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What started out as an experimental fighter aircraft designed to take advantage of advances in aerospace engine technology and to keep up with the new bombing aircraft of the time, the P-38 was thrust into production as the United States scrambled to produce fighter aircraft during the Second World War. Under these circumstances, solid integration, risk and scope management would have prevented the problems of engine reliability, compressibility and insufficient cockpit heat that resulted from the accelerated production, testing and fielding schedule. As a result, the operator in the Northern Europe was burdened with an aircraft that did not meet his needs. What was true in 1939 for the P-38 is true today for the F-35, when we pursue advances in technology, we must clearly understand the warfighter's needs, wants and expectations, integrate all stakeholders into the development process, and have a strategy to mitigate potential adverse events.

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THE P-38 LIGHTNING AIRCRAFT:

LESSONS LEARNED FOR FUTURE WEAPON SYSTEMS DEVELOPMENT

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF MILITARY STUDIES

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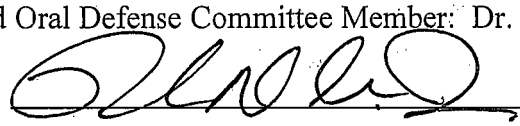
Approved: 

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Executive Summary

Title: The P-38 Lightning Aircraft: Lessons Learned for Future Weapon Systems Development

Author: Major Thomas Anthony Atkinson, USMC

Thesis: In the context of project management best practices, the P-38 case study provides a valuable lesson learned that may be applied to future weapons systems development and acquisition: the importance of integration, risk, and scope management.

Discussion: The P-38 Lightning resulted from a 1936 U.S. Army Air Corps proposal for a twin-engine interceptor fighter. The proposal was designed to take advantage of advances in aerospace engine and turbo-superchargers technology so that the new fighter could climb quickly and interdict bombers at high altitudes while carrying heavy armament. Lockheed, despite never having built a military aircraft, won the twin-engine competition. Its first XP-38 aircraft crashed while trying to set a new speed record in early 1939. Despite the crash, The U.S. Army Air Corps lobbied for the aircraft and Lockheed was given a contract for thirteen service-test YP-38s a few months later. As America's involvement in World War II seemed all but inevitable, the U.S. Army Air Corps accelerated the development, testing and fielding of the P-38. The P-38's accelerated delivery led to three critical developmental flaws: 1) poor reliability and performance of the Allison engines; 2) a compressibility problem that threatened to tear the tail off during steep dives; and 3) insufficient cockpit heat. Combined, these flaws greatly affected the aircraft's use in the European Theater of Operations and eventually lead to the Eighth Air Force Commanding General's decision to replace all P-38s with another aircraft platform. Today, the U.S. Government is following two nearly identical paths between the development of the P-38 and the new F-35 Joint Strike Fighter: 1) the DOD is procuring aircraft before completing testing and 2) DOD is trying to eliminate the requirement for a viable alternative aircraft engine.

Conclusion: What started out as an experimental fighter aircraft designed to take advantage of advances in aerospace engine technology and to keep up with the new bombing aircraft of the time, the P-38 was thrust into production as the United States scrambled to produce fighter aircraft during the Second World War. Under these circumstances, solid integration, risk and scope management would have prevented the problems of engine reliability, compressibility and insufficient cockpit heat that resulted from the accelerated production, testing and fielding schedule. As a result, the operator in the Northern Europe was burdened with an aircraft that did not meet his needs. What was true in 1939 for the P-38 is true today for the F-35, when we pursue advances in technology, we must clearly understand the warfighter's needs, wants and expectations, integrate all stakeholders into the development process, and have a strategy to mitigate potential adverse events.

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List of Acronyms

BHP	Brake Horse Power
DBT	Design-Build Team
D.C.	District of Columbia
DOD	Department of Defense
DODI	Department of Defense Instruction
ETO	European Theater of Operations
GAO	U.S. Government Accountability Office
GE	General Electric
JSF	Joint Strike Fighter
MPH	Miles Per Hour
PMBOK	*A Guide to the Project Management Body of Knowledge*
TEL	Tetraethyl Lead
U.S.	United States
WER	War Emergency Rating

Preface

As a member of the Department of Defense (DOD) Acquisition Workforce, a certified Project Management Professional, and an Aircraft Maintenance Officer, my interests are in studying commercial best practices that can be applied to DOD weapon systems acquisitions and aircraft sustainment. Of special interest to me are the product development and lean manufacturing techniques perfected by Boeing and Toyota. The P-38 Lightning case study provided me the opportunity to use Boeing's and Toyota's best practices as well as DOD Acquisition Instructions and the *Guide to the Project Management Body of Knowledge* to analyze the aircraft's development. I wanted to see what could have been done differently, using today's resources, to prevent the aircraft's flaws from occurring. What I found is that the U.S. Government is following a similar development strategy for the F-35 Joint Strike Fighter as its namesake some sixty years earlier.

In researching this thesis, I am grateful for the assistance of Rachel S. Kingcade, Chief Reference and Command and Staff College Direct Support Librarian, who was instrumental in helping me find books, periodical articles, papers and information on the P-38 aircraft's development and its use in Northern Europe during World War II. In writing this thesis, I am equally grateful to Dr. Paul D. Gelpi, Dr. Douglas E. Streusand and Lieutenant Colonel Michael L. Carter, USMC whose advice, guidance, and encouragement helped make this a reality. Finally, I would like to thank Dr. Craig A. Swanson for suggesting I analyze the P-38's development as a thesis topic.

Introduction

At the start of World War II, the Lockheed P-38 Lightning was the fastest American fighter aircraft available.[1] The revolutionary twin-engine single-seat fighter "had flying characteristics unlike any other airplane up to that time."[2]. Nearly 10,000 P-38 aircraft were built by 1945 and in the European Theater of Operations (ETO) P-38s destroyed 2,540 enemy aircraft alone.[3] The P-38 did very well in the warm-weather Pacific war zones. In Northern Europe, the harsh climate and excellent high altitude performance of enemy aircraft "caused it not to be one of the most favorite aircraft by American pilots" largely due to the aircraft's developmental flaws.[4]

The purpose of this paper is to study the P-38 Lightning's developmental flaws that manifested themselves in the ETO during World War II and offer lessons learned that could be applied to today's systems acquisition management. In the context of project management best practices, the P-38 development provides an excellent historical case study. Today, the U.S. Government and Lockheed Martin are pursuing a development strategy for the F-35 Lightning II Joint Strike Fighter that is similar to the P-38 of seventy years ago. It is likely then that the problems and challenges the operators experienced in the ETO could occur again if the F-35 program office does not adhere to the lessons learned of the P-38.

The study begins with an overview of the initial requirements that lead to the P-38 and some of the issues during development, testing, and fielding. Next, the study focuses on some of the major discrepancies in the ETO that eventually led to the Eighth Air Force Commanding General's decision to replace all P-38s with another aircraft platform. It concludes with an analysis of lessons learned for future weapons systems development and a discussion on why the P-38's lessons learned are applicable to the new F-35.

Why a Twin-Engine Pursuit Aircraft?

