LOCKHEED MARTIN

Internship Report

Lockheed Martin Aeronautics
F-35 Program Quality Technologies

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TERMA

DTU

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Internship report

Lockheed Martin Aeronautics Company
F-35 Program – Quality Technologies

An internship performed at:

Lockheed Martin Corporation

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Preface

This report is written towards the complete fulfillment of the coursework requirement for portfolio credit at the Technical University of Denmark (DTU) in the spring semester of 2018. It also aims towards being released for the public to be part of the recruiting efforts at Terma A/S in Denmark. At the same time it serves as partial technical documentation for the Roller Drone project within Quality Technologies under Quality and Mission Success. The report is the final documentation of a 5 month long engineering internship at Lockheed Martin Aeronautics in Fort Worth, Texas carried out by Danish engineering intern Jesper Lund studying for a Master's degree in Materials- and Manufacturing Engineering at the Technical University of Denmark (DTU) in Denmark, Europe.

The report briefly goes into Lockheed Martin, its business areas, and heritage as an aerospace company. Then an overview of the work carried out at Quality Technologies within Quality and Mission Success at Lockheed Martin Aeronautics in Fort Worth, Texas is given. This primarily focuses on the Suite of Drones project and the development of the Roller Drone autonomous inspection type drone. Lastly, an account of the personal experience of going to the United States and working for Lockheed Martin Aeronautics on the F-35 Joint Strike Fighter program is laid out.

I would like to acknowledge the tremendous help and guidance I have received from the entire Quality Technologies team. It has been a true pleasure working alongside these dedicated and skilled individuals. I would like to thank the Customer Programs Denmark office for providing excellent help in navigating the murky waters of business rules and regulations, and making sure that the administration side of the internship has gone smoothly. I would like to extend my thanks to Terma A/S in Denmark for supporting the internship program in most all ways imaginable, and my thanks to Terma North America for taking good care of us 8 Danish engineering interns, while we have been in Fort Worth. Lastly, I would like to thank the seven other Danish interns for excellent company and team spirit in this endeavor. To all, it has been greatly appreciated, and I have enjoyed every moment. I hope that we will all meet again down the road, sooner rather than later!

It has been an absolutely amazing experience working on the cutting edge of technology for the most advanced tech company in the world, Lockheed Martin. I am very grateful to have been given the opportunity.

Jesper Lund
Fort Worth, June 2018

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List of abbreviations

ADP	Advanced Development Programs
CAD	Computer-Aided Design
CAR	Corrective Action Request
CTOL	Conventional Takeoff and Landing
CV	Carrier Variant
EMAS	Electronic Mate and Alignment System
ESH	Environment, Safety and Health
FOD	Foreign Object Damage/Debris
IFG	Integrated Fighter Group
LM	Lockheed Martin Corporation
LMPI	Lockheed Martin Proprietary Information
MFC	Missiles and Fire Control
PDCA	Plan - Do - Check – Adjust
PDM	Product Data Management
PPV	Product Process Verification
QMS	Quality & Mission Success
QualTech	Quality Technologies
SOW	Statement of Work
STOVL	Short Takeoff/Vertical Landing
MRO	Maintenance and Repair Operations

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1 Introduction

In the spring semester of 2018, eight Danish engineering interns, see Figure 1-2 and Figure 1-3, from the Technical University Denmark (DTU) has been employed for a semester long internship with Lockheed Martin Aeronautics Co. in Fort Worth, Texas, in the United States of America. They have been the fourth team of Danish interns to do so.

The internship is a collaborative effort between Lockheed Martin Aeronautics Co., Danish defense contractor Terma A/S and three major Danish universities. The universities include the Aarhus University, Aalborg University and the Technical University of Denmark (DTU). Initiated by Lockheed Martin in 2015, the students are invited to be an integrated part of the engineering team working on the mass production of the 5th generation stealth fighter, the F-35 Lightning II. These interns take part in solving the engineering challenges faced daily in what is currently one of the world's largest production of fighter aircraft. The outcome, apart from the technical work contributed to Lockheed Martin Aeronautics, is the invaluable insight into the American defense and aerospace industry that they bring back with them to Denmark. The skills and competencies, gained, are extremely valuable to Danish industry and cannot be attained anywhere in Denmark.

Denmark has been a partner country in the development of the F-35 Joint Strike Fighter program since 1997. Through both financial, equipment, and personnel contributions, Denmark has actively taken part in the development efforts. The most visible contribution has arguably been the F-16 Fighting Falcon ET-210 chase plane, maintenance crew, and test pilot Lt Col. Casper "PEL" Nielsen. This plane has conducted many exciting test flights, right from the beginning to the end of the F-35 flight test program as seen in Figure 1-1.

Additionally, many components for the F-35 Lightning II is made in Denmark. This among other things includes certain composite panels, the so called skins of the aircraft, and the gun pod for the B and C variants of the aircraft. The Danish defense contractor Terma has been chosen as a provider for these parts to the program. As the main focus from the onset of the F-35 program has been affordability, this is a true testament to the capable Danish defense and aerospace industry. In June of 2016, the Danish participation in the program culminated, with the Danish parliament voting in favor of buying 27 F-35 Lightning II aircraft to replace the existing Royal Danish Airforce fleet of aging F-16 Fighting Falcons dating back to the early 1980's.

As is evident, this internship is therefore not only invaluable to the engineering students that are chosen, but is also an important piece of a larger political mission, ranging all the way from geopolitical security considerations on a global scale to international business collaborations.

Figure 1-1 Royal Danish Airforce F-16 Fighting Falcon ET-210 acting as an F-35 chase plane during F-35 flight tests. Copyright: Royal Danish Airforce Photo

Figure 1-2: The eight Danish interns: from the back left Emil Hølmkjær, Lenni Busk, Jesper Lund, Nils Toudal, Mads Hellemann, Lukas Høghøj, and from the front left Kenneth Jensen, Kristoffer Olesen, and from the Lockheed Martin Aeronautics F-35 Denmark Program Office: Elyse Michniak and Doug Vanotterloo.
Copyright: Lockheed Martin Photo.

Figure 1-3 Press photo of Jesper Lund and an F-35A taken at the Lockheed Martin Aeronautics 2018 Jet Day Event.
Copyright: Lockheed Martin Photo.

2 Company background

Lockheed Martin is a leading American aerospace, defense, security and advanced technologies company. It is divided into four distinct business units: Missiles and fire control, Rotary and Mission Systems, Space, and Aeronautics. These four business units make advanced technologies ranging over such diverse fields as intercontinental ballistic nuclear missiles, power plant technologies, ships, helicopters, satellites, and military aircraft. Recently Lockheed Martin has also ventured into research for cyber warfare systems and new energy sources such as thermonuclear fusion. The corporation employs over 100.000 people across the world.

2.1 Lockheed Martin Aeronautics

Lockheed Martin Aeronautics is an aircraft manufacturer with headquarters in Fort Worth, Texas. The product lineup includes the F-16 Fighting Falcon, the C-130J Super Hercules cargo plane and the T-50 Golden Eagle jet trainer. However, the F-35 Lightning II aircraft under the Joint Strike Fighter program is the main source of revenue for Lockheed Martin Aeronautics, and constitutes a major part of the business for the Lockheed Martin Corporation, with its estimated $800 bn in revenue until 2070, as well. Apart from manufacturing new aircraft, sustainment, maintenance and repair operations on legacy aircraft are a large part of the business as well. These aircraft include the F-22 Raptor air superiority fighter, the F-16 Fighting Falcon fighter, the C-5 Galaxy heavy airlifter, the P-3 Orion marine operations aircraft, and the U-2 Dragon Lady spy plane.

