Internship at Lockheed Martin Aeronautics

From January 16 to June 15, 2017

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Introduction

The following is a report from my internship at Lockheed Martin Aeronautics from January 16 to June 15, 2017. The internship program is provided together with Terma A/S and it is the 3rd year that the program has been running with 3 different teams of interns.

At the end of May 2016, I was selected for an Internship at Lockheed Martin in Fort Worth, USA. I was selected together with 5 others - 4 of them were also students at Technical University of Denmark (DTU), while the last one selected was a student at Aarhus University (AU). We shared many of the same experiences during the 6 months in Fort Worth - both at Lockheed Martin and in our spare time.

Figure 1 *All 6 Danish interns in front of the main building at Lockheed Martin Aeronautics in Fort Worth*

We were placed in different departments and locations at Lockheed Martin but everybody worked with some aspect of the F-35 Joint Strike Fighter. I was placed in the Wing Manufacturing Transition Team where I was involved in projects to ramp up the production of the F-35 production rate capability. The tasks in the team varied from developing workstations improvements to organizing tooling and factory project schedules.

Finally, I want to thank Terma for offering the internship and helping with all the practical stuff. I also want to thank Lockheed Martin and especially my team - I felt like a part of team from the first day and I learned a lot from them.

Lockheed Martin

The company was formed by the merger of Lockheed Corporation with Martin Marietta in 1995 and the company's main business areas are Aerospace, Defense, Information Security, and Advanced Technologies. The Aeronautic' divisional headquarter is located at United States Air Force Plant 4 in Fort Worth and has additional production in Marietta, Georgia and Palmdale, California. The company has a product portfolio of many famous airplanes, which included for instance the C-130J Super Hercules, C-5 Galaxy, F-16 Fighting Falcon (purchased from General Dynamics), F-117 Nighthawk, F-22 Raptor, and F-35 Lightning II.

United States Air Force Plant 4

The plant is adjacent to Naval Air station Joint Reserve Base Fort Worth and military aircrafts have been manufactured on the plant since 1942 – pictures of the manufacturing during the WW2 are shown different places at the plant and they can be really fascinating to look at. The two following figures show current pictures of the Plant and the Air station:

Figure 2: United States Air Force Plant 4 (left) and the Naval Air Station Joint Reserve (Right) (Source: Wikipedia)

The plant is a contractor-operated aerospace facility and currently it is operated by Lockheed Martin Aeronautics, which manufactures both the F-16 and F-35 at the plant. However, the F-16 manufacturing in Fort Worth is planned to relocate this year, in order to make space for the full production of F-35. Currently, approximately 16,000 people are employed at the plant and it was really fascinating to be a part of a company with that many employees, and experience how a company of that size is managed.

The Joint Strike Fighter (JSF) Program

The intention of the JSF program was to replace a wide range of existing fighter, strike, and ground attack aircrafts for the United States and their allies. Different concepts to the JSF program were started in 1993 and it led to submissions to the US Department of Defense by McDonnell Douglas, Northrop Grumman, Lockheed Martin, and Boeing. However, only two contracts to develop prototypes were awarded in 1996, one each to Lockheed Martin and Boeing. Each firm produced two aircraft to demonstrate Conventional Takeoff and Landing (CTOL), Carrier Takeoff and Landing (CV), and Short Takeoff and Landing (STOVL). The two different prototypes are illustrated on the two following pictures:

Figure 3 - The Boeing X-32 (left) and the Lockheed Martin X-35 (right) (source: Wikipedia)

The contract was awarded in 2001 to Lockheed Martin by the US Department of Defense and the main reason for that decision was the method X-35 used to achieve STOVL flight. The X-35 became the basis of the F-35 Lightning II - which first flew on December 15, 2006 – and they are currently being produced at a low rate.

The F-35 Lightning II

The United States primarily funds the F-35 development, with additional funding from partners - which include the United Kingdom, Australia, Italy, Canada, the Netherlands, Turkey, Norway, and Denmark. The plane is a single-seat, single-engine, all-weather stealth multirole fighter, and it is designed to perform air defense missions and ground attack. Three main models of the F-35 Lightning II exist:

- F-35A Conventional takeoff and landing (CTOL)
- F-35B Short takeoff and vertical landing (STOVL)
- F-35C Carrier Version (CV)

In order to keep development, production, and operating costs down the three variants share more than 80 percent of their parts. Nonetheless, the three variants are designed to replace a wide range of tactical fighters and attack aircrafts for the US air Force, Navy, and the Marine Corps.

