June
2017

TERMA

LOCKHEED MARTIN

Technical University of Denmark DTU

Lockheed Martin Aeronautics

F-35 PROGRAM INTERNSHIP THROUGH TERMA A/S

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1 Introduction

This report concerns my 5 months internship at Lockheed Martin Aeronautics in Fort Worth, Texas from January to June 2017. The internship will become part of my Master's degree in Materials and Manufacturing Engineering that I am pursuing at Technical University of Denmark. These past months I have worked as a quality engineering intern in the final assembly of the F-35 jet under manager Michael Cucinotta.

The main role of the quality engineer is to solve and prevent problems occurring in the production. As I am writing this report the F-35 production is still in its Low Rate Initial Production of 4-5 jets per month. The quality engineer plays a big role in ramping up the production to full rate of 20 jets per month in 2018/2019. In order to reach this capacity and bring down the price of the jet, the quality engineer has to optimize the processes ensuring a smooth production with limited non-conformances.

Figure 1: Picture of the Final Assembly line in Fort Worth. The Fort Worth plant stretches 1 mile.

1.1 Motivation

Before this internship, aeronautics itself had never caught my interest, however, my fascination lied within advanced technology in general. The F-35 jet utilizes many state of the art technologies that I thought would be very interesting to work with as well as many complex materials that suits my master's degree. Another motivating factor has been the salary. The internship is well paid which I thought would give freedom to get some traveling done. Lastly, I thought this experience would become very beneficial for me in my future career and on my resume.

1.2 Applying for the internship

Our head of studies, Karen Pantleon, made me aware of this internship when she in the spring 2016 informed that DTU for the second time had an agreement with Terma and Lockheed Martin about interning in Texas. Initially, I thought the competition would be very high, thus I didn't bother applying for the internship. However, fellow students informed me that six positions were open and the chances of receiving this internship seemed more likely. A few weeks after my application was sent, I was contacted by Terma for an interview. Apparently, this went well as I later on was invited to a phone interview with Lockheed Martin. A few days later I was offered the position in Fort Worth, Texas.

Figure 2: Picture from intro meeting at Terma, Aarhus before heading the Fort Worth. On the picture are five interns and three Terma emloyees.

2 Fort Worth

Fort Worth started in 1849 as a military base marking "where the West begins". Native Americans were to remain west of the line tracing from Fort Worth down to the Rio Grande. The river that divides Texas with Mexico. Along this line armed frontiers were located every 100 miles in order to hold the front as shown in Figure 3. After just a few years this line moved further west and the military abandoned Fort Worth, however, within this timeframe a community had developed and the fort became a civilized town.

Towards the north in Kansas a railroad had recently been built. Big groups of cattle were herded from around Texas to the railroad for selloff. Fort Worth was on the main road and it developed into a red light district for the passing cowboys. However, in 1876 Fort Worth got its own railroad. Soon the word spread and cowboys herded their cattle here. Fort Worth became a Cowtown with stock shows, rodeo and meatpacker industry (City-of-Fort-Worth, 2017).