Although the main assembly plant is located next to the headquarters at Air Force Plant 4 in Fort Worth, Texas, Lockheed Martin Aeronautics has several locations across the US as seen in Figure 2-1. The most famous location is Palmdale, California that houses the Advanced Development Programs (ADP) informally known as the Skunkworks, see Figure 2-3.

Figure 2-1: Lockheed Martin Aeronautics locations in the United States of America [1]

2.2 Skunkworks

The Advanced Development Programs is a subunit of Lockheed Martin Aeronautics, previously under Lockheed before the merger with Martin Marietta. The unit is located in the desert near Palmdale, California close to Los Angeles. It focuses primarily on the development of new aircraft prototypes, advanced aeronautics, control systems, and materials research. It also houses a research ground that works on a compact nuclear fusion reactor. Since its conception in 1943 the Skunkworks has made many quantum leaps in aircraft technology. The most famous and iconic designs include the to date world's fastest air breathing manned aircraft the SR-71 Blackbird, the U-2 Dragon Lady spy plane, the stealth F-117 Night Hawk and the air superiority fighter, F-22 Raptor. This was also the unit that made the initial design for the F-35 Lightning II.

Among the high-profile current projects that have been publically released are: the Quiet Supersonic Technology X-plane designed to reduce supersonic booms created when breaking the sound barrier; MQ-25 autonomous refueling drone for autonomous air-to-air refueling the F-35 Lightning II; The Hybrid Airship troop transport blimp: and the Compact fusion reactor. However, most of the ground breaking discoveries to come out of Skunk Works have all come from Top Secret military projects. Currently, job openings at the Palmdale facilities and with the Advanced Development Programs are all strictly for US Citizens and requires a Top Secret Security clearance with Special Access. This requires a 5 year background check to be performed. Much of what is being worked on, however, is not publically released. However, whatever the Advanced Development Programs truly have in the works, it is most likely going to impact the future of Aviation.

Figure 2-2: The SR-71 Blackbird spy plane, to date still the fastest air breathing, manned aircraft in the world.

Skunk Works® Logo

Figure 2-3: The logo of the Lockheed Martin Aeronautics Advanced Development programs, a.k.a. Skunkworks.

Figure 2-4: The F-117 Nighthawk tactical stealth bomber.

2.3 F-35 Lightning II

The F-35 Lighting II is the world's most advanced stealth, supersonic capable multi-role fighter. It was designed to take over from an ever increasing number of different aircraft within the marine core, navy, and air force. The aircraft to be replaced by the F-35A are among others the F-16 Fighting Falcon, the GR4 Tornado and the A-10 Warthog. The F-35B variant with its short take off and vertical landing capabilities (STOVL) will replace the British made AV-8 Harrier Jump Jet. While, lastly, the navy F-35C version being optimized for carrier operation will replace the F/A-18 Hornet and F/A-18 Super Hornet in the US Navy. These three versions may be seen in Figure 2-5 to 2-7 on the next page.

Stealth

One of the main specifications for the new Joint Strike Fighter was the so called low radar cross section, low observability, or stealth. The concept of stealth means being less observable to enemy radar, which is exceedingly important for the first parts of a military engagement. Being low observable to radar means that the aircraft can penetrate into enemy airspace undetected and destroy enemy strategic installations such as surface-to-air missile sites and radar stations, allowing for opening of the airspace to conventional air assets such as strategic bombers, surveillance aircraft and tankers. However, radar cross section increases with proximity to the enemy radar station, and the aircraft is not invisible to radar at very close distance.

Stealth, however, comes with restrictions on the physical appearance of the aircraft. All surfaces must either reflect radar waves away from the transmitting radar station of completely absorb them. All radar waves that are reflected back to the enemy radar station will increase the detected cross section. For this reason the radar cross section is also different from different angles of view to the aircraft.

Since the best control of stealth is achieved by having completely smooth surfaces, tolerances on panel gaps are exceedingly important. The F-35 Lightning II is the first aircraft to rely primarily on tight tolerances to ensure good stealth properties. This is especially impressive as it is also among the first fighter aircraft to be built primarily with composite exo-structures as opposed to aerospace grade aluminum or titanium.

The limitations on the physical appearance also means the airplane may not be able to maneuver as aggressively as fighters that are optimized for increasing the so called flight envelope, the flying characteristics of the aircraft. This means that the aircraft may be less capable in a fighter-to-fighter air combat, i.e. dogfight, using the guns in certain configurations. However, owing to its stealth properties it can engage enemy aircraft with missiles before the enemy aircraft can detect it. The F-35 also has external mounting points for bombs, missiles and fuel tanks, even though using these negates stealth properties. This is usable after the primary air battle in close air support (CAS) operations for ground troops, when stealth is not required, but a larger payload and range is desired. This makes the F-35 Lightning II a very versatile aircraft being able to operate in different roles during different stages of a conflict

Reducing Costs

By reducing the number of different aircraft models in inventory, the supply chain for maintenance and repair operations (MRO) can be reduced and streamlined. This will in turn mean that the lifetime cost for operating the aircraft can be significantly reduced. Affordability has been the main goal for the project from the onset.

Joint Strike Fighter Program

To meet this primary goal international partners have been brought in to be able to share development cost and leverage economies of scale. This has been done under the F-35 Joint Strike Fighter Program. Under this program, The United States of America has partnered with Australia, Canada, Italy, the Netherlands, Norway, Turkey and Denmark to co-develop and operate the F-35 Lightning II. Other countries who have purchased the aircraft include Israel, Japan and the Republic of Korea. To further decrease the cost of the program, the widely used strategy of counter purchasing parts and services in the buyer countries has not been utilized. This means that all contracts for parts and services are awarded based on price and quality and not politics.

Denmark has been a partner country in the Joint Strike Fighter program since 1997, where the first commitment for 10 mio. USD was awarded for initial specification and development. Since then the Danish commitment has only increased up until June of 2016 when the Danish parliament passed the bill of purchase of 27 F-35A Lightning II aircraft into law, thus committing to buy and operate this aircraft within the Royal Danish Air Force (RDAF).

Figure 2-5: F-35A conventional take-off variant that the Royal Danish Airforce will operate.

Figure 2-6: F-35B Short Takeoff/Vertical Landing with lift fan and swiveled engine [2]

Figure 2-7: F-35C Carrier Variant (CV) with folded wingtip sections and robust landing gear [2]

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2.4 Quality Technologies

Quality Technologies (QualTech) is a team under Quality and Mission Success in Lockheed Martin Aeronautics Co, see Figure 2-8. The primary focus of the team is to discover, develop and implement new emerging technological solutions to inspection and quality assurance purposes in the manufacturing of aircraft. Although, physically located at LMA's headquarters in Fort Worth, Texas, where the F-35 is manufactured, the team serves all manufacturing operations on all aircraft models. This includes the U-2 Dragon Lady, C-130 Hercules, P-3 Orion, F-16 Fighting Falcon and sustainment operations on aircraft such as the cargo plane C-5 Galaxy and the air superiority fighter F-22 Raptor. To a lesser degree, Advanced Development Programs, a.k.a. Skunkworks are also served.