Lockheed Martin was awarded the prime contract but several other companies make structural parts or subassemblies to the plane. Currently, Lockheed Martin Aeronautics provides wings, forward fuselage, and aircraft flight control system. Northrop Grumman provides center fuselage, weapons bay, and arrestor gear for the CV-variant. BAE Systems provides aft fuselage, crew life support and escape systems, empennages together with the vertical and horizontal tails. Furthermore, several parts are made from other minor suppliers – all the different structure parts and suppliers are shown on the following figure:

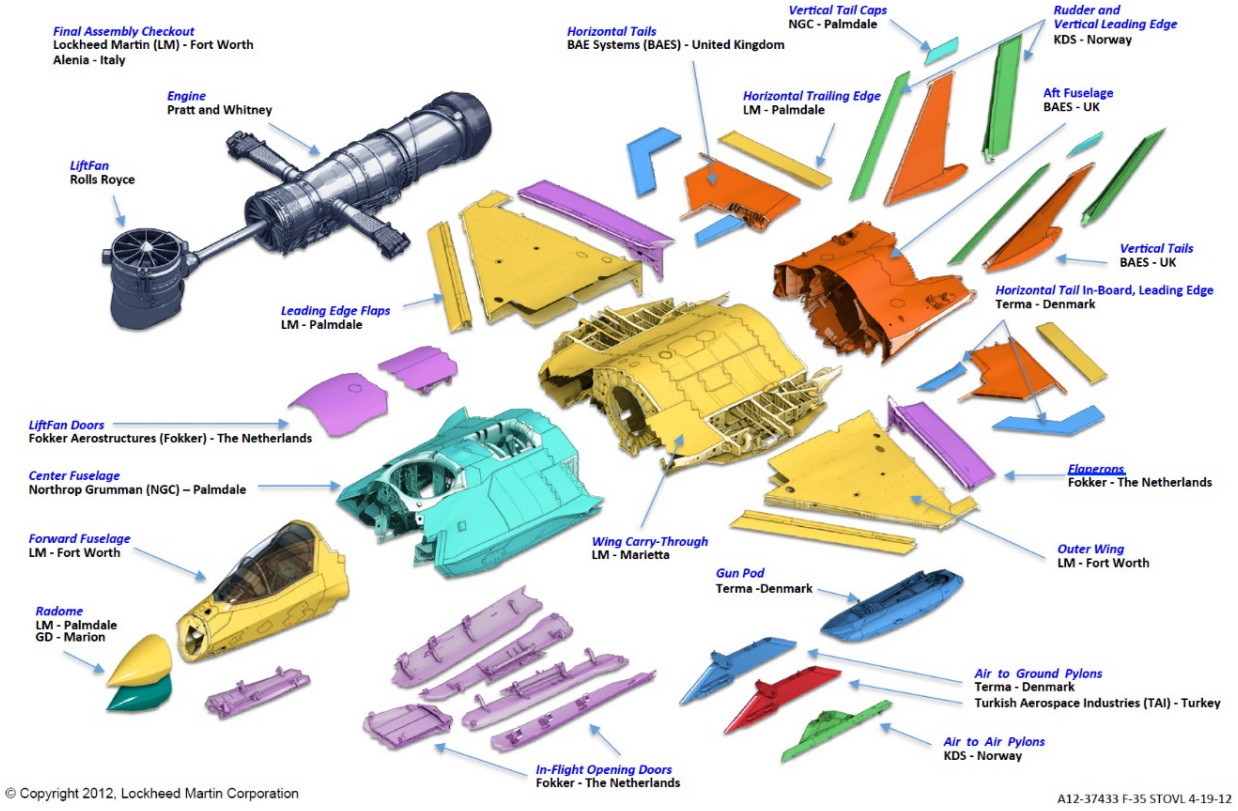

Figure 4 The figure shows all the different suppliers to F-35 STOVL

The final assembly is mainly performed in Fort Worth but recently additional assembly plants are established in both Alenia in Italy and Nagoya in Japan.