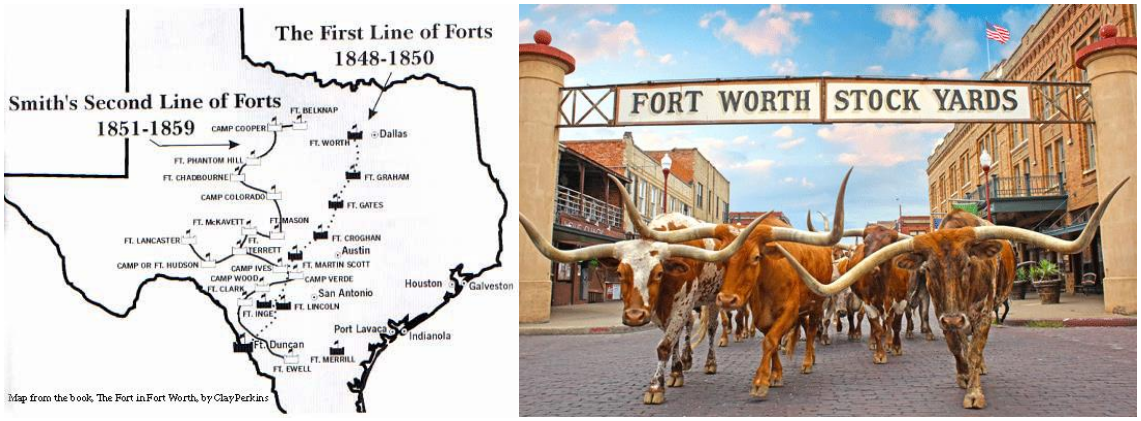

Figure 3: Left, the line of forts dividing the East and the Wild West (Fort-Tour-Systems, 2017). Right, Longhorns at the Stockyards located in the old part of Fort Worth (City-of-Fort-Worth, 2017).

Today Fort Worth is a large, thriving city without being too busy or crowded. One can easily sense its roots and history among its many attractions.

It is reasonable to say that the city is owned by only a few families. They are good a keeping the city clean and they have their own security personnel walking around the streets keeping order. Fort Worth is full of good places to eat and bars to get a drink.

2.1 Marquis at Stonegate

As for the previous interns, our group chose to stay at Marquis at Stonegate on Hulen st. This has been convenient as we took over the apartments from the Dutch interns who just ended their stay, thus they could pass on their furniture.

Marquis is a gated community with controlled entrances and a reception – a fairly common concept around here. The apartments are a bit more costly, however, you get a good service, a pool with BBQ, a modest fitness room and breakfast on Saturdays with the other residents.

Here at Marquis Brad and Travis also lives. Two guys who have befriended all the interns since the program started for the Dutch students 13 years ago. They have been very helpful throughout the stay and are good at showing the interns around Fort Worth, especially the bars.

2.2 Installation and Initial work

Prior to traveling to Texas the intern group bought all the furniture from the previous Dutch interns for a reasonably price. With the furniture in place, we needed to get electricity and internet installed. Acquiring some cars was the next thing that was needed to do in order to get set. The group agreed on getting two cars with one of them being able to fit all 6 interns. As expected, the car purchasing process proved itself very time consuming but eventually a 2005 Volvo XC90 and a 2007 Ford Focus ST were bought. Buying cars from the previous, Dutch interns is worth considering.

Figure 4: Pictures from the Volvo going to New Orleans and of the pool at Marquis.

3 Lockheed Martin, Terma and the F-35 Program

Lockheed Martin is a company with a rich history dating back to 1912 where the Glenn L. Martin Company was established in Los Angeles. Later that year the Lockheed Brothers started the Lockheed Aircraft Company just 400 miles away. Both companies had success and began selling aircrafts to the United States military. Jumping forward to 1995 reveals the merging of Martin Marietta producing the F-16 Fighting Falcon and the Lockheed Corporation producing the F-22 Raptor. In 2001 the Lockheed Martin Corporation was awarded the Joint Strike Fighter contract of building the F-35 Lightning II for the U.S. Airforce, Navy, Marine and the U.K. Royal Airforce and Navy.

Today the Joint Strike Fighter Program includes United States, United Kingdom, Canada, Italy, Australia, Japan, South Korea, Israel, Netherlands, Norway and Denmark. More than 3000 F-35 jets are planned for production from 2006 through 2040s making JSF the largest military project in history. 27 of these Jets are confirmed for Denmark. As the Danish government confirmed procuring the F-35 jet, the Danish industrial participation increased in the Joint Strike Fighter Program (Lockheed-Martin, 2017).

Terma A/S is the biggest Danish supplier and partner to the F-35 Lightning II. With a revenue of $ 260 million Terma A/S employs 1.257 people (Terma, 2017). As of the recent Danish purchase of the F-35 the order intake has greatly increased in Terma Aero Structures. This increase will create a few hundred new jobs in the facility in Grenaa, Denmark during the ramp-up of the F-35 production. Today Terma supplies the F-35 with about 150 different part numbers which includes different composite skins, gun pods and pylons.

