Internship Report

Lockheed Martin, F-35 Rate Transition

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Preface

Throughout my internship and the period of leading up to it I have experienced nothing but helpful and friendly people. I would like to thank my fellow interns, Emil Hølmkjær, Jesper Lund, Kenneth Jensen, Kristoffer Vinther Olesen, Lenni Helleskov Busk, Lukas Høghøj and Mads Hellemann for the great experiences we've had living in and exploring Texas and the US together. Furthermore I would like to thank my cubemates Max Winter and Jonathan Zichy, coworkers AD King and John Brooke, lead Michael Slimmer, manager Mike Lally as well as all the other employees at Lockheed Martin I have encountered and who have helped make my internship special at work and outside of it.

Lastly but not least I would like to thank Elyse Michniak, Thor Pauli Andersen and Jeppe Doloris for their great work coordinating the internship from the three parties, Lockheed Martin, Terma and DTU.

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Introduction

Figure 1: Air Force plant 4

The internship took place at Lockheed Martin Aeronautics' Fort Worth facility, located at the United States Air Force Plant 4, just outside of Fort Worth, Texas, USA.

The plant was built during the Second World War in order to produce the B-24 Liberator plane, and was the largest building in the world at the time. Since then a number of military aircraft has been built in the facility which now exclusively produces the F-35.

The main production line is located inside building 4, the long building with a blue stripe shown in figure 1, and spans the entire length of the building. At this production site the wingboxes and forward fuselage for the plane is build and they are mated with sections produced throughout the world to produce the final plane which is tested and flown away from the on-site runway.

The F-35

Figure 2: F-35 CTOL

The F-35 is a modern fighter jet produced by Lockheed Martin Aeronautics and procured by a number of countries including the United States of America, the United Kingdom, The Netherlands, Italy, Norway, Australia, Turkey, Israel, Japan, South Korea and Denmark.

Denmark has participated in the F-35 Joint Strike Fighter program since 2002 and provided an F-16 to serve as chase plane during the Development, Test and Evaluation program. Denmark has decided to buy 27 of the F-35A version with the first plane expected to be delivered in 2021.

The plane is produced in 3 versions in order to suit different military branches needs, the A version is a conventional take-off and landing plane (CTOL), mainly used by airforces and is the most produced version, as well as the widest exported version. Denmark is among the costumers of this variant of the aircraft. The B version can perform a short take-off and vertical landing (STOVL) and is thus suited for use on smaller aircraft carriers and forward bases. This version of the plane has been bought by the Royal Navy, Italian navy and the US Marine Corp. Finally there is the C version, this is the carrier version (CV) of the plane, and is built with a larger, foldable wing and stronger frame in order to be able to operate from carrier ships. This version has exclusively been sold to the US Navy.

The plane is produced in 5 sections around the world and assembled and tested at the Lockheed Martin facility in Fort Worth. The 5 sections are the engine produced by Pratt and Whitney in the USA, the aft produced by BAE Systems in the UK, the wing section, compromised of the two wingboxes and a center wing produced by various companies in Italy, Israel, the US and at Lockheed Martin in Fort Worth, the center fuselage produced by Northrop Grumman in the US and finally the forward fuselage is produced by Lockheed Martin in Fort Worth. Each of these section include thousands of components produced by suppliers from throughout the world, such as Terma in Denmark.

The three versions are largely similar but a number of components and tools used for the different versions are distinct. In the wing section, where I worked, especially the C version of the aircraft diverges by having larger wing planes, aiding landing on carrier ships.

Projects

During my time at Lockheed Martin I were assisting the rate transition group in the wing area. The job of the rate transition group is to procure the necessary tooling for increasing the production pace from the low rate initial production to full rate production which is a transition scheduled to be finished around year 2020.