As part of the quality organization under LMA, the focus is production quality and monitoring. This means, that the team also works with task such as calibrating measuring equipment, carries out First Article Inspections (FAIs) and Product Process Verification (PPVs).

In developing new technologies, the Quality Technologies team works actively together with several universities and partners in industry to develop new technologies that are applicable to the aerospace industry. This involves college engineering interns, senior design projects, thesis collaborations, development, and ground breaking research projects. From a Danish perspective this is especially interesting, as the potential for active research collaborations with the Technical University of Denmark (DTU) is currently being discussed and research collaborations may be underway in the near future.

Currently the team is focused on the technologies such as autonomous drones and machine learning for the application of inspection in aircraft production. The team develops prototypes in-house as well, as through industrial and academic collaborations, and is focused on improving quality and lowering the cost of inspection processes in manufacturing operations. This is a core pillar of the F-35 Joint Strike fighter program, and the work of the team is thus in perfect alignment with overall program goals.

Figure 2-8: The spring 2018 QualTech team at Lockheed Martin Aeronautics. Picture taken at the Jet Day event. Copyright: Lockheed Martin Photo

3 Work done

The primary outcome of the internship was of course the work carried out. In our case, this was mainly the development of autonomous inspection type drones. I worked exclusively on a hubless wheel based design for a rolling inspection type drone usable for run station and runway inspections in Flight Line operations. Kenneth, the other Danish intern with Quality Technologies, worked on a rover type drone with a ducted fan for driving on walls and in an inverted position. This drone was tasked with doing various in-production inspections.

Furthermore, a more comprehensive concept around the drone prototypes was developed. The concept called the Suite of Drones aimed at having different drone vehicles for different tasks, again carrying interchangeable sensors. The latter was dubbed the Suite of Sensors. To support better rapid prototyping capabilities within the Quality Technologies team, a plan for a New Drone Lab was laid out. Recommendations on production capabilities and tools and machinery needed was given. Finally, the inspection process in the F-35 Program was reviewed with the goal of uncovering needs for technological solutions to high value problems. A primary goal of this effort was also to determine an Inspector of The Future. Applying new, emerging technologies the goal was to streamline the inspection process. The overall goal was to increase the quality of inspections, at the same time as man hours spent on inspections were reduced.

3.1 Roller Drone

The main project was the Inspection Type Roller Drone. The project had been initiated by former Dutch, college intern Karan Vir Bairns. He conceived of the concept of having a completely spherical shaped inspection drone for autonomous Foreign Object Debris (FOD) identification and retrieval. And a design for this was proposed. The project was handed over, and the initially work focused on specifying the modes of operation, the specifications and the restrictions, as an industrial partner, Sphero Inc., was to be taken in to the project. From there a Version 3 prototype was built aiming to resolve the shortcomings of the initial design.

3.1.1 Roller Drone Specifications

The Roller Drone is a proposed inspection type autonomous drone for foreign object debris (FOD) inspection and removal applications in jet aircraft operation and manufacturing areas. The aim of the development project is cost reduction on those inspection tasks that may be easily automated, i.e. Flight Line, runway and run station FOD walks, floor inspection in manufacturing areas, inspections directly on aircraft, and perimeter security patrolling. These routine tasks require man hours on a daily basis in all areas where jet aircraft operate. The autonomous FOD retrieval drone technology may also find military applications, for example in situations where the safety of inspection personnel cannot be guaranteed such as deployment to military operated airfields in active war zones. Furthermore, the prototype may also add new strategic military capability in deploying FOD inspection and removal drones for opening disused or ad hoc airfields (For this application, more drones could for example be airdropped from a military jet aircraft to prepare the runway for safe operation and landing in one single mission).

To be effective the design was aimed fulfil the following requirements:

1. Not pose a danger to the environment, personnel or aircraft.
2. Not carry home base wireless communications systems.
3. Autonomously identify and remove FOD.
4. Have a closed form factor, i.e. inherently not be source of FOD (even in case of malfunction).
5. Operate in most all weather conditions.

The currently desired form factor is that of a *closed sphere* with internal drivetrain, navigation and FOD retrieval system. This is unlikely to leave FOD behind even in case of malfunction as all mechanical parts are carried on the inside. Furthermore, this form factor provides good maneuverability, i.e. 360 degree turns, and inherent stability. It is also insensitive to varying terrain. A home base with wireless charging for internal batteries may be added to provide prolonged autonomous operation without opening for maintenance. Below, the specific objectives and technical requirements are given.

Objectives

1. Foreign object debris (FOD) inspection and removal in and on airfield areas.
2. FOD inspection in aircraft production.
3. Perimeter security and surveillance.
4. Inspection directly on aircraft and run station operations.

Technical requirements

1. Not pose danger to operating environment.
2. No home base wireless communication.
3. Autonomous FOD detection and removal.
4. Closed physical form factor.
5. Weather resistant

Operating Environment

The operating environment for the Rollinspector autonomous inspection type drone is on airfield aprons, in hangars and in aircraft manufacturing areas. These areas are heavily contested by other maintenance and support equipment, see the two figures below. This offers restrictions on the physical form factor of the drone. The drone must also pose a danger to personnel, aircraft or equipment. Operating in this environment means doing tight turns, and accessing tight spaces. The autonomous drone should be able to maneuver in this contested space. From the last figure, the scale of operations may be seen. The magnitude of the distance that must be covered is estimated to exceed 3 miles in a single cycle. The operating surface is tarmac or concrete in outside applications, and painted concrete on inside applications. For military applications possible tall grasses and gravel conditions may be met, as well. These, however, are a secondary objectives to the project.

3.1.2 Prototype Development

After the specifications had been laid down, the process of optimizing the design of the prototype was begun. The initial design was dubbed Version. 1, and a collaborative effort with Southern Methodist University (SMU) was given the designation of Version 2.

Roller Drone Version 1

The initial design for the Roller Drone had proven very difficult to implement. It included using a Sphero toy for propulsion of an encapsulating 3D printed sphere. The navigation system was based on 8 cameras giving a 4π steradians field of view from which navigation and FOD identification should be processed. However, the constant motion of the cameras during operation, an underpowered drivetrain in the Sphero, the lack a general sense of forward-backward or right-left due the omnidirectional motion, and very limited physical space for a FOD retrieval system posed great challenges.

Roller Drone Version 2

The initial concept and design for the Roller Drone was at the beginning of the semester given to two teams of engineering students at the Southern Methodist University (SMU) for their senior design projects. They were tasked with the design of a FOD retrieval and a navigations system. After encountering challenges in fitting the necessary systems into the small form factor, the teams were allowed to increase the initial small dimensions to fit their FOD retrieval and navigation systems. The teams delivered two proposals for FOD retrieval systems. Neither team gave any specific design for navigation – although generic considerations were given.

The first FOD retrieval mechanism proposed, was an iris mechanism type opening in the spherical shell that would allow the drone to roll over the FOD, close the iris mechanism, and subsequently close the iris to retrieve the FOD, carrying it in a compartment inside the drone. Issues with retrieving multiple pieces of FOD in one run, and actuating the iris mechanism was shortcomings of this design.