The F-35 Lightning II comes in the three variants CTOL, STOVL and CV as shown on Figure 5. These were designed to replace the F-16, A-10, F/A-18 and AV-8B in the United States Military making the F-35 a multirole fighter.

Figure 5: The three variants of the F-35 Lightning II. The CTOL (Conventional Take-Off and Landing), STOVL (Short Take-Off and Vertical Landing) and the CV (Carrier Version). (Lockheed-Martin, 2017)

4 Classes

Training and education is a big aspect within the Lockheed Martin Corporation. When new people are hired several classes are important and mandatory to take in order to work in different fields. Some of the classes that we took are briefly described in the following.

4.1 FOD Training

Foreign Object Debris (or Damage) plays a big role when building fighter jets. FOD defines all items, substances or debris that are alien to the aircraft and is estimated to cost the aerospace industry millions of dollars each year (Kraus, et al., 2001). It is required to have completed this one-day class in order to work on the jets. During this class one is taught the significance of FOD and how to prevent and eliminate it. This includes different techniques/rules such as keeping loose items contained, using FOD barriers and accounting for everything that is brought to the jet.

4.2 F-35 Familiarization

The F-35 Lightning II is a pretty complex machine. This three-day course covers everything one wants to know about F-35 jet from the vehicle, to propulsion to mission systems.

4.3 Plan – Do – Check – Act

In PDCA training one is taught problem solving techniques at a general level. PDCA is a four-step iterative tool used to improve processes and products.

4.4 Product Data Management

PDM is a system used to manage, update and publish product data. The F-35 program includes many stakeholders and PDM ensures that everyone has the same understanding of the product. It is mainly used by engineers to view and create the documents associated with the different parts on the jet. E.g. when quality engineering identifies a frequent, essential defect they perform analysis to come up with a suggestion for a corrective action. This suggestion is brought to engineering who implements it technical drawings. Then the corrections are published in the PDM system for everyone in the F-35 program to see.

5 Working at Lockheed

Working at Lockheed has been a great experience. The production plant is huge and has an ambience of patriotism, teamwork and professionalism. However, things move slowly and it can take a long time to get things done and see your work being implemented.

Some of the tasks and projects I have been thrown into include: data analysis and triaging, root cause analysis, variation management, various types of surveillance in the production and on the jets, automating tasks for other employees and doing observations in the production to gather additional data. A few of these projects are presented in the following. Due to security reasons are these projects described with limited detail and the data is made up.

5.1 Fastener problems in Belly Band

When working as a quality engineer one have to solve the different problems that arises in the production. In order to fix and prevent these issues the quality engineer has to go talk to the supervisors and mechanics in order to locate the problems and root causes. Often the quality engineer has to do some observations of the mechanics and procedures to get extensive data for solving the problem.

Figure 6: F-35 AU-1, the first jet for the Royal Australian Air Force. The Belly band panel is indicated by the red lines.

This has been the case for the installation of the belly band panel. The belly band is a composite panel that is located just in front of the air intakes of the jet as shown in Figure 6. During installation the belly band panel is only accessible from the outside and blind fasteners / rivets are used as shown on Figure 7. The fasteners joint together the panel and the structure in very precise predrilled holes. The fasteners are installed by pulling a stem with a pneumatic gun that compresses and deforms the sleeve as shown on the figure. The stem then breaks off and the joint is made. However, every so often a 'bad pull' occurs, meaning the fastener is either angled or the outer ring falls off destroying the fastener. When these non-conformances happen, the mechanic has to drill out the stem and sleeve from the head of the body. The drilled-out parts then fall down inside the aircraft and has very limited access. These parts are now considered FOD and have to be removed.

The only access into the bay is a small drain hole. The operator then has to find and remove the parts with a borescope, which is very time consuming. In order to reach the full rate production and desired cost of the jet this problem amongst others is important to solve.