This work is carried out mainly by manufacturing engineers and consists of being part of the concepting phase for creating a new tool as well as managing the project of designing, fabricating, installing and phasing in the tool. The task of designing and fabricating the tool or production aid is usually handled by specialized vendors and subcontractors who submit so called design reviews in different parts of the design process which are reviewed by the rate transition MEs in order to ensure that the product fulfills the need. In my internship I assisted with the tasks of the MEs in the wing rate transition department, some of the projects I worked on are detailed below.

Training

In order to work efficiently with the tools and the methodology used in Lockheed Martin a number of courses were completed at Lockheed Martin in the beginning of the internship period.

Catia

Catia is a Computer Aided Design (CAD) system widely used in the aerospace industry and the norm within Lockheed Martin and is used daily in the Rate Transition group. Therefore it was essential to get up to speed with Catia as soon as possible.

The course lasted 4 days and included introductions to part and assembly design as well as an introduction into the best practices within CAD used at Lockheed Martin in order to ensure that a model is easily readable, editable and stable.

PDM

Within Lockheed Martin a system called the Product Data Manager (PDM) is used in order to access all of the drawings and associated documentation for aircraft parts, components and systems as well as tools and production aids.

Due to the massive scale of the dataset an advanced search tool is necessary in order to find the correct digital item, PDM is such a search tool. A large number of search parameters can be entered in order to locate the item and the tool has been proven efficient among experienced engineers, however it can be difficult for newer users to utilize which is why the course is mandatory to all new employees.

FOD

A large amount of the damage and unscheduled maintenance in aircraft is caused by foreign object damage (FOD). This type of damage occurs when objects alien to the plane (foreign object debris) causes damage of some kind to the plane.

This might seem like an easily avoidable problem but it turns out that during production and maintenance it happens again and again that foreign objects are left in the plane. Due to the grave consequences mishaps can have and the preventability of the issue a lot of effort is put into avoiding FOD during the production of the F-35. One of these efforts are to train all personnel who will come near the plane how to avoid placing FOD and notice and remove FOD present on the plane. A lot of effort was put into emphasizing how important even small and harmless looking object such as receipts or caps for threadlock can be in the wrong place. Videos of pilots who have experienced accidents or near-miss situations, explaining how important it is and that there are human lives at stake when dealing with FOD. That is one of the most dangerous things, it is such a small action which has to be carried out thousands of time a day, and just a single mistake can potentially be fatal.

PDCA

Plan-Do-Check-Adjust is a methodology taught for problem solving within Lockheed Martin. I, along with the other interns and new hires had a 1-day course in the methodology and how to apply it.

The methodology builds on top of lean thinking and six sigma methodologies and strives to eliminate waste and variation by solving the root cause of a problem. The way to utilize the methodology is by following a so called A3 page (named after the paper size) where the problem is defined, the target is set, a causal analysis of the problem is made, a brainstorm of solutions is conducted, and an action plan is made and implemented and then evaluated.

Production line map

The previous Dutch intern, Rosalie van Casteren, had produced a clearly readable and easily editable map of the projected F-35 wing production line in Microsoft Visio. I was tasked with updating the map and adding in so called Layers in order to switch between showing the current situation and the projected future state.

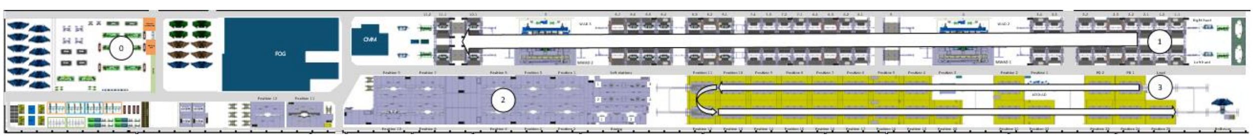


Figure 3: Wing line map

The map of the wing production line can be seen in figure 3. The general manufacturing flow is also marked out and described here.

At step 0 on the map shown in figure 3 an assembly jig (AJ or AJTF) is set up in a MRTO (Miscellaneous reference tool) with details used for locating different components in the wing.