The second, was an elegant universal gripper and mechanically operated drawer mechanism. The universal gripper was a concept, that Quality Technologies was familiar with, and had a prototype of. However, this design carried the gripper on the outside as an integrated part of the shell, and a series of detailed movements combined with an actuated drawer picked FOD up in a very elegant way. This mechanical design, is considered to be the primary outcome of the two senior design projects for the team.

Figure 3-1: Ground crew preparing an F-35 Joint Strike Fighter for take-off.

Figure 3-2: During manufacturing and maintenance operations, the footprint of the F-35 Joint Strike Fighter is highly contested by tools and support equipment. FOD detection and removal, however, remains a priority.

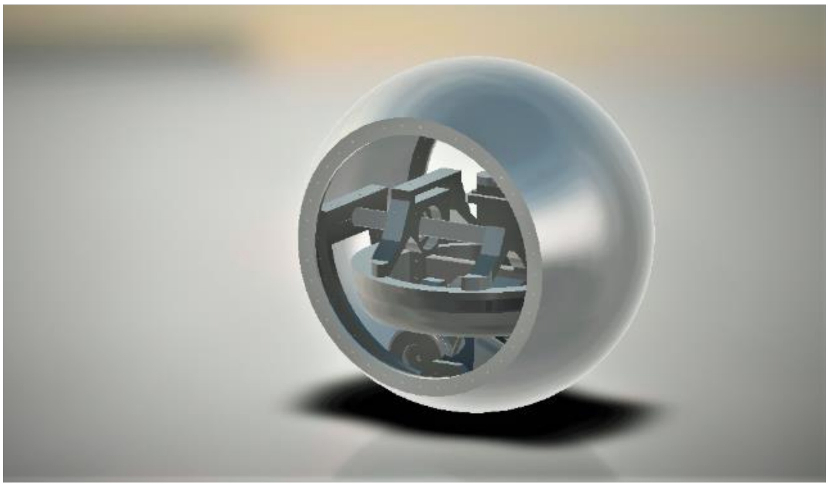

Figure 3-3: The Roller Drone Version 3 design. The drone is designed as a hubless wheel with a main drive running on an outer sphere. The flywheel in the center is used as a reaction weight to lean the drone for turning, and for yawing the drone. This gives the drone a 360 degree turning on the spot capability.

3.1.3 Roller Drone Version 3

A complete redesign of the Roller Drone based on the challenges of the initial designs and the new specifications was to be carried out. This involved increasing the size of the drone radically from the initially proposed to fit a longer range more effective drivetrain and allow for space for sensor systems. In a literature study of these types of robotic prototypes, a design made by the company XRobots in the United Kingdom was found. This was a hubless wheel design for a remote controlled robotic prototype that had similar specifications to those uncovered in the specification part of the project, see Figure 3-3 and Figure 3-4. The design had been publically release under a free license. This was deemed appropriate for the application in mind, and the mechanical platform for the version 3 Roller Drone prototype was based on this.

The approach of modifying an existing design allowed for an extremely rapid prototyping. The released design included CAD drawings of parts and instructions for assembly. The challenge would be to manufacture the parts using 3D printing methods, designing proper electronics circuits and modify the released software to the specifications needed for the roller drone.

Hubless Wheel Design

The prototype design was that of a hubless wheel. This was desirable, as it reduced the requirements for having high torque electric motors for the powertrain. In turn this would reduce power consumption and increase the operating time of the drone. The hubless wheel also gave an intrinsic forward-backward and left-right sense of direction that eases the control of the drone. Challenges that were still present from earlier models was the intrinsic instability of a rolling sphere. Tendency to build up mechanical oscillations / wobbling both in the forwards-backwards and the side-to-side directions during operations indicated that active stabilization measures were needed. Making a full 180 degree on-the-spot turn was a requirement, and this was handled by spinning a flywheel to high rpm and braking it hard. This provides a very good yaw rate on smooth surfaces.

Rapid Prototyping

The manufacturing of the design was based on classic rapid prototyping. This involved 3D printing parts in engineering polymers such as PLA and ABS. A Lockheed Martin Aeronautics shared asset was used for 3D printing large parts, while a purpose bought 3D printer was used for printing parts with a smaller form factor. The prototyping involved using the professional grade Makerbot Z18 and Ultimaker 3. The software suites that were used for slicing was Makerbot Desktop and Cura for each printer respectively. 3D printing polymer parts have become increasingly easy and affordable. However, in depth knowledge of material properties are still essential for getting an optimal result. In addition, print quality is highly influenced by the settings chosen in the slicing software for the 3D printers such as print speed, nozzle temperature, extrusion speed, and layer height.

Figure 3-4: FOD walk at Osana Air Force Base in the Rep. of Korea. Roller Drone inserted for scale.

Figure 3-5: Arduino Mega 2650 used for control and sensor input computing.

Figure 3-6: Raspberry Pi 3B microcomputer used for video capture and machine vision.

Figure 3-7: Lithium Polymer (Li-Po) battery 11.7V.

Figure 3-8: HC-05 Bluetooth Master-Slave module for radio communications for example with a smart phone or tablet computer.

Figure 3-9: BTS7960 12-24V motor driver

Figure 3-10: Pi Camera for use with the Raspberry Pi microcomputer.

Electronics
The electronics and control suite is based on the open source Arduino eco system. An Arduino microprocessor was used to actuate the drone based on sensor input from both on board sensors and a remote control unit. Some of the electronics used may be seen in figures Figure 3-5 to Figure 3-10.The on board sensing is based on the IMU 6050 This IMU gave accurate roll, pitch and yaw data through the I2C data connection, used for actively stabilizing the drone. Furthermore, a potentiometer was used to sense the difference of roll between the outer wheel and the inside reaction mass flywheel. This contributed as input to a nested PID controller doing active stabilization, discussed more in depth below. For actuation purposed two high-torque 12V electric motors where bought. This was used for the main drive, and for rocking the reaction flywheel. Two smaller 24V geared electric motors were implemented to spin the flywheel after command from the remote. Three independent high-current/high-power motor drivers were used in conjunction with high-performing Li-Po batteries, see the figures above.

The remote control unit was based on an Arduino Pro mini (not shown) with four XY joysticks, three toggle switches, and three push buttons. This was powered by a separate power bank. The datalink was provided by two Bluetooth modules as shown in Figure 3-8.

Li-Po Battery Safety
A draw back to the high-performing Li-Po batteries is the inherent fire danger. Li-Po batteries that are used in high-power applications, are faulty, or are being charged and stored under suboptimal conditions, can potentially self-combust. In this case a violent chemical fire breaks out. To protect the health and safety of the personnel working with these drones and batteries in prototyping projects fireproof Li-Po Safe Boxes where purchased. Furthermore a manual for proper use of the Li-Po batteries for future interns was created. For this effort Kenneth Jensen and I were awarded with an award in the form of a Lockheed Martin Coin of Ethics and Integrity.

Software
The software running on the microprocessors was developed as Arduino Sketches. This programming language is similar in nature to the programming language C, but has a dedicated Integrated Development Environment (IDE) and pre-built libraries. The software for the Roller Drone Version 3 was based on the existing prototype software from XRobots, but heavily modified to suit the specifications of this project.

The software for the remote control was based on sensor inputs and the Bluetooth connection. The inputs from the XY joysticks and the switches were read as analog and digital data in respectively. This was then send over serial connection using an architecture based on a start marker, a series of integers and an end marker, to be able to parse correct channels to correct controls for the drone. This data stream was then send over Bluetooth to the drone.