The Rate Transition Team

The overall task for the team is to facilitate the increase of the production rate of the F-35 Lightning II from the current Low Rate Initial Production (LRIP) to Full Rate Production (FRP). I was an intern in a group under the Rate Transition, and it was called the Wing Manufacturing Rate Transition team, which consists of eight engineers besides me. In the team, the engineers mostly work on the design and the maintenance of tooling fixtures and production aids. However, the engineers do not make detail design of new tools, but rather come up with a concept and present it to a number of vendors, and let them come up with a detailed design.

The wing manufacturing line consists of 8 SWBS's (Schedule Work Breakdown Structure), which then can be categorized into 3 main categories: Wing Box, Wing Mate, and Wing System. Each of the 3 main categories have then two manufacturing engineers connected, from the group, which then have the main responsibility of that part of the line. Therefore, the engineers also have management related tasks, where they make improvements to the tool organizing and factory project schedules. The whole Wing Manufacturing line is illustrated on the following figure for a F35A CTOL:

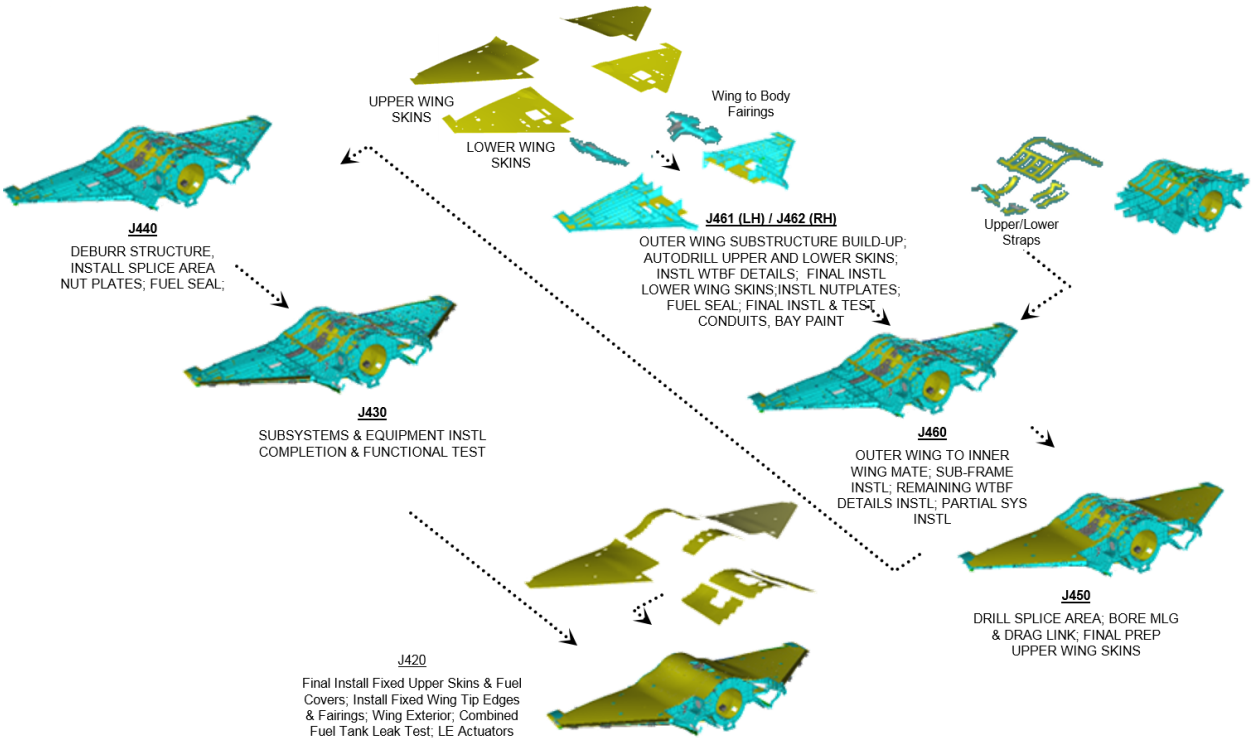

Figure 5 The figure shows the different steps to manufacture a wing for F35A CTOL

The left and right hand wing boxes are built in the first two SWBS's, where holes for both the upper and lower wing skins are drilled and the internal structure are mounted to the lower wing skin. In Wing Mate, the wing boxes are attached to the Wing Carry-Through - which is built by LM in Marietta and shipped to Fort Worth. The fluid system and all electrical wiring are installed in Wing System, plus the upper wing skins are mounted to the inner structure – finally, several test are performed.