The P-38 Lightning was a result of a 1936 U.S. Army Air Corps proposal for a twin-engine interceptor fighter. Lieutenants Benjamin Kelsey and Gordon Saville authored the forward looking proposal for a fighter aircraft with a weapon load of 1,000 pounds and minimum 1,500 horse power that could defeat the new long-range bombers.[5] The proposal specified speeds of over 360 miles per hour (MPH) at altitudes of 20,000 feet, rigid requirements for fuel capacity,[6] and to use the "most powerful engine" of its day, the Allison V-1710C.[7] The U.S. Army Air Corps mandated these specifications so the new aircraft would have long range and ability to climb quickly in order to interdict bombers at high altitudes while carrying heavy armament. In addition to the Allison engines, the authors envisioned the twin-engine interceptor capitalizing on new General Electric turbo-superchargers[8] that were being developed. The turbo-superchargers were required in order to get the necessary Allison engine performance at the specified altitudes. To improve and simplify ground handling, a tricycle undercarriage was specified also.[9] The new aircraft requirement was entitled Specification X-608 and Request For Proposals were submitted to interested aircraft manufactures.

When Lockheed received the U.S. Army Air Corps Specification X-608, the company had never designed or constructed a military aircraft.[10] Lockheed gave Clarence "Kelly" Johnson the responsibility for designing the aircraft and leading the design team. Johnson's design satisfied all the requirements of Specification X-608 including the Allison V-1710 engines and turbo-superchargers but its look was unusual. Two streamlined nacelles carried the Allison engines. The nacelles tapered toward the back of the plane. A vertical tail plane and horizontal stabilizer connected the two nacelles and a small pod between the engines served as the cockpit and housing for the guns.[11] Johnson claimed his design would exceed speeds of 400

MPH. The Lockheed design incorporated everything that Lieutenant Kelsey specified and wanted. On 23 June 1937, the War Department declared Lockheed the winner of the twin-engine competition. Lockheed's design beat Boeing, Consolidated, Curtiss, Douglas, and Vultee. The Project Office at Wright Field gave the aircraft the military designation XP-38 and Lockheed $163,000 to build one prototype aircraft.[12]

It took the Lockheed team about eighteen months to complete their airplane. The complicated skin construction and the XP-38's more complex systems proved more difficult to build than other Lockheed aircraft. Tony LeVier, a Lockheed chief experimental test pilot noted, "Here was an airplane that was totally new and for 1939 when it first flew was absolutely revolutionary. It had flying characteristics unlike any other airplane up to that time."[13] The XP-38 proved Johnson to be correct, easily achieving speeds greater than 400 MPH and despite the unique and radical design, the aircraft proved to be very functional.[14] Early performance testing and the aircraft's speed prompted the flight test team to try to break the cross-continental U.S. speed record. Despite unresolved issues like the flap and brake system problems and limited test hours, on 11 February 1939, Lieutenant Kelsey flew the XP-38 from California to New York. During the flight Lieutenant Kelsey came close to breaking the speed record when the flight ended in disaster "as it crashed and was destroyed upon its attempted landing at Mitchel Field, Long Island, New York" that same evening.[15]

Despite the crash, Major General Henry "Hap" Arnold, Chief of the U.S. Army Air Corps, decided to use the event as an opportunity to put the aircraft into production. He had Lieutenant Kelsey brief top-level officials in Washington, D.C. the day after the crash about how fast the XP-38 was and "how nicely it handled."[16] By April, the U.S. Army Air Corps awarded Lockheed a contract for thirteen service-test YP-38s. Some argue Lockheed would not have

gotten this contract so soon since it would have been necessary to validate Lieutenant Kelsey's claims with "a prototype airplane full of bugs"[17] had the XP-38 survived the New York crash.

When Lockheed won the development and production of the XP-38 aircraft the company had no experience producing combat-type aircraft. By 1939, it had two contracts to develop and produce the most advanced American fighting aircraft.[18] As America's involvement in World War II seemed all but inevitable, the U.S. Army Air Corps urgently needed a long range, high altitude fighter. Despite having zero test hours on the YP-38, the Army ordered 673 P-38 aircraft. Although the XP-38 and YP-38 looked similar, it was a significantly upgraded aircraft over the XP-38 and incorporated a number of changes that the Army knew would require more testing.[19] Lockheed scrambled to build up test hours as quickly as possible on the first YP-38 beginning 16 September 1940. The U.S. Army Air Corps received the thirteenth YP-38 in May 1941 and new problems soon arose.[20]

P-38 Developmental Flaws

During the interwar period, military capability was a low priority for the United States. On the eve of its entry into World War II, the United States scrambled to build up its neglected armed forces, especially the U.S. Army Air Corps. Up until the mid-1930s, the focus of America's air force was defensive and mostly about bombers. As a result, the acquisition of new fighter aircraft took on an entirely new significance, which accelerated the development, testing and fielding of the P-38.[21] The P-38's accelerated delivery for the war effort led to three critical developmental flaws: 1) poor reliability and performance of the Allison engines; 2) a compressibility problem that threatened to tear the tail off during steep dives; and 3) next to no cockpit heat. Combined, these flaws greatly affected the aircraft's ability in the ETO.

The first P-38 to be combat ready was the P-38F, which entered production in March 1942. The aircraft's introduction to the ETO began in July 1942 as part of the initial overseas flights to the United Kingdom. The P-38F incorporated many equipment improvements and changes over previous models including the improved V-1710 engine, giving the P-38 engines a 1425 brake horse power (BHP)[22] rating. However, limitations of the integral wing leading edge intercoolers[23] could not support this rating at higher altitudes.[24]

The introduction of the improved Allison engines resulted in a thirty percent increase in power but that power could not be harnessed without the redesign of the intercooler system. In response to the problems with the integral wing leading edge intercoolers, P-38 operating instructions issued on 13 March 1942 reduced the allowable takeoff and military rating of the engine to 1150 BHP.[25] In response to the restricted rating, Lockheed ran several tests in an attempt to restore the original BHP rating. They determined that in order to achieve optimum engine operating conditions, the temperature of air coming from the intercoolers could not exceed 135 degrees Fahrenheit.

In the summer of 1943, Eighth Air Force received the upgraded P-38H. The P-38H's design included improved engines and turbo-superchargers for better high altitude performance; however, P-38H had the same intercooler inefficiency problems at altitudes between 25,000 and 30,000 feet causing overheated air to be fed to the carburetors.[26] The Allison engines were again downgraded from a War Emergency Rating (WER) of 1600 BHP to 1425, "which was still risky given the limited capacity of the turbo and leading edge intercoolers."[27] Consequently, in November 1943, the P-38J arrived in the United Kingdom and replaced the P-38H aircraft. The main change from the H model was the placement of the intercooler under the engine between

the oil radiators; however, this change did not solve the engine failure problem. In fact, the repositioning of the intercoolers led to "too much cooling at high altitude and pre-detonation."[28]

In addition to problems with the intercoolers, the Allison engines had issues with oil consumption and lubrication. Prior to the P-38H, all models had "hopper" type oil tanks that would lose oil pressure during negative "g" flight maneuvers.[29] This problem created a high number of engine failures and lost aircraft. The P-38J simply could not keep proper engine oil temperatures high enough at altitudes above 22,000 feet. In addition, oil consumption at altitudes of greater than 25,000 feet increased to an average of eight to sixteen pints per hour compared to only two to four pints per hour when flying below 25,000 feet.[30] As a result, U.S. Army Air Force officials reduced engine service life by fifty percent as these problems caused engine seizures and turbine failures.

