



Internship Report

Quality Engineering at Lockheed Martin Aeronautics Company

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Introduction

Motivation for internship

I first heard about this internship when I was still doing my Bachelor's degree in mechanical engineering. It sounded really interesting, but of course I needed to be on my Master's degree to do it so I gave it a shot the year after thinking it was impossible to get it anyway, but there is nothing lost by trying.

My Bachelor's degree is in mechanical engineering and my Master's degree is in Materials and Manufacturing Engineering. For me this was a once in a lifetime opportunity both to get up close and personal with the production of one of the most advanced jets ever built and also the experience of living in the US for the better part of six months.

Preparation and arrival in Fort Worth

The selection process started in May with an online application. Then came an interview with Terma and secondly a phone interview with Lockheed Martin. They are all very friendly, but since I had never tried a phone interview before, I was slightly thrown off by how much more difficult it is to be interviewed by someone you can't see. Once I was selected, the mountain of paperwork appeared. It is fairly straight forward with the help from Kilroy and Terma, but it took a long time and a lot of emails back and forth with Kilroy to get it all in order.

Other stuff that also took some time was applying for grants, organizing housing and takeover of inventory and cars from the previous team of Dutch interns. So the semester up to departure was rather busy.

Once we arrived in Fort Worth we needed to get the cars registered and insured. It was really convenient to just buy the cars from the Dutch interns, that way they were already sitting in the garage when we arrived. Most of us arrived a week before our first day at Lockheed Martin and that was fine to get the practical stuff in order before we started.

Lockheed Martin

The company

Lockheed Martin is a result of a merger between Lockheed Corporation with Martin Marietta in 1995. Lockheed Corporation initially began as Alco Hydro-Aeroplane Company in San Francisco in 1912, just a few months after Glenn L. Martin was established in Los Angeles.

Over the years they have made iconic aircrafts such as, the P-38 Lightning, F-104 Starfighter, U-2 Dragon Lady, SR-71 Blackbird, the F-117A Nighthawk, the F-22 Raptor and of course the F-35 Lightning II.

The headquarters for Lockheed Martin is in Bethesda, Maryland and employs around 100,000 people worldwide.ⁱ

Business areas

Lockheed Martin operates in four different business sectors described shortly below.

Aeronautics

Aeronautics is the section that is responsible for designing, building and sustaining their military aircrafts. Their locations are Fort Worth - Texas, Marietta – Georgia and Palmdale – California which is where the famous Skunk Works are located.

Sustainment of the aircrafts of course consists of maintenance and spare parts but equally important is continued development on upgrades for the existing fleet of aircrafts.

Missiles and fire control

This section is focused on design and manufacturing of things like defense systems against aircrafts and cruise- and ballistic missiles, targeting and navigation systems for aircrafts and tactical missiles, guided projectiles and launch platforms to deploy these weapons. They also develop products for civil nuclear power plants.

Rotary and mission systems

Develops and manufactures products like helicopters both civilian and military, integrated air and missile defense systems, littoral warfare (warfare close to shore), underwater warfare, radar, electronic warfare etc.

Space

Supplies technologies for satellites, for communication, weather forecasting, space exploration and national security.

F-35 program

In 1997 Lockheed and Boeing were selected to compete for the spot as supplier of the plane supposed to replace the F-16, F/A-18 and AV-8B with three different versions of the F-35 Lightning II. It is a so called fifth generation fighter. The project is a collaboration between the United States and 8 other partnering countries. These are, Australia, Canada, Denmark, Italy, the Netherlands, Norway, Turkey, and the United Kingdom. These nations all have companies that supply parts for the F-35 production. Israel, Japan, and the Republic of Korea are also getting the F-35, but they fall into the category of Foreign Military Sales.

The F-35A conventional takeoff and landing (CTOL) is designed for the US air force and is also the version that most partnering countries, Denmark included, will be buying. This is generally a replacement for the F-16.

The F-35B short takeoff and vertical landing (STOVL) is designed for the US Marine Corps. As the name suggests it can take off in a much shorter distance and land vertically using a large lift fan located just behind the cockpit. This will replace the AV-8B. The UK and Italy are also going to operate these.