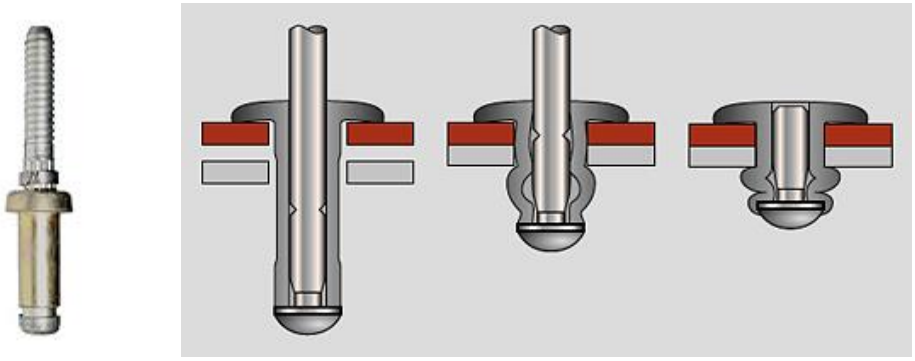

Figure 7: Blind faster. (Monroe) (Marshall-Sales)

Root causes

- Possibly using wrong pneumatic gun to pull the fasteners. We can only observe the day shifts and do not know if the evening and night shifts are using the right gun, which would be a problem.
- Using the wrong blind fastener size. The thickness of the panel on top of the structure can vary as the panel is shimmed to make it flush with the adjacent panels. This is crucial for

the stealth capabilities of the jet. Using a too small or too large fastener will result in a bad pull.

- Some fasteners are defective. It is estimated by the mechanics that a small fraction of the blind fasteners are defective and will result in a bad pull.
- Using the wrong technique. It can be difficult the master the proper technique for installing these blind fasteners. When pulling the trigger on the pneumatic gun one has to physically pull the gun away from the panel in a fast motion without applying any angle.
- Some holes do not have a proper countersink. This affects the installation of the fastener.

Suggestions for corrective actions

- Clearly state what equipment to use.

  - The quality engineer has to check and evaluate the work instruction for the right equipment and how clearly it is stated. If this can be improved the suggestion is sent to Planning that evaluates and implements it in the work instruction.
- Gage the hole size before installing the fastener. Because of the shimming of the panel, the proper fastener might not be the one initially assigned to the hole.

  - One will have to check the instruction again. If it can be improved, the suggestions are sent to planning.
- With defective fasteners it seems that some bad pulls are inevitable. A suggestion for corrective again could be having a larger drain hole for better access to drilled-out fastener parts inside the bay.

  - In this case the quality engineer will have to estimate the sufficient size of the drain hole for easy access to the bay. Then the quality engineer will submit a Problem Report defining the problem and the suggestion for a corrective action. Engineering picks up the Problem Report and calculates if it is possible and feasible to make this change to the aircraft.

After implementing changes to the process for installing the belly band panel it will be monitored. If the corrective actions prevent non-conformances the problem can be validated and closed. If non-conformances still occur the quality engineer will have to reevaluate the problem and take new corrective measures.

5.2 FOD, Chemical and Tool Surveillance

Another interesting task here at Lockheed has been the general surveillance at the floor. Here, routinely surveillance of FOD, chemicals and tools has been carried out. These rather random inspections give some good snapshots of how the production is running. When doing FOD surveillance one gets to crawl around on the jet looking in every bay and corner for objects such as tape, string tie and washers that are foreign to the jet. Often FOD barriers such as caps protecting electrical connections are found missing too. All these FOD findings give good information on how certain processes are running. When FOD keeps showing up in the same locations it could give an indication that some aero code or process should be changed.

When aero codes are changed or implemented they will be monitored with these surveillances. Often it happens that cultural changes become a barrier. It has proven difficult to change peoples' habits and routines.

Another incentive to do these surveillances is to find these non-conformances before the customer represented by DCMA (Defense Contract Management Agency). If DCMA finds problems with the tools, chemicals or critical FOD they can write up a CAR (Corrective Action Request). It is desired to avoid these CARs as many people are involved and they become very costly to process.