There was a third problem related to Allison engines, this problem centered on the fuel system. The aircraft fuel supplied in England was improperly blended and the tetraethyl lead (TEL) compound would condense in the manifolds resulting in destructive detonation. The engines' poor fuel metering at altitude became apparent as engine failure continued to plague the Lightings.[31] Allison developed a solution by designing a carburetor-like device from an intake pipe that would re-atomize any fuel that collected in the pipe.[32] All V-1710 engines required a modification with this device.

The problems surrounding the Allison engines resulting from underperforming intercoolers, oil consumption and improperly blended fuel took several months to correct. At the same time, many new and inexperienced pilots began arriving in the United Kingdom. The Eighth Air Force became increasingly impatient as engine failures "suddenly skyrocketed"[33] and overall confidence in the aircraft plummeted.

Lockheed engineers wanted to replace the Allison engines with Rolls-Royce Merlin 61 engines as early 1941. There were three reasons for wanting to go with Roll-Royce. First, the Engineers believed that Allison was not making an earnest effort to overcome engine problems that were unique to the P-38.[34] Second, a Lockheed study of the Rolls-Royce Merlin engine completed a year earlier revealed that the British engine offered a higher speed in a broader altitude envelope. The Merlin also eliminated the requirement for turbo-superchargers and intercoolers, simplifying engine integration and installation, and it increased reliability at critical altitudes.[35] Lastly, the British Ministry of Aircraft Production had selected Packard Motors Company of Detroit, Michigan to manufacture and produce the Merlin engines so Lockheed would have had an American supplier.

Lockheed's proposal to replace Allisons with Merlins was rejected for a number of reasons. First, the U.S. Army Air Force had made a large commitment to Allison by investing in developing and manufacturing the V-1710 engine having just completed new manufacturing facilities for the V-1710 in 1941.[36] Second, the U.S. Army Air Force was under tremendous pressure to acquire aircraft for the war effort. At the time, Lockheed's production line produced about one fighter aircraft per hour and the War Production Board was unlikely to allow production of P-38s to slow down to allow the switch over to take place.[37] Lastly, it is likely that domestic pressure to employ Americans during the Great Depression made it difficult to justify buying a foreign aircraft engine. General Motors, the largest American corporation and defense contractor at the time, owned Allison.[38]

As a consequence, Allison engine failures were frequent in the ETO. Theses failures resulted in so many missing airmen that pilot morale suffered badly. Colonel Mark Hubbard, 20th Group Commanding Officer, remarked "that during the first three months the 20th Group

was on operations, it had the equivalent of a complete turnover in pilots-seventy percent of, which could be attributed either directly or indirectly to engine trouble. What a needless waste of highly trained men to the enemy!"[39] As confidence in the P-38 declined, Lockheed sent more technical representatives and test pilots to England to try to find a fix to the engine problems. These employees also had to deal with another unrelated problem- compressibility- that was also affecting confidence in the P-38.

The P-38 was the first fighter aircraft to reach speeds fast enough to experience the effects of compressibility. Despite that little was known about compressibility in 1937, Kelly Johnson wrote a report, endorsed by his immediate supervisor, that the XP-38 was likely to encounter compressibility effects as operating speeds and altitudes increased.[40] The U.S. Army Air Corps largely brushed aside this report because no aircraft had encountered such effects before compressibility caused the first YP-38 to lose its tail while pulling out of a dive.[41]

The term compressibility means that air molecules compress around certain points of the airframe as the aircraft travels through the atmosphere. During a high-speed dive, "the wall of air" builds up in front of the diving airplane making it difficult for the pilot to pull out. The airplane wants to increase the dive angle making recovery nearly impossible.[42] The YP models generated shock waves on the wings traveling at Mach 0.67 rendering the aircraft uncontrollable and causing the first one to crash. Pressure to produce aircraft for the war effort prevented Lockheed from making a permanent aerodynamic solution so Lightnings were deployed to the Pacific and European theaters without a fix.[43] Samuel M. Morrison, who flew P-38 aircraft in World War II, describes his encounter with compressibility: "I had put the aircraft into a powered 'split-S' maneuver and the airspeed had reached approximately 350 to 400 indicated.

The aircraft started to shudder, which was primarily felt in the elevator control. Then that control became frozen and ineffective."[44]

A permanent solution to the compressibility problem had to be found for aircraft in the European Theater of Operations. Rarely did enemy aircraft exceed 25,000 feet in combat in the Pacific. But over Northern Europe, P-38s were often involved in high-altitude operations providing escort for U.S. bombers trying to avoid German fighter aircraft, which had excellent high altitude performance.[45] A solution was not in the field until the P-38Js reached the United Kingdom in the summer of 1944.

Lockheed began development of a solution as early as 1942 that could have been incorporated into the aircraft on the production line; however, doing so would have delayed delivery, which was unacceptable to the U.S. Army Air Corps. The Lockheed solution was to put dive brake flaps under each wing outboard of the engines, which broke up much of the airflow and countered the effects of compressibility in a steep dive. By pushing a button on the control wheel, the pilot could activate the flaps allowing recovery from a steep dive during a bombing run or escaping an enemy fighter.[46] A prototype of the brake flaps was successfully tested on a Lightning in February 1943. Kelsey, now a Colonel, tested the device and believed they should have immediately been incorporated into the P-38 production line. The modification was not added until the P-38J-25-LO, fourteen months after the initial test and "this demining bit of negligence certainly cost many P-38 pilots their lives while restricting the fighter from becoming a very efficient warplane."[47]

One enduring problem of the P-38 that was never corrected all the years it was in production was the inadequate cockpit heating. This was a "fundamental design flaw" that Lockheed never anticipated.[48] Bitter cold cockpit temperatures made it extremely difficult for a

pilot conducting escort operations and in dogfights. It affected pilots in the ETO more than those in the warmer Pacific theater since air ducted to the cockpit from the engines was not enough to counter the sub-zero temperatures at high altitude during European winters.[49] In some cases, pilots would be so numb that they would have to be helped from the cockpit.

In order to compensate for the lack of heat, pilots wore many layers of clothing to keep from getting frostbite. These items included leather and lamb's wool, various types of gloves and boots, and eventually pilots were outfitted with electrically heated suits to combat the cold conditions.[50] The cold conditions and layers took its toll and pilot effectiveness dropped along with the temperatures. Royal D. Frey, an U.S. Army Air Force pilot that flew P-38s over Europe on long-range escort missions describes cockpit conditions and how pilots reacted in the following passage from his essay on flying the P-38:

> The other limiting feature, cockpit temperature, would be more correctly identified as "paralyzing." Cockpit heat from the engine manifolds was nonexistent. When you were at 30,000 feet on bomber escort and the air temperature was -55 [degrees Fahrenheit] outside the cockpit, it was -55 [degrees Fahrenheit] inside the cockpit. After thirty minutes or so at such a temperature, a pilot became so numb that he was too miserable to be of any real value; to make matters worse, he did not particularly care. Only his head and neck exposed to the direct rays of the sun retained any warmth.
>
> Not only did the numbness seriously decrease a pilot's efficiency, but the balky clothing he wore further restricted his efforts. For example, I wore double-thickness silk gloves, then heavy chamois gloves, and topped these with heavy leather gauntlets (all British issue). Inside all these layers were fingers almost frozen stiff and completely without feeling. Flipping a single electrical switch required deep concentration, skill, and luck, and the P-38 cockpit was loaded with electrical switches. How we envied the P-47 and P-51 pilots with a heat-producing engine in front of them to maintain a decent cockpit temperature.[51]