The wing for F35B STOVL is slightly similar, while the F35C CV has some significant differences, because the wings are longer and wider, but also fold in half for Aircraft Carrier storage, which requires some additionally work in Wing System.

Working in the Rate Transition Team

The office was a large room with many small cubicles, which typically had between 1 and 4 persons in each – in my cubical, we were two. I had my own assignment, but I spend also a lot of time by following the other engineers and get familiar with what they are doing. I got invited to several meetings and it was interesting to follow how they were discussing the different projects. Furthermore, the others in my team came often by my desk if they were going to the manufacturing floor and asked if I want to join them. The following paragraphs describe some of the projects that I was involved in.

New slider design

In the whole manufacturing line, sliders are used a couple of meters above the ground to operate close to the aircraft. They are simply just pulled from the work station to the outer structure of the airplane, and they are capable of supporting the weight of several mechanics. The sliders are shown on the following figure:

Figure 6 *the sliders used to operate close the aircraft. The picture shows sliders in the final assembly area, however, the sliders are identical in the wing manufacturing (http://www.jsf.mil/images/gallery/sdd/f35_manufacturing/b/sdd_f35manfb_013.jpg)*

The current sliders have several operational opportunities, they are for instance heavy for the mechanics to pull and they collect FOD (Foreign Object Debris). Therefore, my team was given the task to replace them and I was able to follow the process. First, we presented three prototypes for several vendors and then explained which part of the prototypes we did/didn't like. Then we presented a SOW (Statement of Work) to the vendors, where all the technical details and timelines were described.

The vendors came with different bids and proposal to the design and we chose a vendor with a simple design. A couple of months later, we got a presentation from the vendor of a new prototype, which we discussed. We did like the concept and we decided, therefore, that it was the design that we should use. The mechanics were also satisfied with the new design and the installation of the new sliders started a month before my internship ended.

Move Plans for Shipping Container and Wing Skin Dolly

Shipping containers used to transport wing skins from the part suppliers, and dollies used to transport the wing skin to the assembly line have been ordered from a vendor. The first units arrived in Fort Worth and we did a proof load of both the container and dolly, where we tested the functionality by applying a wing skin and see if it was proper protected. We were not satisfied with some minor aspects of the two products, and we decided that the vendor had to make some rework and add some new features for the next containers and dollies.

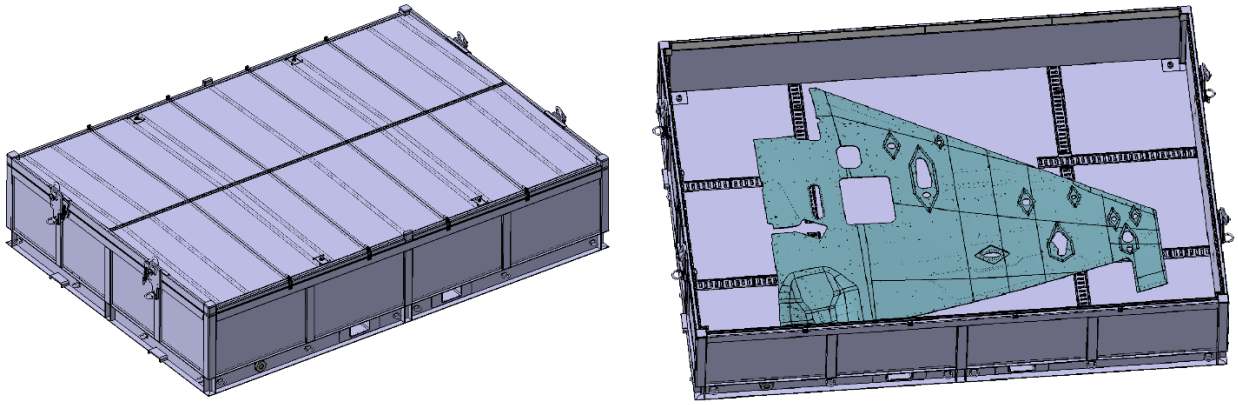

Figure 7 *The Wing Skin container used to transport the wing skin from the part supplier. The container is designed to transport upper and lower wing skin for all three variants*