The software for the drone consists of three parts. The first part takes data from the remote control unit from the serial connection over Bluetooth and parses the information as integers into usable variables. The second part reads data from the sensors on the drone and carries out calculation for stabilization action required for active stabilization. The stabilization is implemented as one nested proportional-integral-derivative controller (PID controller) for the side to side motion. For the forwards-backwards motion a single PID controller is used. These take sensor data as input, set point data from the remote control, and provides an output to be used for the motor drivers.

The largest part of the software development for the prototype was setting up the sensor acquisition and PID controller parts, as the used I2C Devlib library was not well supported. Furthermore, safety concerns relating to the operation of the drone was important. Several safety features was therefore implemented. Among these were an auto-disable function. This disables the drone if the connection to the remote is lost. An emergency stop function on the remote was also implemented.

Tuning up PID controllers was done manually, which proved to be a time consuming process. A PID controller takes three constant values of input that determine the aggressiveness of the controller. To tune for an inherent stabile, dampened system, opposed to an unstable, resonant system is adjusted only by changing these three interconnected constants. This was carried out by a trial and error approach.

Figure 3-11: A Universal Gripper picking up a spring and a shock absorber assembly [3].

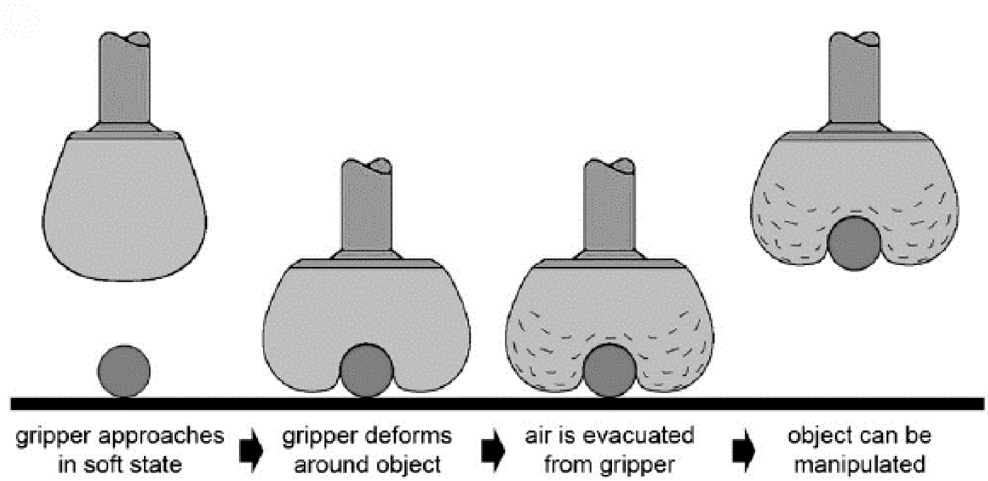

Figure 3-12: The mode of operation of the Universal Gripper [4] .

Autonomous Navigation
The design for the autonomous navigation and FOD identification system was given, but not build during this internship. The system design was based on a senior design project carried out at the École polytechnique fédérale de Lausanne (EPFL), in Lausanne, Switzerland. This design uses four SHARP IR distance measuring devices to carry out obstacle avoidance, and one conventional camera feed to do object recognition. The object recognition is based on the OpenCV machine vision package and written in the programming language Python. The prototype was used for identifying and collecting plastic bottles. However, the technique is applicable to FOD in Lockheed Martin business areas as well. The technical solution involves training of a neural network to carry out effective identification types of FOD that is likely encountered. This design is very promising and technically feasible. All needed electronics has already been procured.

FOD Retrieval System
A FOD retrieval system has not yet been designed. However, the SMU senior design projects presented two possible systems.

The first was a universal gripper type system. This system involves a flexible membrane, a particulate material and a vacuum pump. The membrane with the particulate is forced onto the piece of FOD. Then air is removed from the particulate making it very firm and unpliant. This securely grasps any shape or form of FOD. To release the object, air is let into the particulate again. This type of system, was mounted on the outside shell of the drone combined with an actuated drawer mechanism to retrieve and store the FOD. This allowed for retrieval of small pieces of FOD, which the majority of FOD consists of. This could be for example screws, caps, washers and the like. A primary advantage of this system, is that multiple pieces of FOD may be retrieved during a single sortie.

The second, was a spherical iris mechanism. The main mode of operation of this system, involved having the drone place itself next to a piece of FOD, open the iris mechanism, roll over the FOD, to then close the iris mechanism and thus retrieve the FOD. This approach is challenged by the mechanical complexity of an iris mechanism, but otherwise poses a good design option.

Further work on the Roller Drone in this field is expected to be carried out by future engineering interns.

Industry Collaboration
To gain a competitive advantage, a partner in industry has been sought for. Two companies have products that are similar to the project specifications of the Roller Drone, and they have been contacted. The first company is Sphero, a medium sized toy manufacturer producing a spherical robot of the same name. The second is GuardBot, a small company focusing on research and capabilities.

The Sphero robot comprises of a hard outer shell and an internal drive mechanism. The robot is controlled through Bluetooth through an app on a compatible smartphone. It is the size of a Softball. Initially this was used as the drivetrain for the version 1 Roller Drone.

The GuardBot is the same is size of the Roller Drone version 3 in its standard configuration. It has a patented drivetrain that makes it very stable and gives it a very long operational range. The company has previous experience with operations very similar to what is expected of the Roller Drone. GuardBot is considered to be an excellent candidate for further collaboration.

Outlook
In conclusion, the mechanical platform, drivetrain, controls and stabilization for the Roller Drone Version 3 prototype has been finished and demonstrated. The project is at a point where full operational functionality will be added with autonomous navigation, a FOD identification capability, and FOD retrieval system. There are suggestions and designs laid out for these. With these systems the first proof-of-concept of the autonomous FOD identification and retrieval system can be made.

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3.2 Suite of Drones

The suite of drones is an umbrella project for the individual drone prototype projects. The project aims toward having the “right tool for the job” by having many autonomous drones working actively together in inspection, maintenance, and repair operations. Most drone vehicles are suited for moving just in one environment: on the ground, in the air, on, or in the aircraft structure. When all the information gathered by the different autonomous vehicles are processed in a single system, the entirety of the aircraft manufacturing process may be autonomously inspected.

Manual Inspections

Aircraft manufacturing operations are limited by the low scale of operations. At most, a series of aircraft will be around 3000 ships, and operations must be flexible to accommodate this fact of doing business. This means that investing large sums in specialized automated machinery is not economically viable. Thus, the production line for even 5th generation stealth fighters is dominated by manual labor. Inspections are no exception to this. Most inspections in the production are simple visual inspections to check if the work has been carried out to specifications. The two most used tools are flashlights and handheld mirrors to inspect inside the aircraft structure, as seen in Figure 3-13.

These inspections are slowed down by the movement of the inspector to and from his desk to workstations. Often human factors means that quality issues are not found during the inspections, or issues found are not reported. Often, issues are reported in a way that the mechanic tasked with carrying out the re-work is not able located it. This incurs much waiting time, and slows production tact time. It costs money to the manufacturing operation.