In addition, two other issues compounded the P-38s problems in late 1943 and 1944. The improved power rating for the Allison engines installed in P-38J models increased the maintenance requirements. These maintenance requirements were often overlooked. For

example, whenever the pilots pulled 1600 BHP, the exhaust plugs were required to be changed after the flight. Changing the plugs did not always happen, which caused them to foul and increased the likelihood of engine detonation during subsequent flights.[52] The second issue involved the timing of many new and inexperienced pilots. These pilots were trained in the United States to use engine settings not consistent with Lockheed or Allison technical instructions compounding the engine problems. In the 55th Group, forty percent of the unit was lost while operating P-38s and morale "was getting well down because of the stress involved with lots of long-distance missions, the constant threat of an engine failure, and the fact that poor cockpit heating and the associated windshield fogging was making it a certainty that P-38 was not the right airplane for high-altitude work."[53] Numerous problems with the Allison engines and the slow reaction to the compressibility and cockpit heating problems eventually lead General Doolittle to take matters into his own hands.

General James H. Doolittle became Commanding General of the Eighth Air Force in the spring of 1944. He immediately took action and decided to replace all P-38s and P-47s in the Eighth Air Force with P-51 Mustangs. Doolittle believed the Mustang was a more efficient and more cost effective than either the Lightning or the Thunderbolt and could perform the high-altitude escort and ground attack role better.[54] Since the P-38 was performing well in the Pacific warm weather theater, and commanders there were asking for more, General Doolittle's solution to get rid of the P-38s fit everyone. In Europe, the Lightning had been called an "ice wagon" and was doing a better job in other parts of the world.[55]

Analysis

One of the best long-range interceptors of the war,[56] the P-38 aircraft was born from a requirement for a fighter aircraft that could climb quickly and interdict bombers at high altitudes.

The P-38 requirement pushed aerospace technology at a time when few foresaw the need for a high-altitude fighter aircraft before the outbreak of World War II. In that sense, the P-38 serves as a great example for forward thinking requirements development within the Department of Defense. As a result, the United States was able to produce a modern fighter aircraft for the war effort on relatively short notice. This enormous accomplishment is "a tribute to the sacrifice and commitments at home"[57] by the men and women who pulled together to produce the P-38 as World War II approached.

Kelsey who retired a General and the original author of the X-608 specification, remarked that the P-38 "was born of necessity to counter the dearth of funds for development of new engines."[58] Unfortunately, the specification he wrote insisted on using Allison engines enhanced with new turbo-superchargers and did not allow for Lockheed to choose the best and most suitable engine for the P-38 aircraft. The P-38 would have been better served had then Lieutenant Kelsey written a performance-based specification for the desired capability to be achieved vice specifying the material solution. A performance-based specification would have allowed Lockheed the flexibility to work with engine manufactures to develop and field the best engine available to meet the P-38's demanding speed and high-altitude requirements. Lockheed would have been free to at least explore the proposal to use the high-altitude Merlin engine and test its performance in the P-38. If the Merlin performed in the P-38 as well as other American fighter aircraft of this era, the P-38's overall performance and reliability would have been increased and the problems encountered by the troubled turbo-superchargers and intercoolers eliminated. Furthermore, "weight and complexity would have been reduced, fuels would have become almost no problem at all and all-round performance showed important gains."[59]

The specific requirement for Allison engines with turbo-superchargers combined with the accelerated design, testing and acquisition of the P-38 resulted in many problems and limited the aircraft in its intended environment. These problems and the slow pace to correct them[60] contributed to the need to replace the P-38 in the European Theater of Operations. Using project management best practices, the P-38 case study provides three lessons learned that could be applied to future weapons systems development and acquisitions, the importance of 1) integration management, 2) risk management, and 3) scope management.[61]

Since the Allison engine was mandated, and this component was key to the overall success of the aircraft, Lockheed and Allison needed a close and collaborative working relationship from the beginning of the program. In this context, good integration management would have enabled Lockheed, Allison and the U.S. Army Air Corps to better concentrate their resources on current and potential engine problems before they could critically impact the project.[62] The project integrator, normally the project manager, is responsible for integration and must be critically involved in integrating individuals from the many different functional backgrounds into one operational unit.[63] It appears that the P-38 suffered from a lack of integration between Lockheed and Allison as Lockheed did not work closely with Allison to overcome the V-1710 engine problems but instead was looking to partner with a different manufacture.[64]

Two companies that see supplier integration as critical to the success of their products and are regarded as leaders in their industry are Boeing and Toyota. Boeing learned this lesson during the development of Boeing 747 aircraft when Pan American asked Boeing to build the jet and Pratt and Whitney the engines.[65] Boeing was later surprised to learn that Pratt and Whitney had known about a shaft problem and kept it from them. Joe Sutter, the 747 Chief Engineer, said

in his book *747: Creating the World's First Jumbo Jet and Other Adventures From a Life in Aviation*, "keeping their problems from us could have killed someone on the ramp or even brought down our airplane in flight. We didn't do business that way at Boeing."[66] As a consequence, the program was delayed and Boeing ended up completing 747s with 5,000-pound concrete blocks in the place of the engines to prevent the aircraft from sitting on their tails. 747s filled the Everett, Washington ramp ready to go except missing their engines.[67]

Boeing made sure that they did not repeat this problem when it went into development of the 777. The phrase 'Working Together' was Boeing's slogan for the 777 aimed at getting production, engineers, suppliers and the customers to work together to make the best aircraft. Chuck Chadwell, then head of General Electric's commercial engines, one of three 777 engine suppliers said, "I first remember [Alan Mulally, 777 General Manager,] when he took over the program and started this 'Working Together'...He was looking for the best solution for the program. Treating suppliers like they're your enemy may not get you the best product out the door." Mulally made all three engine suppliers pledge to reveal any problems with their engines in order to deal with the problems before they could affect the project.[68] In fact, Boeing has an engineer that serves as the company's business and technical interface between Boeing and its engine manufacturers. On behalf of its customers, Boeing takes responsibility for integrating the engines to the airframe and the aircraft's total performance because "their fate and reputation could be harmed by a bad engine."[69]

Toyota, before its current difficulties, had a reputation for producing high quality, reliable automobiles by building and integrating highly capable suppliers that share their commitment to lean manufacturing into their enterprise and "much of the award winning quality that distinguishes Toyota and Lexus results from the excellence in innovation, engineering,

manufacture, and overall reliability of Toyota's suppliers."[70] Toyota establishes agreements with its suppliers that analyze costs, establish prices and share profits built on mutual trust and interdependence. Constant improvement, complete honesty, and not taking advantage of one another are an interest for all parties.[71] As Liker writes, "What really cements Toyota as the model for supplier relations is its approach to learning and growing together with its suppliers."[72] The U.S. Army Air Corps was responsible for overall integration management and ensuring that Lockheed and Allison established similar supplier relationships. Since the U.S. Army Air Corps specified that Allison's engines would be used on the aircraft the U.S. Army Air Corps had a vested interest to see that both Lockheed and Allison worked together to solve the engine problems early in development and incorporated changes into earlier engine and aircraft platforms for the overall project's success.