The F-35C carrier version (CV) is designed for the US navy to operate from their aircraft carriers. This version has a larger wing span and strengthened landing gear for catapult launches off the aircraft carriers. It also has the largest range of the three variants.ⁱⁱ




F-35 LIGHTNING II SPECS	F-35A 	F-35B 	F-35C 
Length	51.4 ft / 15.7 m	51.2 ft / 15.6 m	51.5 ft / 15.7 m
Height	14.4 ft / 4.38 m	14.3 ft / 4.36 m	14.7 ft / 4.48 m
Wingspan	35 ft / 10.7 m	35 ft / 10.7 m	43 ft / 13.1 m
Wing area	460 ft ² / 42.7 m ²	460 ft ² / 42.7 m ²	668 ft ² / 62.1 m ²
Horizontal tail span	22.5 ft / 6.86 m	21.8 ft / 6.65 m	26.3 ft / 8.02 m
Weight empty	29,300 lb	32,300 lb	34,800 lb
Internal fuel capacity	18,250 lb / 8,278 kg	13,500 lb / 6,125 kg	19,750 lb / 8,960 kg
Weapons payload	18,000 lb / 8,160 kg	15,000 lb / 6,800 kg	18,000 lb / 8,160 kg
Standard internal weapons load	<ul style="list-style-type: none"> • 25 mm GAU-22/A cannon • Two AIM-120C/D air-to-air missiles • Two 2,000-pound GBU-31 JDAM guided bombs 	<ul style="list-style-type: none"> • Two AIM-120C/D air-to-air missiles • Two 1,000-pound GBU-32 JDAM guided bombs 	<ul style="list-style-type: none"> • Two AIM-120C/D air-to-air missiles • Two 2,000-pound GBU-31 JDAM guided bombs
Maximum weight	70,000 lb class	60,000 lb class	70,000 lb class
Propulsion* (uninstalled thrust ratings)	F135-PW-100 40,000 lb Max. 25,000 lb Mil. Vertical N/A	F135-PW-600 40,000 lb Max. 25,000 lb Mil. 40,500 lb Vertical	F135-PW-100 40,000 lb Max. 25,000 lb Mil. Vertical N/A
Speed (full internal weapons load)	Mach 1.6 (~1,200 mph)	Mach 1.6 (~1,200 mph)	Mach 1.6 (~1,200 mph)
Combat radius (internal fuel)	>590 nm / 1,093 km (USAF profile)	>450 nm / 833 km (USMC profile)	>600 nm / 1,100 km (USN profile)
Range (internal fuel)	>1,200 nm / 2,200 km (USAF profile)	>900 nm / 1,667 km (USMC profile)	>1,200 nm / 2,200 km (USN profile)
Max g-rating	9.0	7.0	7.5

Figure 1 Comparison of the three variantsⁱⁱⁱ

They were initially supposed to share 70% of the parts which would of course be good for logistics and economic reasons, but over the course of the program that has fallen to only 25% of part commonality between the three variants.^{iv}

Denmark

In June 2016 Denmark agreed to buy 27 F-35As to replace the ageing F-16s. The first delivery will be in 2021 to Luke Airforce Base in Arizona for pilot training. Delivery to Denmark will take place in 2022. Amongst the Danish suppliers are Terma and Multicut. With Terma supplying over 70 components for the F-35. Amongst which are; composite skin panels, gun pod, pylons, radar electronics etc.



Figure 2 Components supplied by Terma for the F-35^v

Working at LM

Working at Lockheed Martin is a fun experience. The people are generally very open and happy to help which made us feel very welcome. The employees at Lockheed Martin are generally a good mix of newly graduated engineers and very experienced people who have been in the industry for 30+ years with a lot of these being ex-military. We spend the first days doing nothing but bonding with colleagues and getting to know the team. For whatever reason, but most likely the age and size of the company, the administrative processes at Lockheed Martin takes forever, especially when you are a foreign national, since we aren't really in any of their systems. So even getting a computer and then a login for it took few days and getting CATIA to work took weeks. That just seems to be the name of the game out here. However we were able to work around the limitations with help from my colleagues. The learning curve initially was quite steep. A lot of new people to meet and also a fair few rules regarding security and safety. Since I had only used VBA very briefly before starting work, that was quite a challenge as well. Another issue is just finding your way around the long hallways that all look more or less identical. You get used to all of it though. The great thing about such a large company is that there is always new places to explore as long as one of your colleagues has the time to give you a tour.

