytheon is the only company out of the four major defense contractors to have avoided major ethics scandals throughout its history. This is a big testament to its commitment of doing business the right way.



## LOCKHEED MARTIN

Lockheed Martin's culture can only be described with different characteristics than those of Raytheon. One of those characteristics is the value that it places on its assets. Lockheed recognizes that its engineers are the most valuable resource that it has. Because of this, managers invest in their employees, and as a result, strengthen the whole company. One example of how they accomplish this was illustrated by former Lockheed Martin CEO Augustine Norman. He wrote about taking customers to work sites to meet with employees, which "helps those workers appreciate the enormous importance of their jobs, especially when the customers are a pilot who flew one of [Lockheed Martin's] airplanes in the Persian Gulf War and an astronaut who will soon bet his life in one of [its] products."<sup>23</sup>

Another way that Lockheed's culture differs from Raytheon's is that it has been developed throughout all of its mergers. While Raytheon has acquired smaller companies, Lockheed has gone through many major changes to which the company has had to adjust. These changes have given the company the shape it has today.

Lockheed's management has maintained that even though there might be culture differences between the merging organizations, those culture differences can never become an excuse for not being able to do one's job. It has also found ways to make the company better by merging the best attributes of each organization's culture. For example, Augustine Norman said that "some companies have the tradition of doing their long-range planning on a probabilistic basis where they assign a probability to each program, while other companies plan on a quantum basis where they say, either [they will] win this program or [they will] lose it. [Lockheed Martin has] come up with a melded way of planning that is stronger than either of these approaches."<sup>24</sup>

In the long run, this has helped to strengthen the company in both its management and engineering capabilities.

In contrast to Raytheon, Lockheed Martin's ethics have been called into question. In 1976 the U.S. Senate declared that over the course of 20 years Lockheed made illegal bribes to foreign countries in order to secure contracts from them. As a result, CEO Dan Haughton and vice chairman Carl Kotchian resigned from the company, and Congress enacted tougher anti-bribery laws.<sup>25</sup>

After the company's major mergers, Lockheed began efforts to make ethics more central to its organization. It began using the "Ethics Challenge," a board game developed for the company by ethics experts. The game is played by all employees once a year, and it asks questions based on previous situations that have occurred in the company. It is the company's hope that when employees are faced with questionable choices, they will remember this training or turn to one of the designated ethics officers for advice.<sup>24</sup>

## BOEING

Boeing's culture has been under much scrutiny over the past decade. The interest in the company's internal workings began in 2003, when the Pentagon discovered that in 1998 Boeing had won a rocket-launch contract by using proprietary documents from Lockheed Martin. This resulted in Boeing being barred from participating and bidding on launch contracts for two years.<sup>26</sup>