Generally the words tool and fixture is used for items (and computer programs) that has influence on the final dimensions and tolerances of the finished product, thus having to adhere to strict standards. While production aids, consisting of lots of different items like dollies (a rolling rack or other holding device, here most often used for wingskins), trollies (a wheeled loadbar that rides the overhead rail on the wing structures and wing systems assembly lines), carts (more general term, carts often contains details for a fixture or tool) and more are necessary for component security and production efficiency but will not directly influence the finished product. Details are smaller removable subassemblies which most often is part of a tool and thus has to adhere to those standards but can also be a part of a production aid.

At step 1 the wingbox is assembled as it travels down the rail line through different stations, along the arrow. This is done by first clamping down the spars and ribs to the details attached to the AJ. Then the lower wingskin is attached, holes are drilled and the wing skin are removed in order to deburr and clean the holes, after which the skin is permanently attached. Then the upper wingskin comes on and undergoes the same process of drilling, disassembly, deburring and cleaning but is not permanently attached yet.

While all of this happens each hole is treated with an anti-corrosion agent, brackets are installed and seals are added in order to make the wings tight so that they can contain fuel and other steps.

The wingboxes are then transferred to the mate stations at step 2 on the wing line map (figure 3), where they are joined with the center wing which is produced at the Lockheed Martin plant in Marietta, Georgia, USA. At the mate stations wings remain stationary for the entire duration of the process, at current rate about 25 days. Here the wingboxes are aligned with high precision with the center wing, holes are drilled, and the sections are disassembled and deburred before being permanently attached. After this holes are drilled for attaching the landing gear and the wings are then transferred to step 3.

In the wing systems line (step 3) the wing (entire wing section of the plane, including both wingboxes *and* the center) moves along a rail, going in a U shape where the wing is filled with the necessary tubing, electronics equipment, actuators, tubes and pumps in order to operate all systems such as the fuel system, associated electronic systems as well as the control surfaces on leading and trailing edges. Furthermore, for the STOVL version of the plane the stabilizers used for short take off and hovering are also added along with the additional systems used for operating them.

The completed wing is then rolled over to a horizontal position and lifted using a crane to the next stage in the manufacturing process of an F-35 where the wing is added to the aft, center and forward section of the airplane.

Wingskin flow

My first assignment at Lockheed Martin were to map out the flow of wing skins in the wing production line and chart it out on the map of the production line described above. This might initially seem like a strange assignment, wouldn't a world leading manufacturer of military aircraft know where an expensive component moves within their own factory?

Of course they do. There exists very meticulous plans of when a wingskin is put on, how that procedure happens, how to ensure the skin is not damaged during the procedure, when it's taken off again, how it is stored and how it is to be ensured that the correct procedures are followed. However, these documents are not easily readable and requires hours of studies in order to fully understand, and in addition to this there might have been incorporated changes on the actual manufacturing floor or changes in the documents might not have been incorporated on the floor due to practicality or resistance to change.

In the end is it difficult to grasp the current situation even though thorough paperwork exists describing procedures, changes to said procedures and pushback against said changes.

Therefor a survey of how the wingskins actually moves on the floor, where they are stored and for how long, which dollies are used, where they come from and where they go were conducted and the results added to the wing line map in order to make it easy to understand and convey to a layperson. This will hopefully make it easier to understand how changes to other parts of the process will affect the wing skins in terms of floor space and isle traffic and reversely, how a change in wingskin flow will affect other processes.

Dolly modification

An incident had occurred where a CV wing skin, which is taller than other wingskins but like all other wingskins are a component of significant value, had traveled an unusual path and on its way hit the ceiling of an aisle.

Due to the high profile of the accident, both in terms of the damaged component that needed rework but also the signal it sends to the costumer a solution was necessary in order to ensure such an incident would not occur again.

A wide array of solutions were suggested, ranging from increasing training of the tug operators over installing warning systems to completely eliminating the problem by modifying all of the wingskin dollies used to tug wingskins around on.