Quality Engineering

The quality engineering department in Fort Worth is there to ensure that every F-35 that leaves the production line meets the customer's expectations. They do this by analyzing the defects that are found on the jet by the inspectors. Each time a discrepancy between the blueprint and the actual build is found it is written up as a new defect. Each report might, however, include several defects in case, for instance, five holes are elongated in the same area, this will be five defects but just one quality assurance report (QAR) that the quality engineers will have to look at. These QARs are input to their Quality Assurance Document System (QADS). The quality engineers' job is to look at the individual QARs as they come in to evaluate each situation, both to figure out why it happened and how to solve it, which usually requires collaboration with the engineering team that designed the jet and the manufacturing engineers who plan the build process. The quality engineers also monitor trends in the defects to minimize reoccurring defects by acting on the so called high drivers. These are defects that either happen very frequently or is very costly to correct. This is measured in SRR hours, which is an acronym for Scrap, Rework and Repair, which is just the number of man hours it takes to fix the defect. They can then work with the mechanics and other departments to decrease the number of that particular defect. Apart from the internal quality control by Lockheed Martin, the customer, the U.S. Department of Defense, also makes inspections of the jets and audits of Lockheed Martin's processes to ensure that they are getting the product that they want, but Lockheed Martin strives to find all defects before they are caught by DMCA (the agency under the U.S. Department of Defense that does the inspections and audits).

Training Courses

During my stay at Lockheed Martin I have had the opportunity to take part in several classes described in the following sections.

Product Process Verification (PPV)

This class was a very quick and superficial introduction to how to conduct reviews of production processes and adjust them to ensure that they are both easy to do consistently and safely. This then ends up on the operational card (OpCard) which is a set of instructions for the mechanics on how to perform a particular task.

CATIA V5

This was a four day class where we were taught how to use CATIA V5, which is the CAD program Lockheed Martin and most of the aerospace sector uses. It is largely very similar to Solidworks which I am used to from School, but there were still a lot of details that were different which was good to figure out. The class started out with the very basics of using it as a CAD program and ended with making assemblies of several parts. Most of the exercises were basically to take a machine drawing and from that draw the part in CATIA from that. I found this to be quite a good way to learn it.

Plan Do Check Adjust (PDCA)

PDCA is a model for problem solving. It is a four step model for continuous and systematic improvement of a process or whatever. First you plan your changes, then you do the changes, then check the results, adjust the change and repeat until a satisfactory result is achieved. The class also teaches several methods for identifying the root cause of the issue. There were methods for identifying the most critical issues and how to prioritize what issues to tackle first, like what kinds of waste an organization has. This process can be written down on a paper to show the intended process and the results, this is called an A3. Named after the paper size used for it, for whatever reason.

This class ended with handing in an A3 based on a problem in our own departments that we were to tackle. One important thing was that the problem was within our sphere of control, which as a brand new intern at Lockheed Martin has the size of a green pea. So to get it going required quite a lot of collaboration from my colleagues so they could set things in motion that I could not.

The subject of the A3 was about the time it takes to read a QAR (Quality Assurance Report) from the inspectors when they find a discrepancy on a plane. The documentation for these reports aren't consistent from inspector to inspector which makes it difficult to read. So what we wanted to do was to decrease the time it took to read a QAR accurately and understand what the problem was. This project will be described in detail later.

Foreign Object Debris (FOD)

This was a half day class that taught us how to act and dress around the plane to avoid objects being left inside the plane with possibly disastrous consequences if it makes its way into the wrong spot. There was also a dummy setup of something similar to a wing box with deliberate FOD left all over the place where we practiced searching for the different types of FOD that are most likely to be found, like tools, wipes, cotton swaps etc. A multiple choice quiz later and we had our FOD badges. Which is required for going to the factory floor and actually getting up close and personal with the planes.

Product Data Manager (PDM)

This was a one day class about, as the name suggests, the use of software to manage data for particular products. Lockheed Martin uses this piece of software to manage things like data files, technical drawings and CAD files for all parts on the different programs. This ensures that they can find the information that they need across teams and locations, so even partner companies abroad has access to what they need. This is of course very important for a program like the F-35. It is however a program that we never got access to, so the class was just a quick overview of what it does without going into too much detail since we wouldn't be using it ourselves anyway.