5.3 Repetitive Use-As-Is Defects

Each time a defect or non-conformance is detected in the production, it is written up as either a QAR or SQWK. With the QAR being short for Quality Assurance Report, it is a bit more serious and informative than the SQWK. Depending on how the non-conformance is handled the QAR can be labeled as Accept, Repair, Return, Rework, Scrap and Use-As-Is. The Use-As-Is QARs often concerns parts or holes being just out of tolerance, whereas the Material Review Board later has concluded that the parts can be used as they are without any repair or rework needed. The process looks as follows:

The non-conformance is detected → It is written up in a Quality Assurance Report → The QAR is analyzed by the Material Review Board and deemed acceptable for Use-As-Is → The Material Review Board reports the accepted non-conformance or QAR to the customer.

This process consumes many unnecessary recourses, whereas, the Program Quality Management Plan recently was updated to monitor and take action on repetitive Use-As-Is defects. A Use-As-Is defect has been defined repetitive when the same defect has occurred a certain number of times within a certain number of subsequent jets of the same model (CTOL, STOVL or CV). A small group was assembled to eliminate these defects on the whole F-35 production as well as to bring awareness to opportunities to prevent them.

The idea is that these repetitive Use-As-Is defects will be eliminated through ICAs (Integrated Corrective Action). An ICA is initiated and owned by a person from the department where the QARs are occurring. The purpose of this project is then to help these individual ICA owners with the right path for closure of the ICA ensuring that these specific defects will stop occurring. Often this path would include an *Engineering Category 2 Problem Report for tolerance relief*. A Problem Report is then prompted to engineering, whereto, they evaluate if the specific tolerances can be increased. Defects that used to be just out of tolerance and were deemed Use-As-Is will now be inside the tolerance limit and not be non-conforming. The whole process of writing up the QAR, having the MRB reviewing it and making the customer aware can now be avoided saving many recourses.

My role in this project has been to make a spreadsheet tool using Visual Basic programming that overall can:

- Load all Defect Data from the F-35 production
- Give the defects an ID consisting of a Part number and a Defect Code
- Analyze all the data to find Use-As-Is defects (QARs) of the same ID, same jet variant, and a high frequency causing it to be repetitive.
- Pair up the identified QARs having the same ID with ICA data. The ICA data consists of an ICA number, an ICA owner and the ICA status (Investigation, Limited Action or Validated).

The operator of this tool can now generate reports for CTOL, STOVL and CV respectively containing all the repetitive Use-As-Is QARs. They will be moved to a Master Sheet for all the ICA owners to add additional information and help them work and close the ICA issue properly.

In the Master sheet the ICA owner is filling out data for the Problem Report and Change Request (When engineering has come up with a solution they request a change in the work instruction). This is used by the project group to monitor all the repetitive Use-As-Is defects individually.

It was suspected in the project group that occasionally the ICA owners would have closed and validated their ICA issues without properly resolving the problem. Figure 8 shows a tool I made tracking the individual ICAs with their corresponding QARs for the project operator to use for monitoring. In the presented case the ICA has been closed and validated, however, there are still QARs showing up. The project operator then has to contact the ICA owner and tell him/her to reopen to ICA for further investigation.