In order to determine the feasibility of modifying the dollies I were tasked with doing a study in Catia, drawing and modifying a dolly and using drawings of the dolly and the reference engineering models of the wingskin in order to determine the height. It was determined that by modifying the height of the pads that the wingskin rests on, as well as setting a fixed resting point lengthwise and changing the casters that the dolly rolls on it would be possible to modify the dolly so that it could comfortably and consistently clear the isles with low ceiling.

Currently the price of modifying the dollies are being investigated in order to make an informed decision of how to avoid the problem in the future.

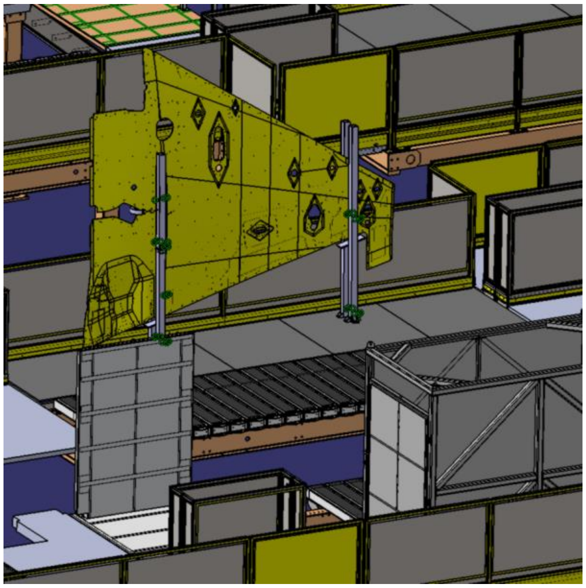
Concepts

In order to further develop the production process new equipment needs are identified and concepts to fulfill these needs are developed. I were involved in the process of developing two concepts, an in station wingskin hanger and a 2-skin sliding dolly, a bit of the thought process and concepts are shown below.

Wingskin hanger

A significant problem in the wing structures line are the presence of wingskin dollies which congests the limited ways of transportation and areas of storage. Due to the production process described above it is needed to store wingskins for a significant amount of time. This has until now happened on dollies which would take up valuable floorspace and are often moved around in order to make space for other operations and/or transportation whereafter they will have to be found again by the original owner at a later point. All of this resulted in a lot of wasted work.

Two concepts were proposed, one using a large part of the design of the current single skin dollies modified for the stationary use and the other using hooks to hoist the skin up above the platforms.



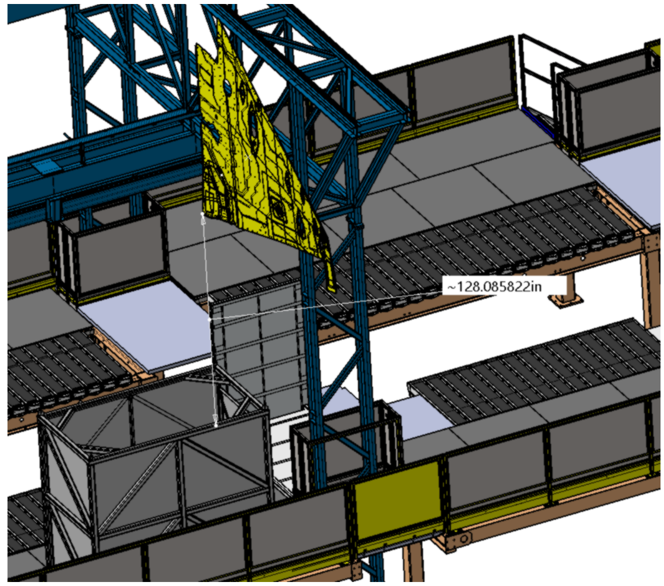


Figure 4: Modified dolly posts

Figure 5: Hook concept

Concept renderings of the two concepts can be seen in figures 4 and 5.

The advantage of the first concept being that it builds on a modified version of an already approved design, making it easier to implement, and it allows for work to be done on the wingskin. However this method of storing the wingskin occupies some of the limited space on the platform and can be in the way of items being transported from the central aisle between the left and right wing assembly line to the assembly jig on the assembly lines.