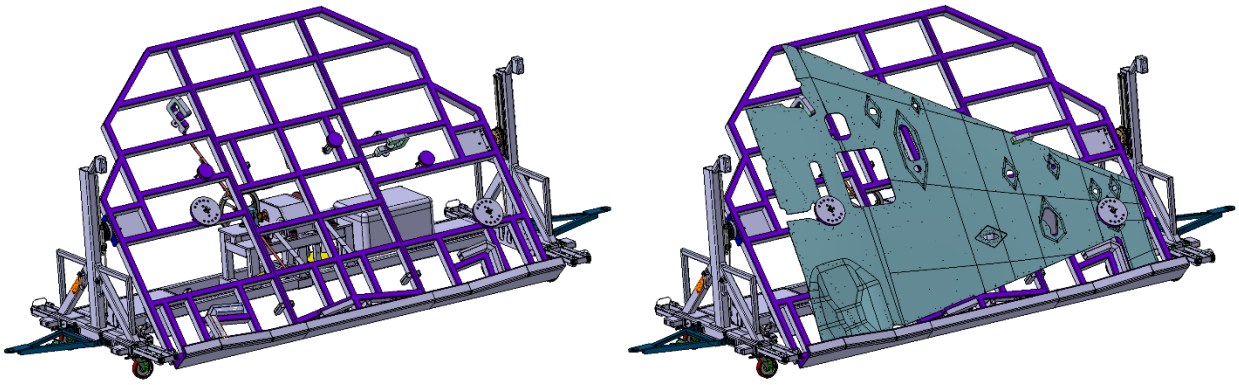

Figure 8 *The Wing Skin Dolly used to transport the wing skin to the assembly line from transportation. The dolly is designed to transport upper and lower wing skin for F35A and F35B*

All lifting/hoisting, towing, or jacking of critical value items needs to have a move plan, which describes each step of the move procedure. Therefore, this movement of the wing skin needed also to have a move plan, and I was given the task to make the move plan for loading and unloading the container and dolly. I

used the Catia V5 models where I could disassemble every part and then take images of the different details. Additionally, I read and followed the standard (AeroCode) for making a move plan and ensured that all instructions and photographs were included.

Milestone to Gantt chart Converter Tool

The wing manufacturing line consists of several thousand tools and production aids, which vary in size from a 3-story building to tiny drills. New tools and production aids are needed all the time in order to ramp up the production to full rate. Every engineer keeps track of new tools, or maintenance of existing tools in order to make sure they arrive before they are needed in production. Each new tool has a unique identification number and is considered a project with related milestones, which shows the engineer what needs to be done next and to point out if the arrival of the tool is going to be late.

There are sometimes more than 50 projects assigned to a single engineer and each project can have up to 10 related milestones. All projects in team are stored in a large Excel spread sheet, where each milestone has no less than 48 properties. The spread sheet is the only way in which this information is presented and it causes several challenges for the engineers. They have a hard time anticipating future workloads and cannot easily identify late milestones.

The previous intern in the group had started on a software tool, which was successful and could transfer the projects and the related milestone to a Gantt chart in Microsoft Project. However, the tool needed more features, error fixing, and better search criteria. The tool was programmed in Microsoft Visual Studio, and the interface together with the created Gantt-chart are shown on the two figures below:

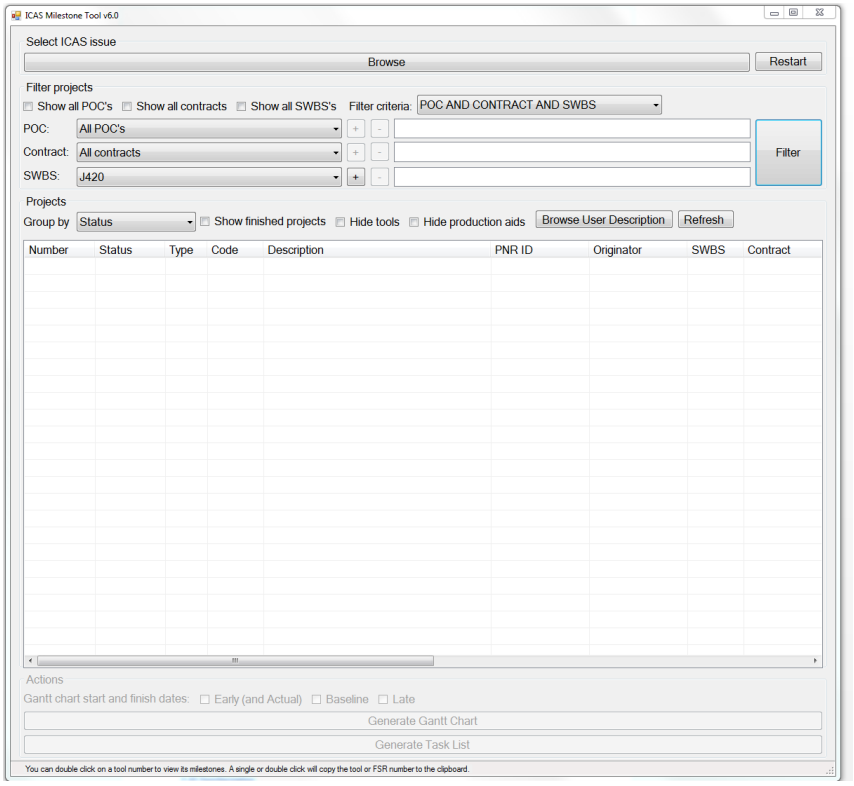

Figure 9 *The figure shows the interface of the ICAS Millstone Tool, which I made in Microsoft Visual Studio*

Task Mode	Task Name	Status	Date Type	TRF Type	Duration	Start	Finish
	JXXXXXXXX - XXXX - JXXX - XXXXXXXXX				**483 days**	**Thu 7/14/16**	**Sun 6/10/18**
✓	XXXX	Complete	Actual start/finish	x	0 days	Thu 9/29/16	Thu 9/29/16
✓	YYYY	Complete	Actual start/finish	x	0 days	Thu 9/29/16	Thu 9/29/16
	ZZZZ	Late	Early start/finish	x	80 days	Tue 6/14/16	Fri 9/30/16
	XXXX	Late	Early start/finish	x	125 days	Tue 11/22/16	Fri 5/12/17
	YYYY	On-time	Early start/finish	x	2 days	Fri 8/4/17	Fri 8/4/17
	ZZZZ	On-time	Early start/finish	x	10 days	Wed 8/9/17	Tue 8/22/17
	XXXX	On-time	Early start/finish	x	5 days	Thu 11/9/17	Tue 11/14/17

Figure 10 *One half of the created Gantt-chart in Microsoft Project with dummy data*

The program was written in the language VB.net which I had no previous experience in, whatsoever. Nevertheless, it did not take me long before I got the basics and I was able to navigate in the code. The tool was successful and it is used in the team as intended.

MS-Project for the Team

Everybody in the team also have projects which are not registered in the previous Excel spread sheet - these projects are typically big and could for instance be extension of a work station. I was then giving the task to make a MS-project, which included all these projects. In order to do that, I was first giving an old document, which had not been updated for a year, with milestones for some projects.

I spoke to everybody on the team about which major projects they have and which milestones could be added to each project. After that, I linked all the different milestone across the different projects and used the auto schedule function. It was then more visual for everybody in the team, how the different projects in the team interact with each other and they could for instance see if a delayed milestone is critical for all the following milestones or not.

Tool database

The whole wing manufacturing line has more than 2000 tools and the engineers have different databases where they can search for a specific tool. However, none of them has a combination of pictures, dimensions, and a description of what the function of the tool is. Therefore, the engineers needed a tool list, where they quickly can find all these kind of information. This would solve some situations, when for instance an engineer knows how a tool looks like and in which station it is used but needs to find the tool number.

Such a tool list exists already for the manufacturing line of the forward fuselage and a similar list was wanted for the wing manufacturing. In order to make such a list, I was given all the manufacturing plans, where all the steps in the manufacturing lines were explained. By knowing each manufacturing step, I was able to describe how each tool was used. However, the function of some tools were difficult to understand, so I had to ask somebody on the team or go to the floor to see exactly how it is used.

The task required plenty of manual work but I felt that I learned a lot from that task. Especially, all the considerations there are when a product has so tight tolerances – when I did the description of the tools, I thought many times: “That was a great idea to do it in that way, I had never thought of doing it that way”.