The second lesson learned from the P-38 case study is the need for risk management[73] (the process of planning, identifying, and controlling project risk).[74] The purpose of managing risk on a project is to enhance opportunities and impacts of positive events while minimizing or eliminating the probability or impact of adverse events. P-38 program required a solid risk management plan from the beginning to reduce inevitable adverse events that would occur; the government was procuring a new multi-engine aircraft using newly developed engine technology that would expand the speed and flight envelop of fighter aircraft by a company that had no experience in that discipline.

Technological uncertainty, as a product of developing and pushing the limits of current technology, defined the P-38 from the beginning. This is a natural result anytime DOD expands its knowledge horizons in order to possess the best weapon systems.[75] Mitigating technological uncertainty requires managing risk throughout the development process and "is especially

relevant to meeting cost and schedule goals."[76] Critical to managing technological risk is testing the technology in a relevant environment for it to be considered mature enough for product development and fielding.[77] The U.S. Army Air Corps, needing to procure fighter aircraft at the onset of World War II, shortened the P-38's design-test-and-build process when it ordered 673 aircraft before the YP-38 prototypes were fully tested. Consequently, the U.S. Army Air Corps failed to identify and mitigate risks that developed in the ETO.

Using another example from the automobile industry helps to illustrate this point. Chrysler, under pressure to increase revenue, shortened their normal cycle of designing, testing, and building automobiles in 1975 when Chrysler introduced their Aspen and Volaré models. As Lee Iacocca stated, "The customers who bought Aspens and Volarés in 1975 were actually acting as Chrysler's development engineers. When these cars first came out, they were still in the development phase...Customers complained, and more than three and a half million cars were brought back to the dealers for free repairs—free to the customer, that is." [78] The Volaré's rusted fender program alone cost Chrysler $109 million in 1980 when Chrysler was seeking government loan guarantees. Similarly for the P-38, theater pilots were acting as test pilots in the face of the enemy. Where Chrysler desired quick profit, Chrysler ended up spending lots of money in repair costs and lost customers in the end. The U.S. Army Air Corps' desire to get the P-38 aircraft to the field quicker and shortchanging the development process, resulted in the engine, compressibility, and cockpit heating problems that impacted its use in the ETO.

Lastly, when a particular risk is identified, like compressibility, but a conscious decision to accept the risk is made, then the project team needs a contingency plan to handle the identified risk in the event that it materializes. The contingency plan should consist of two things. First, identify the contingency reserve resources (time, money, people, etc.) and management actions

(retesting, additional time for further design activities) that may have to occur. Second, ensure that appropriate administrative actions are taken to identify the contingency reserve to accomplish those management actions.[79] As March and Shapira articulate, "Society values risk taking but not gambling, and what is meant by gambling is risk taking that turns out badly...Thus, risky choices that turn out badly are seen, after the fact, to have been mistakes. The warning signs that were ignored seem clearer than they were; the courses that were followed seem unambiguously misguided."[80] A case could be made, that with all the factors affecting the P-38 development–an inexperienced developer, government-mandated unproven engine technology, and an accelerated production schedule to meet wartime demands–that the P-38 was a gamble.

The final lesson that may be learned from the P-38 case study is the importance of scope management[81] both in terms of the aircraft's development and its entire lifecycle. Critical to managing scope and requirements is to properly define scope and to ensure the stakeholder's[82] and/or customer's needs, wants and expectations are analyzed and converted into requirements.[83] For firms like Boeing and Toyota, these requirements are then translated into product design and manufacturing through after-market customer support in order to give the customer the right product or service.[84]

Before Boeing began the 777 project, it spent a lot of time with its airline customers to try to understand from their perspective what "their world was really like," [85] what their needs would be five, ten, twenty years into the future, and what was most important for the airline to generate revenue. What they found was that the airlines want a family of planes focused on the passenger's "comfort, convenience, and attraction of the journey."[86] When it came time to design the 777, Boeing took unprecedented measures to reach out to potential customers and get

their inputs to help design the best new airplane.[87] This led to the design-build team (DBT) concept, where airline customers and component manufacturers around the world joined Boeing Engineering to design and manufacture an aircraft that balanced all the different stakeholder objectives. The goal of the DBTs was threefold: 1) get the design right before people began making the 777, 2) get test articles closer to the final product, and 3) enable testing to go smoother so the aircraft could enter service earlier.[88]

The 737 is a good example of how Boeing continues to listen to customers after their product is designed and in service. Twice during the 737's lifespan, the aircraft was considered for cancellation due to flat orders. Both times Boeing improved the 737 to meet new customer requirements. The first time, they modified the plane so it could take off and land on gravel and grass airstrips. The second modification, Boeing increased capacity and range and added new engines, which became the 737-300.[89] Today, the 737 is the most-ordered and most-produced jet airliner in history.[90]

Similar to Boeing, Toyota believes in putting customers first and doing the right thing for the customer. Before developing a new automobile, Toyota spends a lot of time understanding what customers want in a vehicle. Liker writes that for Toyota, "It is not sufficient for leaders to pore over marketing data or listen to marketing presentations and get an abstract sense of the customer." Instead, Toyota tries "to get inside the heads of customers and develop a visceral sense of what purchasing a Toyota means to [them]."[91] At the same time, Toyota is very concerned about their customers after they have purchased a vehicle. Liker gives many examples in his book on how Toyota goes out of its way to maintain customer satisfaction. One example had to due with Toyota's Lexus brand and customers complaining that the tires were wearing out prematurely. The tires were chosen to enhance the ride and were well within

Toyota's specifications but they received over five percent customer complaints, well above the less than one percent they are used to. To compensate, Toyota "sent the owners of every Lexus where these tires were specified a coupon they could redeem for $500 and apologized if they had any inconvenience with their tires and felt that they wore out early."[92]

Perhaps if Boeing's and Toyota's emphasis on understanding stakeholders' needs, wants and expectations were used by Lockheed, they would have identified the cockpit heat requirement before the aircraft went into production and was delivered to the warfighter. A thorough scope definition and stakeholder analysis would have uncovered the requirement for a better cockpit heating system and would have allowed the P-38 to operate in the sub-zero temperatures of Northern Europe. Finally, even if this problem were not discovered before the first production model was fielded, good customer relations would have provided Lockheed the necessary feedback to incorporate a cockpit heating solution earlier in the aircraft's lifespan.

Applicability of the P-38 Lessons Learned to the F-35

In October 2001, Lockheed Martin won the competition for the F-35 Joint Strike Fighter (JSF). Lockheed Martin will produce three different variants of the fighter aircraft for the U.S. Air Force, U.S. Navy, U.S. Marine Corps and other international partners.[93] The JSF is DOD's most expensive aircraft acquisition program and represents a "quantum leap over legacy tactical aircraft capabilities."[94] The F-35 JSF was given the name 'Lighting II' after the P-38, which preceded it by sixty years. Ironically, the U.S. Government is following a similar development strategy for the new F-35 as the P-38: 1) DOD is procuring aircraft before completing testing and 2) DOD is trying to eliminate the requirement for a viable alternative aircraft engine.