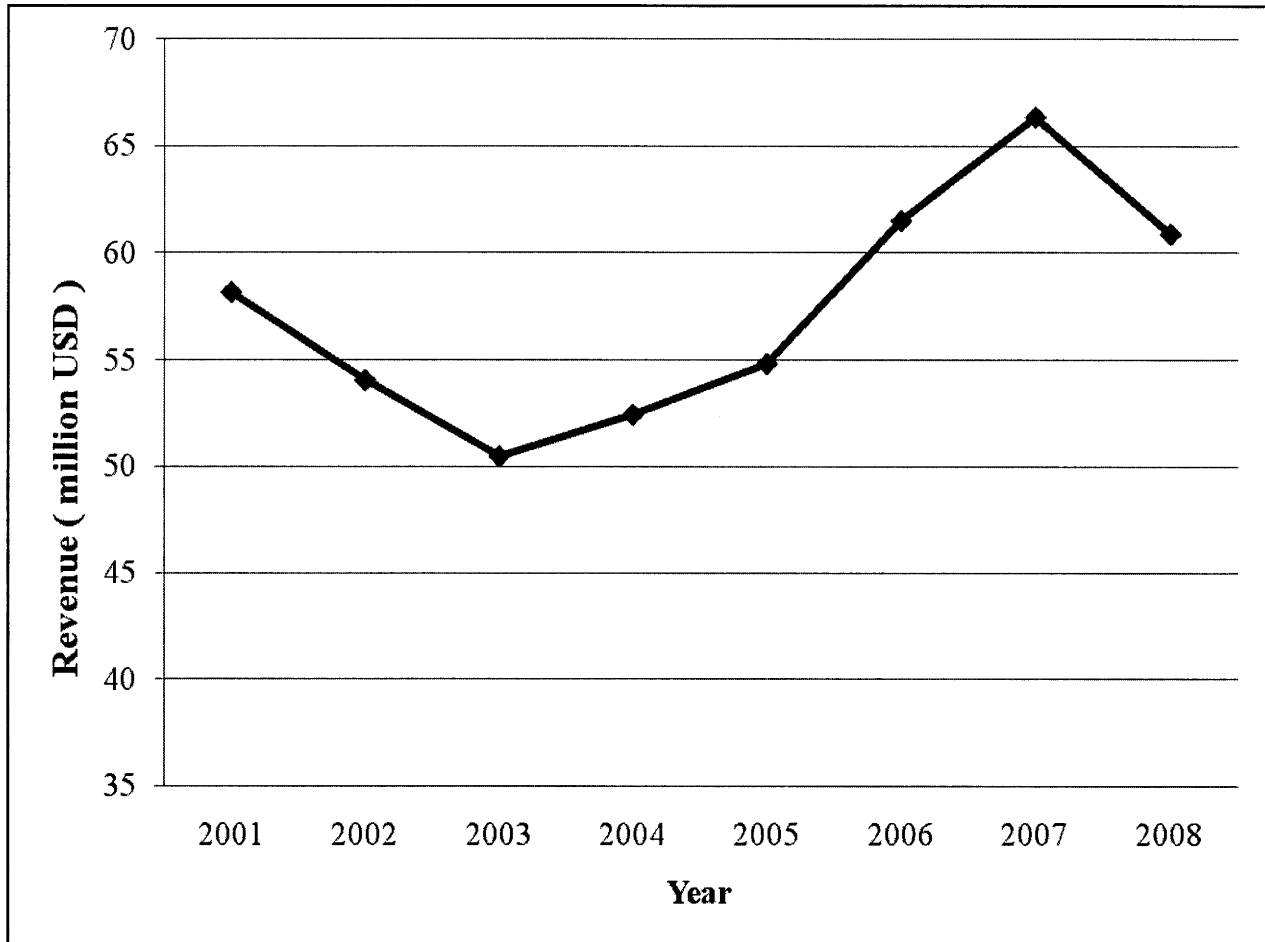
The spotlight on Boeing intensified later that year when the Air Force agreed to lease 100 refueling tankers from Boeing for \$22 billion, which was more expensive than purchasing the tankers would have been. After inquiry into the contract, it was revealed that Boeing CFO Mike

Sears had offered the Air Force's #2 procurement officer, Darleen Druyun, a job in a high-level position at Boeing. She then shared with the company the price that Airbus had offered for the tankers, which allowed it to win the contract. This resulted in Sears's forced resignation and sentence of four months in prison, as well as Druyun's sentence of nine months. Boeing CEO Phil Condit also resigned.<sup>8</sup>

Boeing's image took a hit once more in 2005, when CEO Harry Stonecipher, was forced to resign after it was discovered that he had been having an extramarital affair with Boeing executive Debra Peabody stemming from an annual Boeing executive retreat. This was very appalling to investors and the public who had been assured by Stonecipher when he took over for Condit that Boeing's culture would change. Stonecipher had even created an internal governance office which required employees to sign ethics statements. He was also quoted in Boeing's in-house magazine as saying "without integrity you cannot conduct business successfully. Firing people who lack integrity is good business."<sup>26</sup>

Another aspect of Boeing's culture that was brought to light because of the scandals is what Stanley Holmes calls "an unhealthy focus on internal politics."<sup>26</sup> Because of the need for a change in management after every incident, managers were more focused on trying to get top positions in the company than they were about managing their engineers. There are many company memos from this time period in which managers tried to cast blame or doubt about other executives while trying to exert influence to be put in those top positions.