Training and classes

In the beginning of my internship, I was also able to take different classes, which I later used to solve my daily assignments. I took the following classes:

Applied Foreign Object Debris (FOD) Prevention Certification

FOD is a substance, debris, loose hardware etc. which is anywhere on the airplane where it potentially could cause damage. They are a major cause of aircraft damage and unscheduled maintenance. Preventing FOD is everyone's responsibility and therefore, all personnel are required to undergo the class. I learned how to behave in the different FOD prevention areas, in general prevent FOD, and how to identify it.

Foreign Object Debris (FOD) Free Audit

The class was an extended version of the Applied FOD Prevention. In the class we learned more specific ways to identify FOD in the aircraft. The teacher showed mockups of different subassemblies where various types of FOD were hidden and we had to find them.

F-35 Familiarization

This class took three days and it gave an overview of the whole JSF program. The teacher pointed out the difference between the three variants, explained the design considerations and clarify how this fighter is different from previous aircrafts.

Problem Do Check Adjust (PDCA) – Problem Solving Training

The class taught me a systematic way to solve problems and how to continually improve processes. The class is previously known as lean six sigma. After the class, we were given a homework assignment, which we had to complete in order to get our certification.

CATIA V5 Fundamentals

The class took five days and I learned how to design parts and use Catia V5 in a professional way. The teacher showed many of the powerful features that the program has and helped us when we drew different parts as exercise.

CATIA V5 Assembly design

The class took two days and was an extended version of the fundamental class. We learned how to assemble parts and how to quickly change the part design so a part could be assembled. We had a big assignment where we assembled a wing with ribs, spars, wing skins, and the fluid system. Additionally, we learned the methodology and the different standards that Lockheed Martin Aeronautics use in Catia.

CATIA V5 Drafting

The class took also two days and was basically about how to transfer the part from "design mode" into a 2D drawing and insert dimensions and tolerances. The class taught us both the methodology and the different standards that Lockheed Martin Aeronautics use.

Product Data Management (PDM)

In the class, we learned how data - for instance CAD models or drawings – are saved with their associated documents. I saw how to track and manage all changes to product related data in the JSF program. However, I was not allowed to use the program at Lockheed Martin, though, it was still good to learn how it works.

Rapid Prototyping (3D Printing)

It was not an official class, but I got tours in two different Rapid Prototyping laboratories, where I saw all the different 3D-printers and different parts printed in both metal and polymer. The printed parts were mainly designed concepts, which should be tested later in a wind tunnel, and manufacturing tools – so far, no structural parts to the aircraft were printed.

The engineers in the laboratories explained the different challenges that they have when they are printing, which were mainly dimensional distortion and residual stresses due to the high temperature gradient in the parts during printing. Furthermore, I got the chance to print my own part, which is shown on the two figures below:

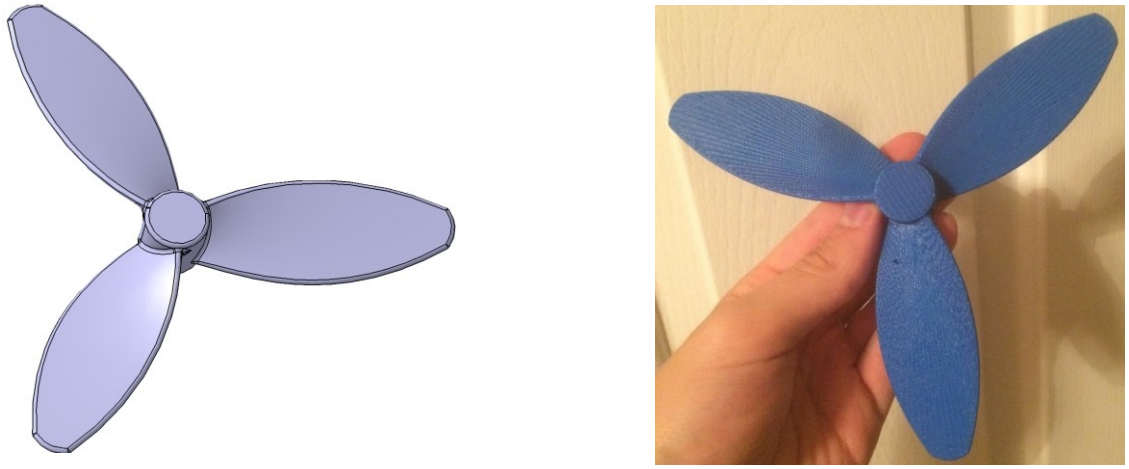

Figure 11 *the part designed in Catia V5 by using the advanced shape design functions (left) the 3D printed part after the supporting structure was dissolved and removed (right)*

The part did not have any practical use, but I learned how to use the CAM (Computer Aid Manufacturing) function in Catia V5 and handle the 3D printers.