In the face of developmental problems and cost overruns, the program office decided to compress the design-test-build process by procuring "up to 307 aircraft at an estimated cost of

$58.2 billion before completing development flight testing."[95] As was the case with the P-38, this approach increases the risk that developmental flaws will not be discovered until after production and fielding when flaws are more difficult and costly to correct. It is highly likely that flaws could manifest themselves at the least opportune time, like during a time of war, when the nation and the military need the capability the most.

Perhaps learning the lessons of the P-38, in 1998 Congress directed DOD to develop an alternative engine for the F-35.[96] An alternative engine would provide the program better engine performance and reliability, as competition would incentivize manufacturers to build better engines. A fully tested alternative engine would reduce the impacts a defective engine can have on the aircraft fleet, like operators in the ETO experienced with the Allison engines. However, since 2006, DOD has been trying to get the alternative engine program canceled despite Congress continuing to restore the funding.

The F-35 Lightning II program- like the P-38 Lightning program of seventy years ago- will need solid integration, risk and scope management since the program is compressing the design-test-build process and pursuing a sole-source engine manufacture. Good integration management will enable Lockheed Martin, its subcontractors, and the U.S. Government to prevent potential problems before they can critically impact the aircraft. A good risk management plan is absolutely a necessity as the probability for problems are high as the program procures aircraft before the completion of design testing. Finally, the program needs a good scope management plan to ensure it has a thorough understanding of all the diverse stakeholders' needs, wants and expectations as it goes forward with the compressed schedule. A solid stakeholder analysis in critical to get the design right before production so that seemingly trivial requirements, like cockpit heat, do not limit the aircraft's effectiveness during times of

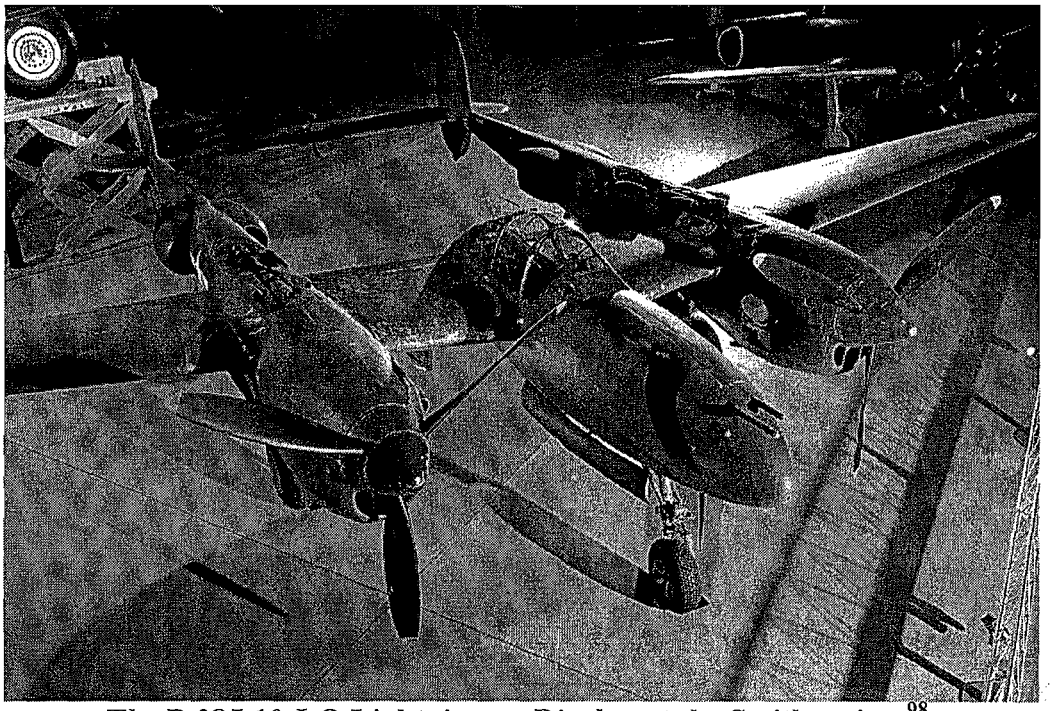
war. In addition, good scope and integration management will help get test articles closer to the final product and will ensure successful testing so the aircraft can enter service on their timeline.

Conclusion

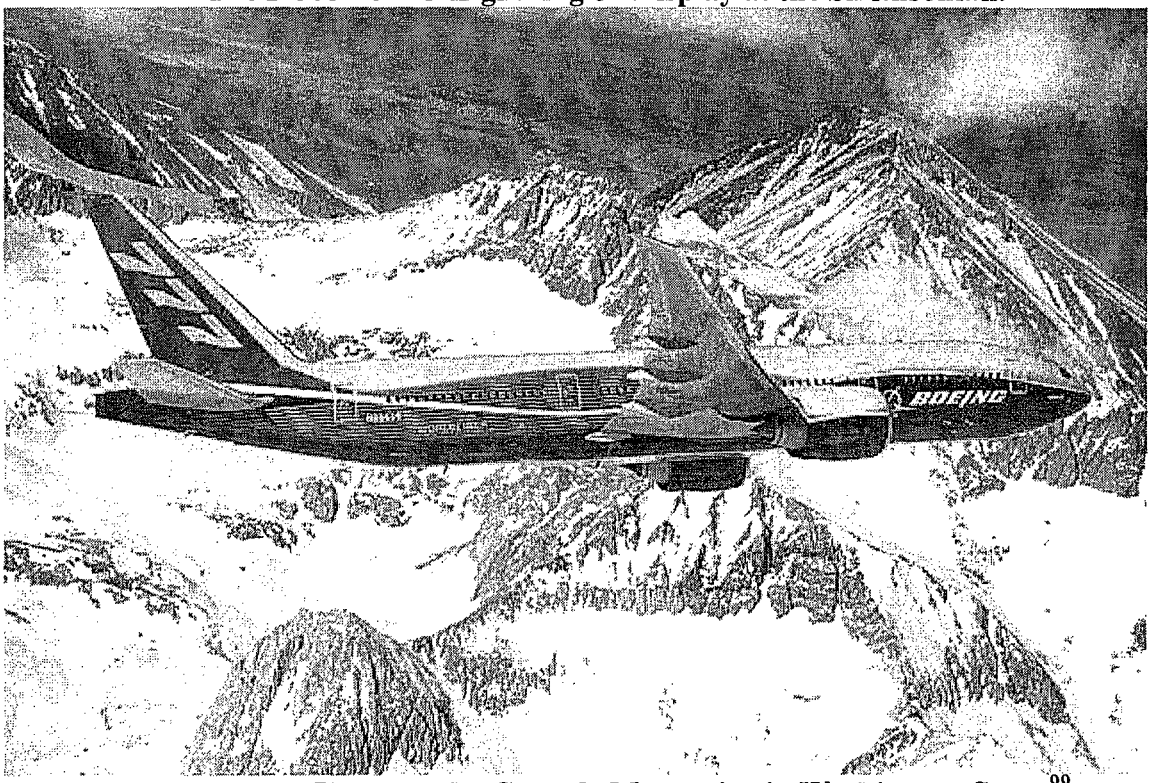
What started out as an experimental fighter aircraft designed to take advantage of advances in aerospace engine technology and to keep up with the new bombing aircraft of the time, the P-38 was thrust into production as the United States scrambled to produce fighter aircraft during the Second World War. Under these circumstances, solid integration, risk and scope management would have prevented the problems of engine reliability, compressibility and next to no cockpit heat that resulted from the accelerated production, testing and fielding schedule.