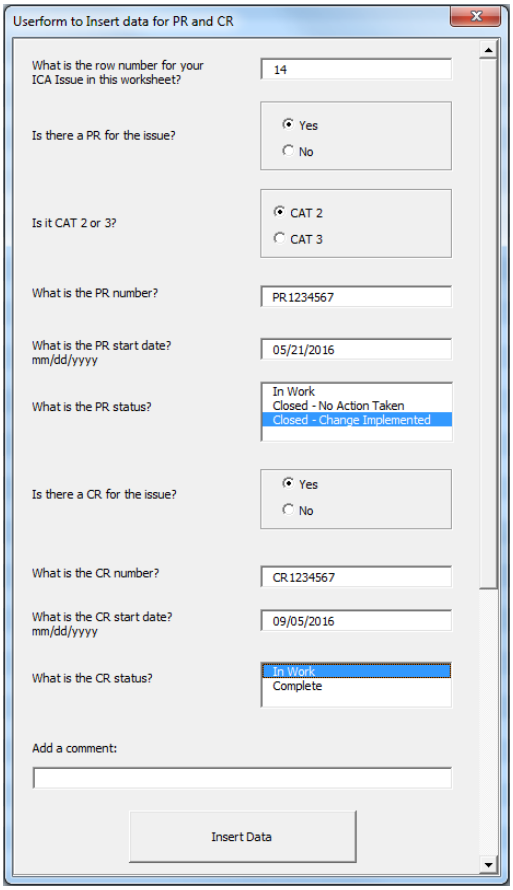

Figure 8: Userform for ICA owners to provide data for Problem Reports and Corrective Action Reports.

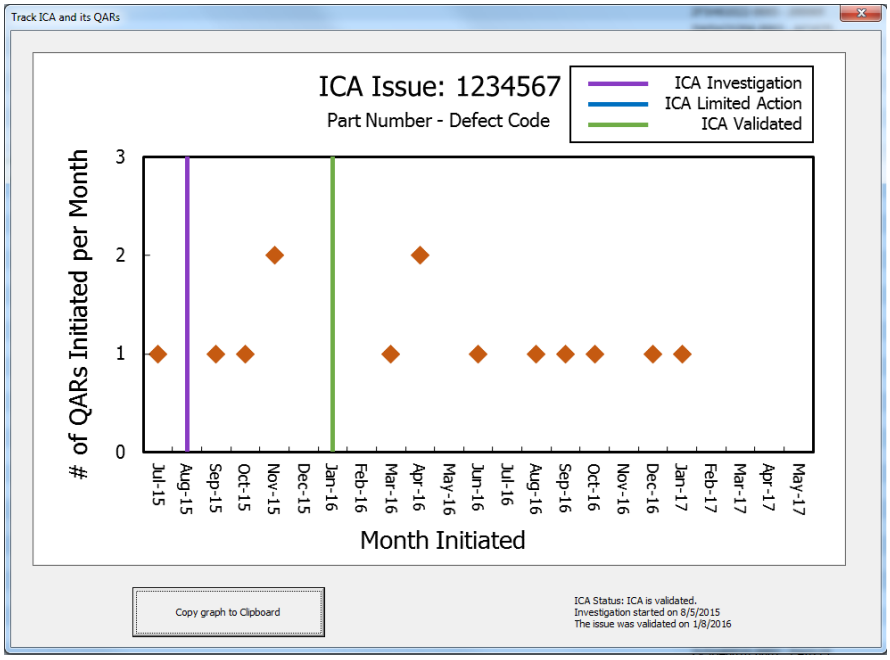

Figure 9: Graph for tracking ICAs by status and its associated QARs. If QARs follow after a validation, the ICA needs to be reinvestigated.

6 Outside Work

Big Bend National Park

The intern group arrived in Fort Worth about one week prior to the start of the internship. I took this opportunity to bring my girlfriend down to Big Bend National Park for some hiking and camping. Big Bend is an 8 hour drive away from Fort Worth, however, it was very much worth the time. The scenery and nature was just outstanding. We took the Laguna Meadow Trail being an 8 km hike up into the mountains. Here we camped for the night in and woke up to mule deer outside our tent. There were some fresh bear droppings in the area keeping up the excitement. We did some more hiking and saw the Rio Grande.

Figure 10: Pictures from Big Bend National Park

New Orleans – Mardi Gras

New Orleans, a capitol of jazz and blues is a place I absolutely recommend to go. We went on the weekend before the official Mardi Gras. At this time the city turns into one big carnival with huge parades and people partying all over the place. People travel very long distances in order to take part in the annual Mardi Gras making the city very packed. From Fort Worth the drive is about 8 hours. It is a good idea to book accommodation as soon as possible, as the prices get very high.

Figure 11 Pictures from the Mardi Gras. Left is showing one of the parades. Right is showing the interns wearing the famous beads which were considered a currency during Mardi Gras.

Amongst other activities in Texas I have been seeing NASA, watching baseball and basket games and canoeing on the Caddo Lake with stunning wildlife such as alligators. Some of the interns also had a very enjoyable kayaking/fishing trip on the Brazos River with Glen from work.