Work projects

During my internship I have had a few major projects which will be described in the following sections. There were also smaller side projects and times where I just tagged along when one of my colleagues were doing something interesting on the floor.

Containment

This wasn't a single project, but several smaller projects where I helped my colleagues with containment of issues on the jets. It is initiated by someone noticing that a repetitive defect is found on multiple jets over a short period of time. This means that something in the production is going wrong and it needs to be corrected quickly. We then go to the production line and look for that defect on all jets that are far enough along to have had that particular work done. Then the process is to figure out exactly what jets are affected by the problem and making sure that they don't go any further before it is corrected. The next step is to look at what might have caused the problem and how to correct that. Examples of this is buying new tools because those issued to the mechanics don't work for a particular component. These issues creep up occasionally when the specification changes slightly to mitigate one issue, but then the existing tools aren't the right size/shape/spec to work this new specification and on it goes.

Heatmap improvement

The heatmap is a program developed with Matlab by some of the previous Danish interns. In short, its function is to make a 3D view of where all reported discrepancies on the plane are physically found. Say if a discrepancy is found on the wing tip, a little red dot will show up on the wing tip of the 3D model of the plane. The point is to easily visualize where the discrepancies are and find discrepancies in the same area because they might be related in one way or another. It already had several ways of sorting and filtering the input data which could be used to square off an area and only show discrepancies in that area, but it wasn't very intuitive. What we did was implement a new functionality so that you could use the mouse to draw a rectangular box in the 3D view and then use that as a filter so it only shows discrepancies found in that area. That of course filters the list of discrepancies shown, so it is easy to find them.

QAR Template

This is the same project I did the A3 on for the PDCA class. As explained in that section we wanted to make these documents more consistent. To do this we made a VBA program in Excel where the inspector is asked to type in all the necessary information and upload the pictures for the PowerPoint document and then the Excel program creates the PowerPoint document and fills in all the information with what the inspector types in. The advantage of doing this is that we can structure it quite strictly to ensure consistency between documents from different inspectors. First the inspector fills in the basic information

about the jet and the drawing number that the problem relates to. Then they are asked to mark where the problem is on a picture of the jet from the front, side and top view. This gives the reader a good idea about the location of the problem. To get enough information they are required to upload three images with an optional fourth. The three pictures are supposed to be an overview picture so it is easy to see what part of the jet we are looking at. When the picture is uploaded it also asks the user to point an arrow in the forward direction of the jet to make it easier. The second picture is one that is slightly closer up. The third picture is a full on close up picture where the inspector can click anywhere on the jet to add an arrow and a textbox to label part numbers for instance. The fourth optional picture is a picture of the so called part mark, which is a label printed on most components that show amongst other things which supplier made it. This makes it easier to figure out if it is a supplier issue and in that case which supplier. Once the user is through all the steps they can close the excel program and save the PowerPoint file or edit it in case they input something incorrectly or they need to do something out of the ordinary to make it clearer what the issue is.

This could for instance be a case where several holes in the same area is written up under the same QAR. Then the idea is that they can make the documentation with this program on one of them and then add for instance a table to the PowerPoint document with the dimensions of all the holes in that area. This will give enough information for the people reading the QAR and cause minimal extra work for the inspector.

Basically the idea behind this program is that it should be as quick to run through as possible, to make the inspectors more inclined to use it. Writing up a good looking and easily readable QAR with this takes just a couple of minutes and as few button presses as possible. It would definitely take longer doing it manually in PowerPoint and be less consistent. The downside is that sometimes the program might not quite allow them the flexibility they want. So with this program we try to cover 95% of all QAR reports and make them a whole lot easier and faster to write up. In the remaining 5% more work will need to be done after finishing the program, but it is all editable like if it had been created in PowerPoint from the start. It might cause some double work though. However taking any edge cases into account when making the program would not only be almost impossible but also make it more complex and more difficult to use. So the program asks them to upload the necessary information. Any extra is up to them to do in PowerPoint afterwards with all the flexibility that it gives them.