The P-38's problems in the ETO could occur today as the U.S. Government and Lockheed Martin pursue a similar development strategy for the F-35 Lightning II Joint Strike Fighter. What was true in 1939 for the P-38 is true today for the F-35, when DoD pursues advances in technology, program managers must clearly understand the warfighter's needs, wants and expectations, integrate all stakeholders into the development process, and have a strategy to mitigate potential adverse events. As Forsberg, Mooz and Cotterman explain in their book, *Visualizing Project Management: A Model for Business and Technical Success,* "Whenever we pursue opportunity we normally incur risk."[97] Thus, the necessity for sound integration, risk and scope management.

Appendix A: Photos

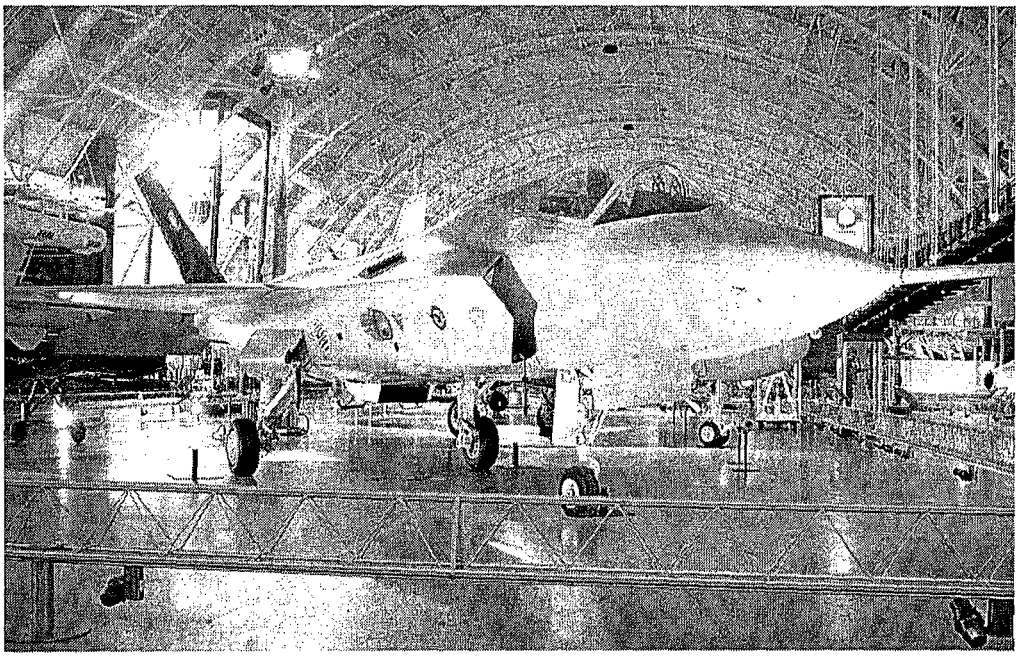


The P-38J-10-LO Lightning on Display at the Smithsonian.[98]



A new 777 flies over the Cascade Mountains in Washington State.[99]

2007 Toyota Tundra: Toyota is known for high quality and customer satisfaction.[100]



The X-35B Lightning II Joint Strike Fighter on Display at the Smithsonian.[101]

End Notes

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[2] Jesse Alexander, *P-38 Lightning* (Osceola, WI: Motorbooks International, Publishers and Wholesalers Inc, 1990), 30.

[3] Andrew W. Waters, *All The U.S. Air Force Airplanes 1907-1983* (New York: Hippocrene Books, 1983), 254.

[4] Alexander, 32-35.

[5] Carlos Kopp, "Der Gabelschwarnz Teufel." http:/home.att.net/~ww2aviation/P-38.html (accessed October 9, 2009).

[6] Anthony Shennan, *The Lockheed P.38 Lightning: A History* (Campbelltown, Australia: Historian Publishers, 1970), 1.

[7] Warren M. Bodie, *The Lockheed P-38 Lightning* (Hiawassee, GA: Widewing Publications, 1991), 14.

[8] Turbo-Supercharger is a type of supercharger driven not by the engine, but by a turbine that is powered by exhaust gases. Source: yourdictionary.com.

[9] Michael O'Leary, *Fighting Lightnings: The Complete Story of Lockheed's Fabulous P-38 Lightning During World War Two* (Canoga Park, CA: War Eagle Publications, 1988), 5.

[10] David Mondey, *A Concise Guide to American Aircraft of World War II* (New York: Smithmark Publishers, 1996), 165-166.

[11] J. Rickard, *Lockheed P-38 Lightning – Development,* May 30, 2007. http://www.historyofwar.org/articles/weapons_P-38_development.html (accessed October 9, 2009).

[12] Bodie, 19.

[13] Alexander, 30.

[14] Kopp.

[15] Charles Joseph Sedey, "German And American Airframes In World War II: A Study" (Masters Thesis, California State University, Fullerton, 2003), 82.

[16] Jeffrey L. Ethell, *P-38 Lightning* (New York: Zokeisha Publications, Ltd., 1983), 5.

[17] Ethell, 5.

[18] Bodie, xvi.

[19] Changes to the YP included enlarging the engine booms and adding new air scoops below the engine nacelles for the oil coolers to overcome the engine overheating problem; swapping engines so that the tips of the propellers turned towards the center of the aircraft to try to counter the tail buffeting problem; installing new more powerful "F" series Allison engines which had propellers nearer the top of the engine vice the middle. This caused the nacelles to become taller and slightly less elegant that XP. Source: Rickard.

[20] O'Leary, 20.

[21] Daniel D. Whitney, *Vee's For Victory!: The Story of the Allison V-1710 Aircraft Engine 1929-1948* (Atglen, PA: Schiffer Publishing Ltd., 1998), 137.

[22] Brake Horse Power means the power delivered at the propeller shaft (main drive or main output) of an aircraft engine. Source: aviation-terms.com.

[23] An Intercooler is a pre-cooler or a heat exchanger that is like a radiator. It is a component of an air-conditioning system fitted between a compressor and the turbine of a cold air unit or that used between the turbocharger and the cylinder of a reciprocating engine. Source: answers.com.

[24] Whitney, 139.

[25] Whitney, 139.

[26] Roger A. Freeman, *Mighty Eighth War Manual* (Osceola, WI: Motorbooks International, Publishers and Wholesalers Inc, 1991), 184.

[27] Whitney, 142.

[28] Freeman, 185.

[29] Whitney, 142.

[30] Freeman, 185.

[31] Freeman, 186.

[32] Whitney, 144.

[33] Bodie, 199.

[34] Bodie, 167.

[35] Bodie, 77.

[36] Bodie, 242.

[37] Bodie, 167-168.

[38] Bodie points out that Lieutenant General William Knudsen had been the top executive at General Motors Corp. and was President's Franklin D. Roosevelt's director general of the Office of Production Management, earlier civilian counterpart of the War Production Board, during this timeframe. Source: Bodie, 242.

[39] Frey, Royal D., "P-38 Lightning," *Flying American Combat Aircraft of WWII: 1939-1945*, ed. by Robin Higham, 61-73 (Mechanicsburg, PA: Stackpole Books, 2004), 69.