Culture of Accountability

This training took 4 hours and it was mandatory for everybody in the Rate Transition Team to participate. The object of the training was to learn how we could change our working culture and follow LM's beliefs: Decide and Act, Shatter Silos, Drive Change, and Raise the Bar. We should then discuss in our team, which small changes that we could do in order to follow the beliefs.

Other Classes

In the early start of the internship, all interns got a guided tour inside the factory by Don Kinard which has academic doctorate degrees in both manufacturing and material science. Furthermore, it turned out that he teaches some small classes of 1 hour duration at Lockheed Martin and I was able to follow the following classes:

- "Life in a Material World" – A history and status of materials and structures development for advanced aircrafts.
- "Manufacturing System Design" – A Systems Engineering approach to Manufacturing.
- "The Future of the Digital Thread" – A review of the JSF digital thread philosophy and its future direction.
- "F-35 Producibility" – Tools and techniques used for the F-35 Producibility.

Cultural experience

I experienced the American work culture each day where working days normally are 10 hours. It took a couple of weeks before I got use to the long working days, but I liked my assignments at LM so it was not a problem at all. Many of the employees have a military background, and I could both feel and see that the other employees were proud of their job - it was not unusual to meet people who have been working at the factory for more than 25 years.

Furthermore, it seems like that the company almost has developed its own language – they use acronyms for almost everything. It took a couple of week before I got used to the most basic acronyms, but still after 5 months, I occasionally need to ask what an acronym stands for. There exist a dictionary of acronyms and aerospace related terms, but I could not look in to it because I am a foreign national. However, everybody was really kind to explain an acronym or term to me.

I felt really welcome by the other coworkers and they truly love to tell and explain what they are doing – if I for instance just ask a tiny question about the manufacturing process, I could sometime get a 30 minute long answered or they will walk together with me to the manufacturing floor and show it. Additionally, roughly once a week, my coworkers and I went outside the factory for lunch and we got all kind of Texan food, which include a lot of burgers, barbeque, and tacos.

Living in Texas

Texas is a very special place to live and I experienced a quite different culture than what I am used to in Denmark. Occasionally, our coworkers and neighbors invited us to dinner or ask us to join them for an outdoor activity like going to a shooting range or watching a sport event. I liked that we did some many things with Americans, so we got a real experience of living in the US, and not just do all the tourist thing.

However, we also did a lot of tourism! We went several times to a place in Fort Worth called “The Stockyards”, which celebrate Fort Worth’s long tradition as a part of the cattle industry – people wear cowboy hats, the restaurants serve a lot of barbeque, and they have a stadium for rodeo. We also bought two cars and one of them was a big Volvo SUV which could seat 7 people. We used it to drive to the following places:

- NASA Space Center Houston, Texas
- San Antonio, Texas
- New Orleans, Louisiana
- Dallas, Texas
- Several State and National Parks

Additionally, we also bought flight tickets for both Washington DC and Denver, where we saw the Rocky Mountains.

Conclusion and Tricks for future Interns

I will definitely recommend applying for an internship at Lockheed Martin - it is a once in a life time experience. I learned a lot from my internship, and working in an enormous factory, with machines and tools bigger than a normal Danish house, is really fascinating for an engineer. Additionally, it is also a great opportunity for experience a different culture, and get a new perspective of how things are done in other countries.

We lived at Marquise Stonegate in a suburb to Fort Worth and I will highly recommend future interns to stay at the same place. The apartments are big and there are both a swimming pool and a gym, which are free to use. It is additionally a good idea to contact Marquise Stone early and make contact to the previous interns. We bought all our furniture from the previous Dutch interns, which bought the furniture from the Danish intern before them, and it was really nice to move directly into the apartments without going out and buying beds, tables, cutlery, and stuff like that.

We bought a Volvo SUV which could seat 7 people for $5000 and a Ford focus ST for $3000 – both cars were from 2007. We did not have any maintenance of the cars and I will not recommend to buy cheaper cars.