These factors create a less than ideal work environment for engineers. The negative feelings and atmospheres are transferred over to them. When Harry Stonecipher joined the company, he described its engineering culture as "arrogant."<sup>27</sup>



*Figure 6.<sup>8</sup> Boeing's revenues from 2001 to 2008. There is a noticeable decrease during the years in which the company went through ethics scandals.*

Consequently, many analysts have concluded that the company's overall culture is responsible for a major decrease in revenue in recent years. Unfavorable dispositions in the company have led to a downturn in its performance. As shown in Figure 6, Boeing's revenue decreased during its period of turmoil. Managers are not applying the right strategies to improve their culture which is reflected in their performance.

## NORTHROP GRUMMAN

Part of Northrop Grumman's culture can be observed in its human capital strategy. Although all defense contractors understand the need to attract the brightest engineers to their companies in order to succeed in their industry, this company goes beyond the standard recruiting efforts in order to guarantee that it will obtain very capable employees.

Because engineers working in the defense industry must be U.S. citizens, the pool of potential new employees is small. Only 15% of college graduates work in engineering and science, and only half of those are citizens. Therefore, Northrop Grumman is committed to fighting what Bill Roberts calls "the war for talent."<sup>28</sup>

In the last few years, Northrop Grumman has installed satellite offices. These offices offer employees the chance to reduce commutes and work close to home. Northrop also strongly emphasizes to potential recruits the opportunities of telecommuting and flextime that are available at the company.<sup>28</sup> These features allow it to attract and retain engineers. Additionally, they allow it to target women of childbearing age and to integrate them as successful team members.

Although it has a talent acquisition program that strengthens its culture, Northrop Grumman also has had problems with its ethics. In the 1970s, it was discovered that Northrop had made illegal payments to the Richard Nixon 1972 campaign fund, and that the company regularly invited Pentagon officials and Congressmen to its hunting lodge. As a result, President Thomas Jones was forced to resign. In 1989, the company was also found guilty of falsifying test results for cruise missiles and jets. Moreover, the company has spent billions of dollars over the last two decades settling lawsuits for overcharging the government on several projects.<sup>9</sup>

These incidents have demonstrated that Northrop Grumman's culture does not lead employees to act in accordance to the highest ethical standards. This affects project development

greatly since engineers are not motivated to design the best solutions and produce the best results possible for their clients. Instead, they end up fudging tests to make it appear as though they have done their job.

Although Northrop Grumman is constantly seeking to attract the best engineering talent, it does not promote a culture that will lead it to success. Instead, the flaws in the organization lead it to generate less revenue and leave it with a smaller income.

## 6. CONCLUSIONS

The companies that make up most of the defense industry, Raytheon, Lockheed Martin, Boeing, and Northrop Grumman, have very similar organization characteristics. They mostly use a matrix structure to run their businesses. They exhibit group relationships, employ an intermediate degree of centralization, and issue a decreasing span of control with increasing power. Moreover, in order to ensure that they receive government contracts, the companies follow the Department of Defense Acquisition Model. They also apply engineering management consistent with military standards, and they use Capability Maturity Model Integration to their highest capability.

Even though defense contractors are alike in these aspects, they each have very different company cultures. Raytheon's culture places a very strong emphasis on its Six Sigma management philosophy, which is a major driving force for the whole organization's operations. Its culture also includes a great value placed on training and graduate education, a confident and customer-focused attitude, and a high regard for ethics.

Lockheed Martin's current culture is the result of the several mergers that the company has gone through. It believes in making sure that employees feel the impact of their work, and it has recently put an emphasis on ethics as a result of questionable activities by employees.