The hook concept moves the skin into otherwise unused space, however it is not possible to do work on the skin while in the hanger.

2 Skin sliding dolly

Another concept was a new proposal for a 2 skin dolly. Currently skins are stored and moved on a mix of single skin dollies, 2 skin dollies and 8-pack dollies. A new wing skin flow developed by John Brookes would require a number of 8-pack dollies for storage and a larger number of 2-skin dollies (a shipset) than currently possessed. Therefor a rework of these dollies were considered in order to improve the dollies for the new use case. The sought improvements include a smaller footprint and the ability to work on both sides of the wingskins while the wingskin is placed in the dolly. In addition to this the skin can also be placed facing both directions, making the loading more flexible.

The dolly has similarities to a previous prototype dolly but is also differentiated by being adapted to CTOL and STOVL skins primarily instead of CV skins, making them easier to place in the dolly. This is due to the fact that CTOL and STOVL makes up the vast majority of planes produced. However the CV skins are taller making stability on the dolly more of a concern, which was

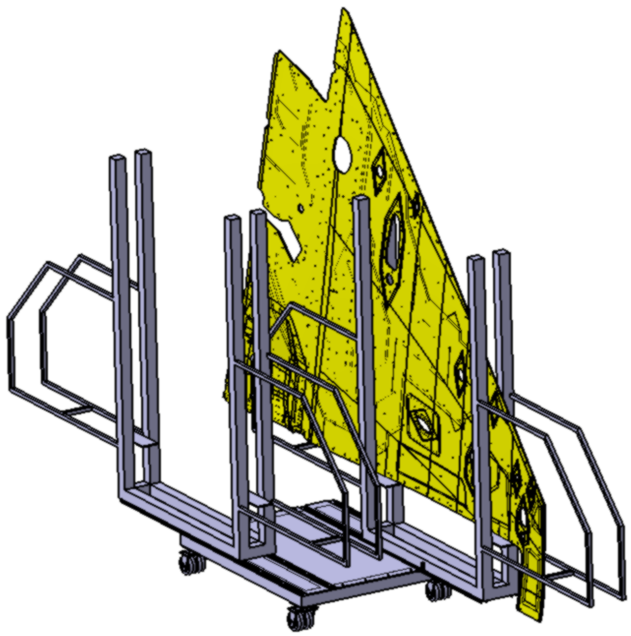


Figure 6: 2 skin sliding dolly

presumably the main design consideration in the previous dolly design, while this concept is more focused on usability after the required amount of security is achieved. Additionally the CV wingskin sits lower in this design, making it clear more roofs avoiding the problem described in the dolly modification section.

Move plans

In order to ensure that every move can be completed safely for both personnel and components every significant lift, hoist or move of a component must have a plan detailing the individual steps in the move. This is done in order to make sure they are done safely and after procedure and that all the necessary safety measures are taken.

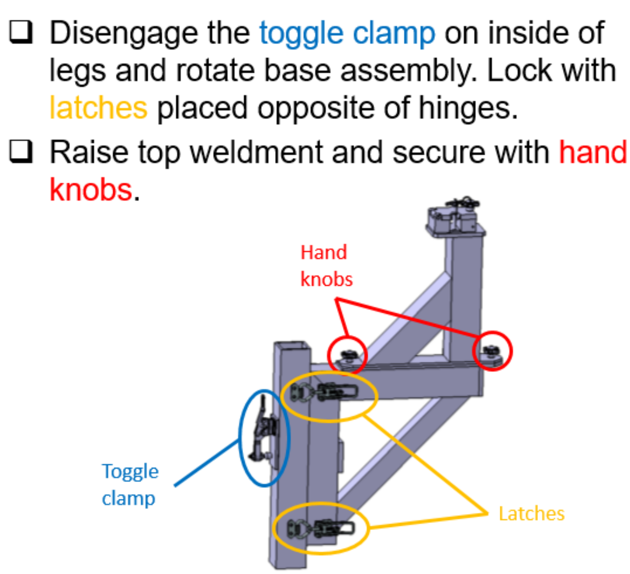


Figure 7: Example from move plan

I were a part of creating and editing a number of such move plans for various new and changed moves. Such plans require a lot of attention to detail by making sure every single substep is described, such as clamping down a hinged detail after it has been folded out, as well as marking where such clamps are to be found, but are otherwise quite straightforward.