Inspect App

The Inspection App was made by some previous interns in Final Assembly at some point in time. Our department wanted to use it as well. Most of the plane is separated into mostly rectangular bays by the internal rib structure of the jet. So when all the work related to a particular bay is done it goes through a final inspection / buy off. If it passes it is sealed off to avoid any changes being done in that bay before it moves up the production line to be sealed up completely by the outer skin panels. What the Inspect App does is that it visually breaks the sections up into smaller pieces using pictures of the larger section and close up pictures of each bay or section to be inspected during this final inspection. For each close up picture there are tabs that guide the inspector in what pieces they need to look at and what common problems they need to look for. For instance you can click the tab 'clamps' the program then highlights all the clamps in that picture and makes sure that the inspector checks their size, if they are tight enough, if they are bent etc. The inspector can click on each defect he has checked for and that will count up a percentage of how close he is to being done with that bay. This gives a structured approach to inspecting the jet and is especially beneficial to new inspectors who aren't very familiar with the process. It also helps in case the inspection of a bay overlaps with two work shifts. So another inspector can quickly pick up where the other one stopped without inspecting the same thing twice or even worse, forgetting to inspect a part.

The highlighting of the clamps, tubes etc. in each bay is done manually using Photoshop, so the program can just switch between pictures of the bay with different things highlighted. In some cases a bay is particularly complicated and/or large that, that bay is split into several zones. So they are for instance asked to first inspect the lower half of the bay and once that is done, inspect the upper half. This is to avoid missing a component because there are so many of them.

Damage to engine rail

They had a problem where the rail that supports the engine in the center fuselage was being damaged. No one knew where this problem actually occurred between being manufactured in their plant in Marietta, although unlikely because it is inspected very thoroughly before being shipped out, and being handled through the shipping and moved between stations in the Fort Worth plant. This meant the problem kept being sent back and forth between departments, so I helped a co-worker follow the center fuselage through the Fort Worth plant, from when they first open it up in shipping to all the work stations it goes through, to figure out where the damage was most likely occurring. Once that was identified we had a close look at the processes and work that is carried out at that particular station to figure out what exactly caused the issue.

Opportunities

During our internship we also got a chance to meet the Honorable Brian Mikkelsen, the Danish minister of industry, Business and Financial Affairs when he visited the factory in March. We had a private meeting with him and his delegation before the more formal affairs began. This was a fun opportunity and gave us the chance to give him our view on working for Lockheed Martin, Terma's contribution to the project and the chance it gives us as students to be a part of it.



Figure 3 Brian Mikkelsen (center), Michael Dithmer, secretary of ministry of industry, Business and Financial Affairs (center right, back row) and us interns scattered around them.

We also got the chance to meet representatives from Dansk Industri, Dansk Metal and Multicut since they were at the factory in Fort Worth to sign contracts regarding three Danish machinist interns, from Multicut, who are to work at Lockheed Martin in May and June 2018.

We were also invited to Terma North Americas office in Fort Worth by Donny Weaver to see their facilities and learn about what they do.

Through an organization called LMents, which is for young employees of Lockheed Martin we got to try the F-35 simulator.



Figure 4 Picture of us in the F-35 simulator.

Spare time activities

Big Bend

One of our first big trips were to Big Bend National Park. It was fairly early in the season, so there wasn't a lot of people which was really nice. We almost had the place to ourselves. The landscape is absolutely fantastic and definitely worth the 8 hour drive from Fort Worth. Especially the early morning hours had a lot of fog laying as a thick carpet across the landscape. That was quite spectacular. The trip started out great with one of the cars having a completely dead battery, but other than that initial hiccup it was fine and a great place to visit.

Houston

Some of us drove to Houston to see the Johnson Space Center. We took the level 9 VIP tour which was quite expensive, but it was really cool to get backstage and see the old Apollo mission control, sit in the space shuttle simulator etc. We also timed it with the Spring Nationals at Royal Purple Raceway so we could experience Top Fuel drag racing. That was a really fun experience, the noise from the cars is absolutely awesome. Getting into the pits while they rebuild the cars was also really cool. They stripped those engines down to the block really, really quickly. The teams were also nice about leaving race-used parts outside the garage for people to take home as souvenirs. I came home with a clutch plate, which is pretty big and heavy, so I'm still not sure if I can get it back to Denmark in my luggage but knowing that it has been part of transmitting 8000+ horsepower to the ground is pretty cool.