[40] Ethell, 5.

[41] Wagner, 262-263.

[42] Alexander, 30.

[43] Ethell, 6-7.

[44] Samuel M. Morrison, "The Lockheed P-38 Lightning," *Aerospace Historian* 30, no. 3 (1983): 157.

[45] Bodie, 77.

[46] O'Leary, 66.

[47] O'Leary, 66.

[48] "The Lockheed P-38 Lightning." available at http://www.plane-crazy.net/links/p38.htm (accessed October 9, 2009).

[49] Freeman, 184.

[50] Alexander, 42.

[51] Frey, 69.

[52] Whitney, 144.

[53] Bodie, 207.

[54] O'Leary, 59.

[55] Ethel, 27.

[56] Bill Gunston, *Aircraft of World War2* (New York: Crescent Books, 1980), 133.

[57] Whitney, 137.

[58] Bodie, 51.

[59] Bodie, xiv.

[60] Higham, 72.

[61] Diana Eastman, "Good, Better, Best." *Boeing Frontiers,* (September 2008): 32.

[62] *A Guide to the Project Management Body of Knowledge*, 3rd Ed., (Newtown Square, PA: Project Management Institute, 2004), 77.

[63] John R. Adams and Brian W. Campbell, "Roles and Responsibilities of the Project Manager." *In Principles of Project Management,* Editor-in-Chief James S. Pennypacker, 67-88. (Sylva, NC: PMI Publications Division, 1997), 73.

[64] The *PMBOK* defines Integration Management as "the characteristics of unification, consolidation, articulation, and integrative actions that are crucial to project completion, successfully meeting customer and other stakeholder requirements, and managing expectations. Source: *PMBOK*, 77.

[65] Karl Sabbagh, *21st-Century Jet: The Making and Marketing of the Boeing 777* (New York: Scribner, 1996), 120.

[66] Joe Sutter with Jay Spenser, *747: Creating the World's First Jumbo Jet and Other Adventures From a Life in Aviation* (New York: Harper Collins Publishers, 2006), 182.

[67] Sutter, 203.

[68] Michael Mecham and Anthony L. Velocci, Jr., "Person of the Year." *Aviation Week & Space Technology,* January 1, 2007, 52.

[69] Sabbagh, 118-120.

[70] Jeffrey K. Liker, *The Toyota Way: 14 Management Principles From The World's Greatest Manufacturer* (New York: McGraw-Hill, 2004), 201.

[71] James P. Womack, Daniel T. Jones, and Daniel Roos, *The Machine That Changed The World: The Story of Lean Production* (New York: Harper Perennial, 1991), 155.

[72] Liker, 216-217.

[73] The *PMBOK* defines Risk Management as "the processes concered with conducting risk management planning, identification, analysis, responses, and monitoring and control on a project; most of these processes are updated throughout the project. The objectives of Project Risk Management are to increase the probability and impact of positive events, and decrease the probability and impact of events adverse to the project." Source: *PMBOK*, 237.

[74] *PMBOK*, 237.

[75] Ethan McKinney, Eugene Gholz, and Harvey M. Sapolsky, "Acquisition reform – Lean 94-03." (Massachusetts Institute of Technology, May 24, 1994).

[76] Department of Defense Instruction 5000.2, *Operations of the Defense Acquisition System* (Department of Defense. December 8, 2008), 18-19.

[77] DODI 5000.2, 18-19.

[78] Lee Iacocca with William Novak, *Iacocca: An Autobiography* (New York: Bantam Books, Inc., 1984), 160.

[79] *DSMC Risk Management Guide for DoD Acquisition,* 4th ed. (Fort Belvoir, VA: Defense Acquisition University Press, February 2001).

[80] J. March and Z. Shapira, "Managerial Perspectives on Risk and Risk Taking," *Management Science*, vol. 33, no. 11 (November 1987), quoted in Kevin Forsberg, PhD, Hal Mooz, PMP, and Howard Cotterman, *Visualizing Project Management,* 2nd ed. (New York: John Wiley & Sons, Inc., 2000), 189-190.

[81] The *PMBOK* defines scope management as "the processes required to ensure that the project includes all the work required, and only the work required, to complete the project successfully. Project scope management is primarily concerned with defining and controlling what is and is not included in the project." Source: *PMBOK*, 103.

[82] The *PMBOK* defines stakeholder as a "person or organization (e.g., customer, sponsor, performing organization, or public) that is actively involved in the project, or whose interests may be positively or negatively affected by execution or completion of the project. A stakeholder may also exert influence over the project and its deliverables." Source: *PMBOK*, 376.

[83] *PMBOK*, 109.

[84] Earll Murman and others, *Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative* (New York: Palgrave, 2002), 92.

[85] Sabbagh, 27.

[86] Sabbagh, 27.

[87] Sabbagh, 47-48.

[88] Sabbagh, 70.

[89] Sabbagh, 33-34.

[90] "737 Family: About the 737 Family," *Boeing.com,* http://www.boeing.com/commercial/737family/background.html (accessed February 20, 2010).

[91] Liker, 178.

[92] Liker, 73-74.

[93] U.S. Government Accountability Office, *DEFENSE ACQUISITIONS: Analysis of Cost for the Joint Strike Fighter Engine Program,* Testimony of Michael Sullivan, Director Acquisition and Sourcing Management before the Subcommittees on Air and Land Forces, and Seapower and Expeditionary Forces, Committee on Armed Services, House of Representatives. (Washington, DC: Government Accountability Office, March 22, 2007), 2.

[94] U.S. Government Accountability Office, *JOINT STRIKE FIGHTER: Recent Decisions by DOD Add to Program Risks,* Report to Congressional Committees. (Washington, DC: Government Accountability Office, March, 2008), 6.

[95] U.S. Government Accountability Office Report to Congress, *JOINT STRIKE FIGHTER: Significant Challenges Remain as DOD Restructures Program,* Testimony of Michael Sullivan, Director Acquisition and Sourcing Management before the Committee on Armed Services, U.S. Senate. (Washington, DC: Government Accountability Office, March 11, 2010), 6.

[96] GAO, *DEFENSE ACQUISITIONS: Analysis of Cost for the Joint Strike Fighter Engine Program,* 2.

[97] Forsberg, Kevin, PhD, Hal Mooz, PMP, and Howard Cotterman, *Visualizing Project Management,* 2nd ed. (New York: John Wiley & Sons, Inc., 2000), 188.

[98] "Lockheed P-38J-10-LO Lightning." available from Smithsonian Air and Space Museum on-line: http://collections.nasm.si.edu/code/emuseum.asp (accessed October 9, 2009).

[99] "Commercial Airplanes," *Boeing.com,* http://www.boeing.com/company offices/gallery/images/commercial/ 777.html (accessed February 4, 2010).

[100] "2007 Toyota Tundra Front View." *Petersen's 4 Wheel & Off-Road.* http://www.4wheeloffroad.com/roadtests/131_0703_2007_toyota_tundra_first_drive/photo_01.html (accessed February 20, 2010).

[101] Lockheed Martin X-35B Joint Strike Fighter available from Smithsonian Air and Space Museum on-line: http://www.nasm.si.edu/collections/artifact.cfm?id=A20030172000 (accessed March 24, 2010).

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