Boeing has a culture that has led it to troubled times. Its attitude has been called "arrogant," and it tends to be focused too much on internal politics. It has also exhibited poor judgment and a lack of ethics.

Northrop Grumman's culture is focused on recruiting and retaining human capital. However, it has also demonstrated that it does not place enough focus on ethical standards.

Company	Culture Overview
Raytheon	Six Sigma Training and higher education Confident outlook Customer focus Exemplary ethics
Lockheed Martin	Melded throughout company's history Ties employees to work New interest in ethics
Boeing	Arrogant engineering Internal politics focus Lower ethical standards
Northrop Grumman	Human capital focus Lower ethical standards

*Figure 7. Overview of companies' cultures. Each company has characteristics that make its culture unique.*

It is these differences in defense companies' cultures that really set the companies apart. Out of the four, Raytheon has the culture that is the most conducive to running a successful company. This is apparent when the financial performance of each company is evaluated. Raytheon's superiority is reflected in several key metrics.



<b>Company</b>	<b>Net Income/Employee</b>
Raytheon	\$22,904.11
Lockheed Martin	\$22,034.25
Boeing	\$16,473.49
Northrop Grumman	-\$10,210.36

*Figure 8.<sup>6-9</sup> Comparison of top defense companies' net income per employee ratio for 2008. Raytheon shows the best performance in this aspect, and it is followed by Lockheed Martin, Boeing, and Northrop Grumman in that order.*

The first of these metrics is the net income per employee ratio. This ratio is a measure of the average income that each employee in the company generates. Therefore, this ratio reveals a company's efficiency in management because it shows its ability to use human capital effectively. As shown in Figure 8, Raytheon ranks first in this aspect with \$23,000 of net income per employee in 2008.

<b>Company</b>	<b>Gross Profit Margin</b>	<b>12-month Revenue Growth</b>
Raytheon	20.10%	8.8%
Lockheed Martin	10.90%	2.1%
Boeing	17.30%	-8.3%
Northrop Grumman	18.30%	5.8%

*Figure 9.<sup>6-9</sup> Gross profit margin and 12-month revenue growth figures for 2008. Raytheon shows the healthiest financial position in both of these metrics.*

Gross profit margin can also be looked at in order to gauge a company's success. This ratio measures the percentage of profit generated from a company's revenues. Consequently, it provides a measure of a company's overall efficiency. A company with a higher margin can generate more profit with the same revenue. Figure 9 reveals that Raytheon is the top performer in this category as well, followed by Northrop Grumman, Boeing, and Lockheed Martin.

The final metric to consider is the revenue growth of each company. This metric shows the percentage that the revenue has grown in a given period, so it is a good indicator of the future direction of the company. Raytheon has the most promising outlook as shown in Figure 9.

Especially crucial to Raytheon's success is Raytheon Six Sigma. The company's mastery of this process has led it to significantly reduce costs and to achieve efficiency throughout the organization. Since its Six Sigma program can trace its origins back to the fathers and foremost experts on the subject, the company has been able to develop it into a highly successful process and embed it deeply in its core so that it influences how all projects are run.

While Lockheed Martin, Boeing, and Northrop Grumman also exhibit positive company culture traits, they do not measure up to Raytheon's, and this has greatly influenced each company's position in the market.