Figure 3-13: Manual inspections of a F-35 centre fuselage at Northrup Grumman similar to those taking place in all aircraft manufacturing operations at Lockheed Martin Aeronautics [5].
Copyright: Northup Grumman Photo

AUTOMATED INSPECTIONS

PRODUCTION INSPECTIONS

Foreign object debris (FOD)

Scratches and corrosion

Tube internal surfaces

Sealant application

Hole alignment

Hole rifling

AND MANY MORE…

CURRENT INSPECTION PROCESS

WAIT TIME
Production halts during inspections

MAN HOURS
Inspection and reporting time (SQWK and QAR)

PROBLEMATIC INSPECTION QUALITY
Missed defects / false positives

PROBLEMATIC REPORT QUALITY
Found defects not reworked

AUTOMATED INSPECTION PROCESS

Autonomous inspection at work station

↓

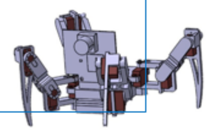
Continuous high quality inspection during production

↓

Immediate rework

↓

Time and Cost Savings



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Continuous, Automated Inspection
A Suite of Drones would be able to do continuous inspections in production. This would mean that the operator carrying out the task could be made aware of any parts outside of specifications, and immediate rework could be done. Essentially, this would eliminate both the inspection (Q-step), the reporting and the rework processes. This would contribute to cost reductions on all aircraft manufacturing operations throughout Lockheed Martin Aeronautics.

Swarming
If the drones are to work together in a collaborative fashion, swarming is integral technology. Having inspection flags being set by one drone and further inspected or even repaired by another with closer access allows the individual drones to be more specialized and efficient in their task.

Suite of Sensors
When a multitude of different drone vehicles are applied, and they are all running similar systems, it is desirable to have interchangeable sensors. Some inspection tasks may require visual inspection, roughness inspection, depth measurements, 3D scans or even the application of tools. Different sensors will be applicable to these different tasks. With this in mind a Suite of Sensors is proposed to be a part of the Suite of Drone project. Having quickly interchangeable sensor will add value and efficiency to the Suite of Drones for the inspector.

Current Prototypes
The current robotic prototypes include the Roller Drone, a detailed account is given above. But also a crawler drone that can inspect on all surfaces even in the inverted state has been designed and built. A robotic arm for inspections is currently being developed, but the prototypes have been built.

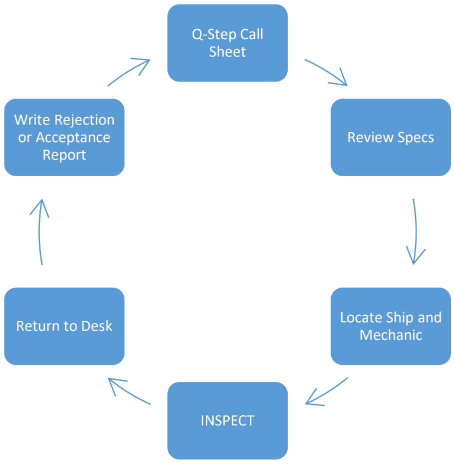
Envisioned Prototypes
Future robotic platforms considered include a spider like design called the Spider Drone, a traditional flying drone and a robotic prototype for internal inspections of tubing and pipes within the interior of the aircraft. These may be seen in the figure on the next page.

Shark Tank Competition
The concept of the Suite of Drones won the 2018 Lockheed Martin Co. wide Shark Tank competition for Innovation and Technology in front of 6 other elected projects. The competition that was held in Orlando, Florida had the top 200 vice presidents and all technical fellows from all of Lockheed Martin's 4 business areas: Aeronautics, Missiles and Fire Control, Rotary and Mission Systems, and Space, in the 700 people large crowd. In turn, a senior specialist board decided that the concept of the Suite of Drones for inspection purposes was the most mature, feasible and impactful of the seven proposed projects. The project won and was awarded a large prize in capital funding.

Competitive Environment
Other major aeronautics companies are heading down the same path and pursuing autonomous drone technology themselves. This includes Airbus that in April of 2018 has released their first autonomous drone for doing airliner inspections between flights reducing costly ground time. This is a part of their Hangar of the Future and Skywise projects, that try aim to automate maintenance and repair operations. This will in turn make flying the Airbus aircraft a competitive in the global marketplace. Boeing has similarly invested many resources into the Boeing Drone Labs, where autonomous ground and flying drones are being built with aircraft inspections in mind.

3.3 Inspector of the Future

The inspector of the future project was carried out to review the manufacturing inspection process. Focusing on technological solutions to processes that are currently carried out manually, the entirety of the inspection process was taken up for review. Three inspectors were shadowed covering all four main build areas: Wings, Wing Systems, Electronic Mate and Alignment Systems (EMAS), and Final Assembly



The inspection process may be seen in the figure above. It is based on a call board for all the stations in the build area the inspector is tasked to. From this all the technical data for a given operation is reviewed. All technical drawings and specifications that the operation must adhere to are specified. Then the inspector will manually locate the build are and mechanic and carry out the inspection. After this a report will be generated accepting the operation, or if faults have been identified a rejection report will be written.

Findings

Initial findings indicate that the process could be optimized by allowing the inspector to bring the software systems physically with him. This would allow him to not return to his desk after each inspection. Often the time spent walking to and from the desktop computer currently used exceeds that which is used on the actual inspection. The inspection also offers possibilities for improvement. Human factors means that often faults are overlooked or not properly documented. This means that faults will flow down the line, and be discovered in later stages of assembly. At this point a mechanic unaccustomed to this particular job, will be tasked with repairing the fault. This causes wait time in inspections, review of specifications that are new to the operator, longer than necessary re-work time, wait time in inspection again, all the while a build team is waiting for the part to be returned to within specifications. This is poses a major challenge to the production. See the figure on the next page.

Recommendations

Technological solutions to the problems mentioned are readily available. A tablet computer could be acquired for the inspectors to bring with them to the build areas. Smart glass technology is currently being developed that would allow inspectors to see stepwise instructions for a given inspection. Some current technologies allows the CAD model for a given build be overlaid with the physical structure. Having the specifications right in front of the inspector would drastically reduce human factors. Having a portable printer for so called QAR tags would reduce the time spent on inspections as well. The QAR tags are the tags used for rejection of a part for a quality issue. Hand held tag printers are at the time of writing already in procurement.

Suite of Drones

However, the goal of Quality Technologies is to reduce inspection processes and time, preferably eliminate it all together, increase quality and reduce costs. In this perspective, the Suite of Drones described in detail in this report probably the most viable approach. The synergistic benefits from having the operators self-inspect would make the Suite of Drones a desirable alternative. Carrying out immediate rework removes several processes of inspection, re-work, waiting time and re-inspection increasing the efficiency of the manufacturing line.