Marquis at Stonegate is located very close to two, free tennis courts, where many great and also frustrating hours have been spent together with Lockheed employees.

Traveling around the different major cities such as Austin, San Antonio and Houston can also be recommended. Each city is very different in terms of culture, architecture and people.

Coming up before leaving United States is a trip to Denver with hiking in the Rockies as well as a sightseeing trip to Washing DC.

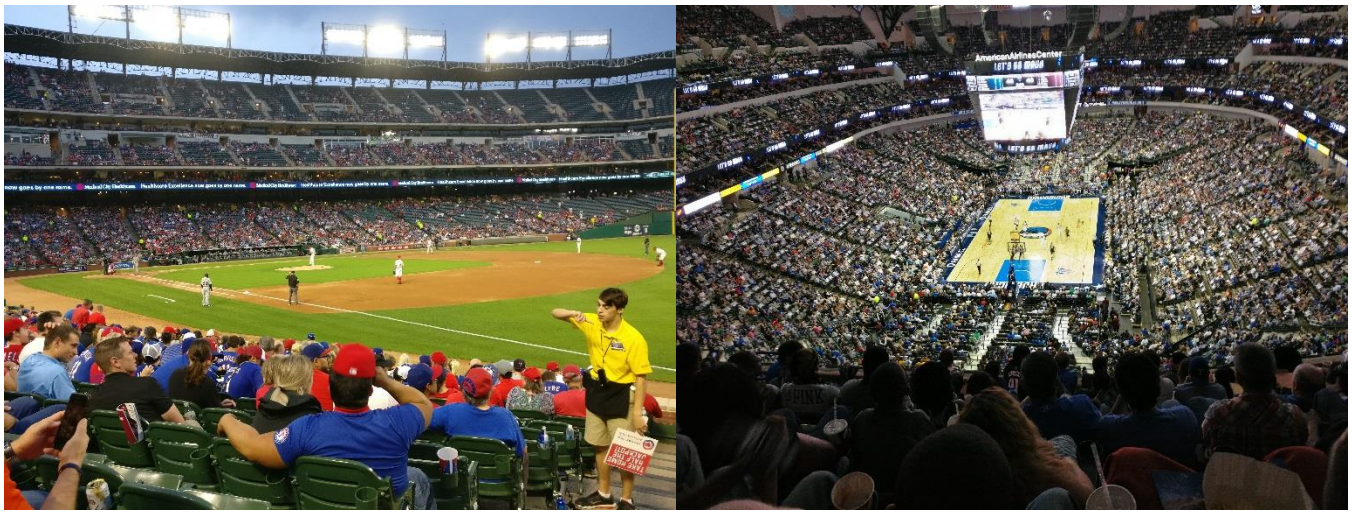

Figure 12: Baseball game with the Texas Rangers against the San Diego Padres. Basket game with the Dallas Mavericks against the Los Angeles Clippers

Figure 13: Left, Texans sitting in the trunk while driving on the highway. Right, Brock Lesnar beating three bad guys in the WWE.

7 Reflection

I have been thrown into many different projects and been introduced to quality engineering in a major American Defense Contractor. This industry is fairly unfamiliar in Denmark and things move very slowly, however, I am certain that future employers will highly value this experience.

Many of my projects have included programming using Visual Basic. Although, I did have some experience before I now master it very well, which I am confident will prove useful for many engineering positions.

I do have a background in quality from a small industrial coating company in Denmark. It is surprising how many similarities there have been between working there and here at Lockheed Martin. This internship has shown me how universal and essential quality is for a company.

It is now evident that my studies at DTU have provided me with a solid engineering background and good problem solving skills. These have been very applicable in my works here at Lockheed Martin.

During this internship there have been some great possibilities for doing traveling and having cultural experiences. Americans are very easy to befriend and I have now created a large network.

My final conclusion is that this internship has been an outstanding, unique experience that I am very happy to have had. I can only recommend any student at DTU/AU/AAU to apply and take any opportunity that might arise.

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