## REFERENCES

- <sup>1</sup>Babcock, D. L. Managing Engineering and Technology. Englewood Cliffs: Prentice Hall, 1991.
- <sup>2</sup>Dhillon, B.S. Engineering and Technology Management Tools and Applications. Norwood: Artech House, 2002.
- <sup>3</sup>Taylor, F.W. The Principles of Scientific Management. New York: Harper & Brothers, 1911.
- <sup>4</sup>Fayol, H. Administration Industrielle et Générale. Paris: La Société de L'Industrie Minérale, 1916.
- <sup>5</sup>"The Early Days." Raytheon Company. 2008. Raytheon Company. 6 March 2009.  
<<http://raytheon.com/ourcompany/history/early/index.html>>.
- <sup>6</sup>Dorsch, J. Raytheon Company. 2009. Hoover's, Inc. 6 March 2009.  
<<http://premium.hoovers.com/subscribe/co/overview.xhtml>>.
- <sup>7</sup>Dorsch, J. Lockheed Martin Corporation. 2009. Hoover's, Inc. 6 March 2009.  
<<http://premium.hoovers.com/subscribe/co/overview.xhtml>>.
- <sup>8</sup>Dorsch, J. The Boeing Company. 2009. Hoover's, Inc. 6 March 2009.  
<<http://premium.hoovers.com/subscribe/co/overview.xhtml>>.
- <sup>9</sup>Dorsch, J. Northrop Grumman Corporation. 2009. Hoover's, Inc. 6 March 2009.  
<<http://premium.hoovers.com/subscribe/co/overview.xhtml>>.
- <sup>10</sup>"Our Heritage." Northrop Grumman. 2009. Northrop Grumman Corporation. 6 March 2009.  
<<http://northropgrumman.com/heritage/index.html>>.
- <sup>11</sup>Zakheim, Dov S. and Ronald T. Kadish. "One-Stop Defense Shopping." The Washington Post. 28 April 2008: A15.

- <sup>12</sup>Norman, Augustine R. "Meeting Ignited Inevitable Consolidation." Defense News. 26 June 2006.
- <sup>13</sup>Engineering Management. Washington, DC: U.S. Department of Defense, 1974.
- <sup>14</sup>"CMMI." Software Engineering Institute, Carnegie Mellon. 2009. Carnegie Mellon University. 17 March 2009. <<http://www.sei.cmu.edu/cmmi/index.html>>.
- <sup>15</sup>"The Evolution of Six Sigma." Six Sigma. 2006. Process Quality Associates, Inc. 17 March 2009. <<http://www.pqa.net/ProdServices/sixsigma/W06002009.html>>.
- <sup>16</sup>Lanyon, Sally. "At Raytheon Six Sigma Works, Too, To Improve HR Management Processes." Journal of Organizational Excellence. Autumn 2003: 29-42.
- <sup>17</sup>"Raytheon Six Sigma Process" Raytheon Company. 2008. Raytheon Company. 6 March 2009. <<http://raytheon.com/ourcompany/ourculture/r6σ/process/index.html>>.
- <sup>18</sup>Whitney, Kellye. "Don Rochi: Vice President and Chief Learning Officer, Raytheon Company." Chief Learning Officer. December 2004: 7.
- <sup>19</sup>Strehlo, Kevin. "Raytheon SPIG Wins Big by Spending Big Bucks on Training." InfoWorld. 8 July 1996: 70.
- <sup>20</sup>Strehlo, Kevin. "Raytheon Lays Down a Practices Path for Developers to Follow." InfoWorld. 24 June 1996: 85.
- <sup>21</sup>Murphy, Victoria and Geoffrey Smith. "Reality Bites at Raytheon." Business Week. 15 November 1999: 78-82.
- <sup>22</sup>Bernstein, Mark. "Raytheon Goes From Traditional Purchasing to an Integrated Supply Chain." World Trade. November 2005: 36-40.
- <sup>23</sup>Norman, Augustine R. "Reshaping an Industry: Lockheed Martin's Survival Story." Harvard Business Review. May/June 1997: 83-94.

<sup>24</sup>Vogl, A.J. "The Latest Chapter." Across the Board. June 1996: 21.

<sup>25</sup>Terris, Daniel. Ethics at Work: Creating Virtue at an American Corporation. Waltham:  
Brandeis, 2006.

<sup>26</sup>Holmes, Stanley. "Why Boeing's Culture Breeds Turmoil." Business Week. 21 March 2005:  
34-36.

<sup>27</sup>Unseem, Jerry. "Boeing to Pieces." Fortune. 22 December 2003: 41-42.

<sup>28</sup>Roberts, Bill. "Going on the Offensive." HRMagazine. May 2008: 54-55.