INSPECTOR OF THE FUTURE

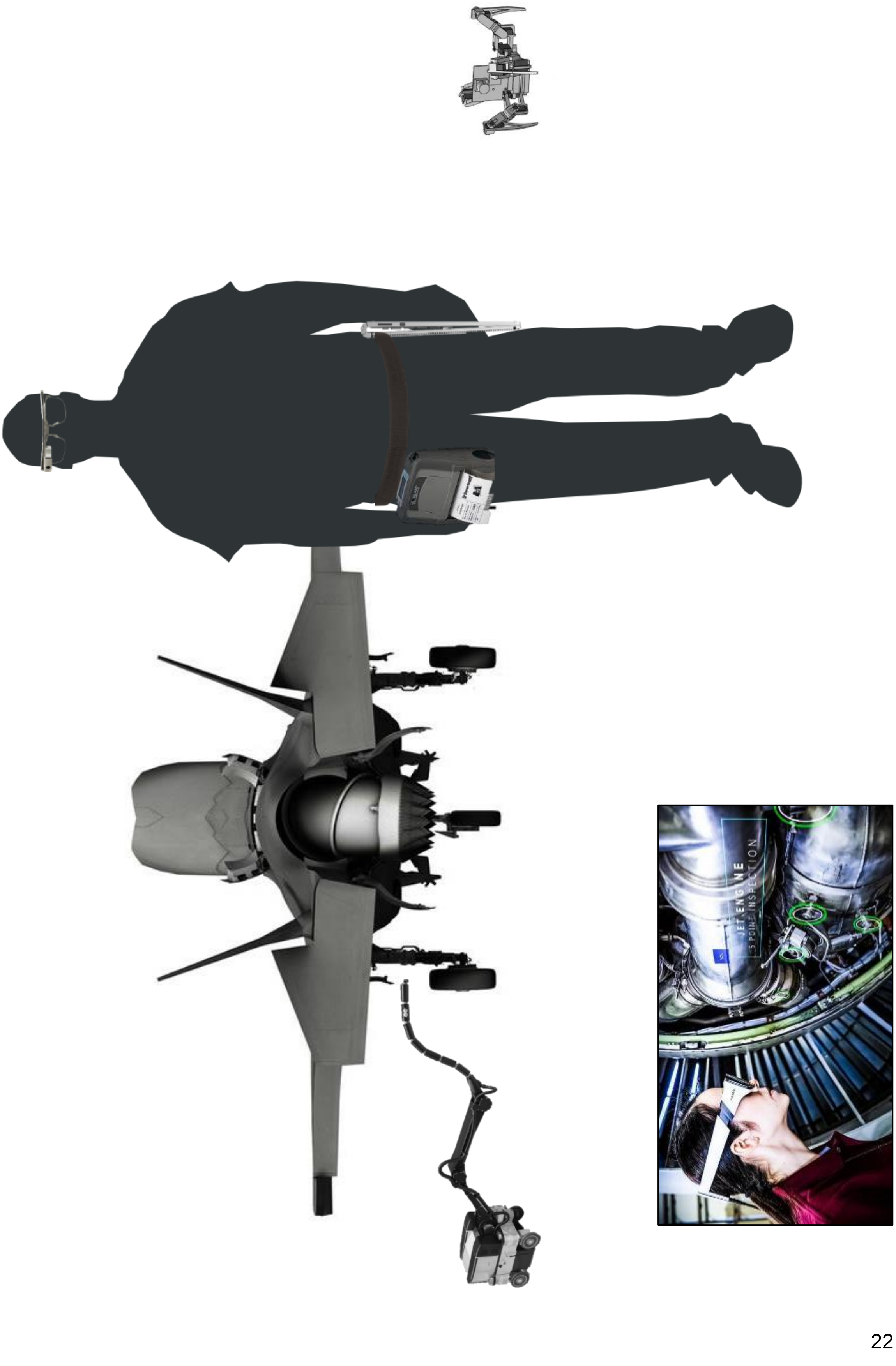


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Figure 3-14 3D printers needed for further drone prototyping.

3.4 New Drone Laboratory

To accommodate the rapid prototyping of new drone prototypes a new lab facility has been set up. A plan for what new capabilities should be brought into the lab was presented along with recommendations for new equipment. The rapid prototyping currently undertaken is based on design in CAD software Catia V5, 3D printed parts, and electronics prototyping based on the Arduino microcontrollers. New additions to the lab capabilities is to support the rapid development of new prototype concepts and mature projects alike.

Electronics Manufacturing
Essential to prototyping is access common tools for electronics manufacturing and assembly. The current lab has simple tools, and upgrades that are critically needed include a Station for Conventional and Surface Mount soldering (SMS) applications, see Figure 3-15. However, a health and safety assessment is needed before making this addition the laboratory facilities. Crimping tools for attaching connectors to wires are needed as well.

Printed Circuit Boards
As projects mature into more progressed designs, prototyping wires become a hinder to furthering the design and keeping a good overview of circuitry. Currently, bread boards and prototyping wires are used. Protoboards would be needed for more complicated wiring of robotic prototypes. Conversely, bringing in a printed circuit board (PCB) capability is not recommended. This process is involved and requires access to hazardous chemicals and access to a dark room. A newer method of PCB production, using a laser printer, photo paper, silver paste and a heat gun may be a viable option. Alternatively, PCBs may be bought from external suppliers.

3D Print Capability
Currently the 3D print capability is based on a single in-house 3D printer and usage of shared Lockheed Martin assets. Since this capacity is becoming the bottleneck in development efforts, it is recommended adding additional 3D printers to the inventory. Especially large format 3D printing is needed, see Figure 3-14.

Figure 3-15: Soldering holder tool and soldering station.

3.5 Training Courses

To work for Lockheed Martin as a quality engineer with the Quality Technologies team a series of trainings are required. Each of the trainings contributed to giving the student interns a better understanding of the approaches taken within aircraft manufacturing and quality inspections at Lockheed Martin Aeronautics.

FOD certification

Foreign object debris/damage (FOD) is a major concern for all aerospace manufacturers. Build areas are continuously inspected for objects foreign to the build at all stages of assembly. Ultimately a piece of FOD left in an aircraft may compromise flight critical systems during operations causing material damage or threaten the life of the crew. FOD in fuel tanks may clog fuel lines causing engine malfunction. FOD left in flight control areas may cause loss of control over the aircraft during flight. FOD lost in areas were electronics are present may cause short circuits compromising electronic systems. All extremely critical emergencies to experience during operation of the aircraft.

The FOD certification covered best practices for reducing FOD during manufacturing, inspection for FOD in finished assemblies, and documentation of findings. The course was required before any direct contact with the aircraft or aircraft subsystems was allowed.

PPV training

Product process verification (PPV) is a process in quality engineering to verify if manufacturing processes are efficient and effective. Participants were trained to carry out a process that included reviewing operations cards, detailed instructions used by mechanics to build the aircraft, shadow the mechanic carrying out the task, and inspect the final result. PPV's at Lockheed Martin Aeronautics follows operations cards that step-by-step detail build operations. Op-cards that often leave quality issues will be reviewed to improve or re-arrange the production steps for increased speed or quality. The skills learned during this training is directly related to classic quality engineering tasks and is directly applicable to all other manufacturing environments.

PDCA problem solving training

Plan Do Check Adjust training is a methodology out of the Lean universe. At Lockheed Martin Aeronautics this is used to document and plan projects. The training mainly focuses on the cycle of planning your work, doing the work, checking for faults and adjusting accordingly. A widely used tool is the PCDA A4 that is used to document a project. The training concluded with a certification in PCDA problem solving.

CATIA V5

Most of the aerospace industry uses CATIA V5 or Siemens NX as CAD software. These are powered to handle thousands of parts in a single assembly, and have dedicated modules for aerospace design and manufacturing. The CATIA V5 basic training gave skills in using this CAD software to design simple parts and assemblies. This training was extremely useful as this was the software used by the Quality Technologies team to design the robotic prototypes.