Arizona

Most of us went to Arizona for both the Yuma and Luke AFB airshows on the same weekend. That was my first ever airshows and a fantastic experience. With planes like F-35, F-22, P51 Mustang, A-10, Blue Angels in their F-18s, Tora! Tora! Tora! Reenacting the attack on Pearl Harbor, a jet powered semi-truck called shockwave and many others appearing.

Zion and Grand Canyon

Four of us flew to Las Vegas, drove to Zion national park where we hiked up angels landing, which was really beautiful, but I'm not good with heights so I had to sit out of the last really steep and narrow bit. Then we drove to the south entrance of Grand Canyon where we had half a day on Saturday to see the different viewpoints and then we arrived at 10am on Sunday to hike down to bottom along the South Kaibab trail. About 10km each way and 1600m of elevation made it quite a challenge and we only just about made it in time to get to the airport in time for our flight that night. It was definitely the most challenging hike I've ever been on, but it was definitely worth the sore legs afterwards.

Apart from this I have also been to New York, Austin, San Antonio, Corpus Christi, a few gun ranges, NASCAR at Texas Motor Speedway, a rodeo, an airshow in Abilene starring both multiple B1s and a single B2 stealth bomber. A few of us also have a trip planned for the Canadian Grand Prix in June which I am sure will be really good fun.



Figure 5 NASCAR at Texas Motor Speedway.



Figure 6 View over Grand Canyon.

Benefits of internship

Technically I have learned a lot about aircrafts, manufacturing and especially methods to ensure consistent products of high quality. Since most of my projects involved VBA programming, which I had barely used before, I have become a lot better at using that as a tool for different daily tasks which I am sure will be very useful in my future career. I have become familiar with what being a quality engineer entails. Working at such a big company was also a good learning experience, to figure out how you need to approach issues. All of which has definitely given me some perspective on my future career decisions. I have also developed a lot personally through interacting with a lot of new people. It is also a fantastic experience to travel around the United States and see what it has to offer. This was my first time here, so it was all very new and exciting. The 9/80 work schedule, giving us every other Friday off, was really useful to go and visit a lot of different places in North America. So overall it has been a great experience and I am very grateful that I got this opportunity.

For future interns

Bring warm clothes. Texas might be known for its heat, but when you arrive in January it can still be freezing. We had perfect 18 degrees C for a couple of days followed by a couple of weeks of below or just above freezing before it started to warm up again. Also, Americans like their offices cold, so bring a few sweaters. It can feel especially bad when you come from 30+ degrees outside into a chilly office where you sit all day.

When you first get into work you'll get a security briefing which you need to pay attention to. In general, if you are in doubt, ask before you do anything that might get you in trouble. Once you get to your cube area, just try to get to know people. Southern hospitality is definitely a thing and they are all very friendly and easy to talk to. Don't worry about that at all. We found that bringing Danish candy was a fun and easy way to engage with them at first.

Ask for work and be specific about the kind of work you want to do early on. Otherwise you can run into periods with little work to do.

For your spare time, try to make a schedule early on to figure out where you want to travel to. The long weekends are really useful, but I found that I quickly had more things I wanted to do than I had weekends to do it on. You can also flex your hours to stretch your weekends further if need be. Saving up the hours to do takes a while though, depending on how long days you are comfortable with.

Spending the occasional lunch break on the patio outside the big cafeteria is a good way to see some aircrafts from the neighboring naval airbase, even just the walk to the car in the afternoon gives quite a good view. Obviously a lot of F-35s and F-16s, F-18s but also C-130 Hercules and even V-22 Ospreys can occasionally be seen flying in and out of the airbase.

Sources

ⁱ <https://www.lockheedmartin.com/en-us/news/features/history.html>

ⁱⁱ <https://www.f35.com/about/variants>

ⁱⁱⁱ https://www.lockheedmartin.com/content/dam/lockheed-martin/aero/documents/F-35/F-35_FastFacts_4-18.pdf

^{iv} <https://www.bloomberg.com/news/features/2017-04-04/is-the-f-35-a-trillion-dollar-mistake>

^v <https://www.terma.com/aeronautics/advanced-aerostructures/the-worlds-largest-industrial-project/>

Front page image: Lockheed Martin