An example from such a move plan can be seen in figure 7.

MRTO Crib Move

In the MRTO Crib assembly jigs are prepared before starting a new build of a wing. In order to increase the production rate an expanded MRTO crib were deemed necessary. Before my arrival a plan for the new layout were already in place incorporating the needs projected by the industrial engineers as well as input from the tooling department who operates the MRTOs.

However the sequence of moves necessary to achieve the new MRTO crib layout were not charted out yet, so I had to coordinate with different engineers, managers and mechanics in order to incorporate their needs and wishes and then come up with a plan for how and when each of the multi ton items such as the MRTOs, MITOs and machining center should be moved in order to avoid conflict in the crowded area and maintain as high uptime as possible in order not to interfere with production.

Throughout the planning and move process there were constantly changing needs which required changes in plans. One of the significant changes were the forecasted increasing amounts of completed wings that needed to be stored as projections for production changed. These wings require significant space to store and move and thus has a great impact to the layout of the crib.

This project has been very interesting to be so involved in since it afforded me an excuse to experience what a number of different departments were dealing with and what was important to them. This project took up a lot of time and effort in order to coordinate with everyone, have the plans vetted and communicate them out, but was very rewarding.

Tooling cart

The details used on the AJs will, as the wing is build up, be replaced with components of the wing which necessitates the need for a cart to follow the AJ to collect the details as they get removed. A new cart were needed since the previous weren't sufficiently ergonomic and were missing so called shadowboxes used in order to ensure that every component is present. Designwork like this is most often handled by different vendors who are chosen through a bidding process. When a vendor is chosen the design work start. However, in order to ensure a satisfactory design, design reviews are performed where the fit and function of the item is evaluated by Lockheed Martin engineers.

I were part of the design review process for the so called Z-beam tooling cart (the Z-beam being a beam mounted to the AJ in order to provide stiffness as well as hold details). Among other complications it turned out that the tooling installed on the AJs were changing and a new prototype design were being trialed which were then incorporated into the design for the tooling cart.

General experience of working at Lockheed Martin

During my internship at Lockheed Martin I gained invaluable experience of working in a large American company. Being able to experience the way work is managed and conducted through meetings for respectively discussion and scheduling, email, calls and informal conversation among colleagues have been different to what I previously have experienced in Denmark.

The way a lot of processes have been systematized in Lockheed Martin, facilitated by the many years of experience and the sheer scale of the company has also been fascinating, and bewildering to witness.

I also learned a number of useful skills and how they are applied in a professional setting. These include learning to use Catia as well as getting experience with using it to open and edit other peoples' models, as well as designing models myself. In addition to this I learned to use Visio and found it to be a very useful tool to create overviews of the complicated floorplan, and the ability to add information to this overview and easily toggle it proved very valuable.

My coworkers has provided me with a wealth of insight into both their specific tasks, the operations of Lockheed Martin Aeronautics both in our department as well as on a larger scale of the company as well as personal insight into life in the United States and in general.

Cultural experiences

Throughout my internship I have had the opportunity to experience living and traveling in the US. I have had many fantastic experiences including eating Texan barbeque, going to a rodeo and a Nascar race, visiting many Texan cities including Fort Worth, Dallas and Austin, participating in sports such as rock climbing, wakeboarding and mountainbiking together with, and competing against dedicated, talented and enthusiastic Americans as well as visiting a large number of state and national parks such as the Dinosaur Valley, Palo Duro Canyon, Big Bend, Grand Canyon and Zion national parks.