Innovation Garage training

The innovation garage is a facility at Lockheed Martin Aeronautics where additive manufacturing techniques and rapid prototyping is encouraged. All employees may after taking this training do projects with the equipment provided in this space. This may be for research or development, but also personal projects are encouraged. In this facility, filament deposition (FDM) printers and a small electronics lab focused on the Raspberry Pi miniaturized single board computer are available. The training focused on how to operate a 3D printer, choosing the optimal settings for different parts, and how to do simple maintenance jobs. It also outlines the Lockheed Martin Aeronautics general rules of conduct and health and safety considerations.

4 Personal Experiences

The professional gain and insights into an American work place that is so different than what it is in Europe is one dimension of the internship program. A wholly different one is the personal experiences gained from living abroad for half a year. The culture, the people, the scenery and the form of living are massive changes. It is in my opinion completely invaluable for one's ability to set perspective on one's own life. For a future employer it is also important to have employees with an outlook into the world beyond the borders of one's own country. This is especially true in a time where most all companies operate in the global market.

4.1 Working at Lockheed Martin Aeronautics

The working culture in the US is different from Denmark in many ways. Most Danes work 37 hour work weeks. Americans work 40 hours a week. Danish employees usually have 6 weeks of paid vacation. Americans in general only have 2 weeks. At Lockheed Martin a so called 9/80 schedule is followed by many employees. In this schedule the employees work 80 hours over 9 work days in a 2 week cycle. This means that every other Friday is a so called off Friday, and conversely that work days are generally longer than in most workplaces.

The company culture is also different. A large part of this is due to the sheer size of the workforce. The factory employs around 12.000 people, and the Lockheed Martin Corporation employs more than 100.000 people. This means that it is a society with its own values and norms, that at first a difficult to decipher. Lockheed Martin Aeronautics is also infamous for its affinity towards the use of acronyms. Every part, every process and every team has its own acronym. A document called Acromania is used to keep track of the thousands of factory specific acronyms on a daily basis. So learning to speak the language is important for any new hire or foreign engineering intern. The systematic pay and compensation schemes may also be unfamiliar to people unaccustomed to large corporations. There are detailed requirements for pay and compensation for each class and type of employee within Lockheed Martin, something rarer in Europe, where salary mostly is individually negotiated based on qualifications and job responsibilities.

Rules, procedures and rigid formal processes is also part of any large corporation. At Lockheed Martin all of these can be found in the online lookup service called the Aero Code. A document that details all procedures for almost all incidents of the daily work.

In recent years, efforts to improve the corporate culture has been carried out. This effort has been named Culture of Accountability. In this, problem solving and inter-team collaborations has been points of extra effort. "Seeing, owning and doing" are the key mantras under the new corporate culture of accountability.

4.2 Aerospace and Defense Industry

Denmark is a small country with a very small aerospace and defense industry. For engineering interns to get to work as an integrated part of the world's largest military complex is an eye opening experience. The industry operates in a political environment were democratically elected politicians legislates under which conditions the industry operates, at the same time as they act as the end customer to many of the products. This means that corporations in this industry must expertly navigate not only technology and business but to a high degree also politics.

This internship, has provided incredible insights into an industry that is otherwise closed off for the normal population. Behind a wall of rules regulating proprietary information (PI) and classified military projects, there is a dedicated work force that works to support their own and allied countries every day. Completely dedicated to the warfighter, it has some of the brightest minds working in Science and Technology applying their knowledge to solving the defense engineering challenges of tomorrow every day.

Figure 4-1: Part of the F-35 Lightning II assembly line at Lockheed Martin Aeronautics in Fort Worth, Texas. Copyright: Lockheed Martin Photo

LOCKHEED MARTIN

Figure 4-2: An F-35 Lightning II after final assembly ready for application of coatings, the so called final finishes. Copyright: Lockheed Martin Photo

4.3 Representing Denmark

For a country to invite foreign nationals into their national military industry, a large amount of trust has to exist. The United States of America and Denmark has always had a strong political and military relationship, and this is of course what this internship program is built on. That means that Danish interns are also expected to act as representatives of their home country. This is a responsibility that will always be lived up to, and one that the interns are constantly mindful of. That Lockheed Martin finds it valuable to have Danish engineering interns as part of their innovative engineering team, is furthermore a testament to the quality of Danish universities and engineering students. There would be no internship, if the Danish interns could not bring value to the teams to which they are assigned.

Feature Article in Danish Newspaper

To attest to the interest that follows the F-35 Joint Strike Fighter Program in Denmark, after receiving a public honorary scholarship, a regional newspaper covering the western region of Denmark contacted me to do an interview covering the internship. As there are many interested parties in the internship, the interview to be conducted had to be approved from several entities. Since the official Danish sponsor was Terma A/S, they were appropriately contacted and consulted on the situation. Also the Program Office for Denmark within Lockheed Martin Aeronautics was asked to approve the interview.

Since I could not speak officially on behalf of neither Lockheed Martin Aeronautics, Terma nor the Danish defense, the format was chosen to be a feature article based on the internship from the perspective of a Danish engineering student interning at Lockheed Martin in the United States of America. The result was a full page feature, providing the internship program with good public relations exposure.

Danish Minister of Industry, Business and Financial Affairs

As part of the Danish involvement in the F-35 Joint Strike Fighter program, the Danish minister for Industry, Business and Financial Affairs, Brian Mikkelsen, visited the Lockheed Martin Aeronautics plant on 7 March 2018. The minister came to sign an internship program for additionally three machinist apprentices to be interning at the plant for 2 months in cooperation with Danish Industry and Dansk Metal two of the largest Danish industry associations. At the meeting the Danish minister also held a half hour meeting with the 8 current interns. The topics discussed were Danish education, skills and relations with United States industry. This meeting also indicated the political involvement and interest behind this internship program. Not only does it strengthen political relations between Denmark and the United States, also Danish industry benefits from a closer understanding and better relations with US defense industry. On a personal level it was a great honor to meet one of the foremost politicians in the Danish political leadership.

Danish Fighter Pilot Students

Texas is home to a much of the American aviation industry owing to an early pioneering spirit within aviation. It is also the home of the Euro-NATO Joint Jet Pilot Training program at Sheppard Airforce Base in Wichita Falls. The air force base is located only two hours of driving north of Fort Worth. Since one of the interns had a personal friend undergoing jet pilot training, the entire team was invited to visit the air force base. The Danish interns were shown around the facility, had the opportunity to test their pilot skills in a T-38 Talon jet trainer simulator, and was introduced to the flight gear used by fighter pilots. The type of jet trainer used was the Northrop T-38 Talon. This aircraft has been in service since the 1960 and has an incredible heritage.

By chance, the Friday of the visit, was also the day that a class of fighter pilots graduated their training. We were invited to the celebrations that included the ceremony were the newly trained fighter received their deployments. The process called "being dropped" involved being given the future aircraft type they would be flying and the air force base they would fly out of. Everything from big C-130 Hercules cargo planes to the 5th generation superiority fighter F-22 Raptor was issued, as well as of course the F-35 Lightning II. Deployments were based on pilot skills and wishes.

Seeing the Euro-NATO Joint Jet Pilot Training and meeting the new fighter pilots was a very big experience. These men and women are effectively the end customer to the work that we do. So getting to know some of them personally was very rewarding.

Figure 4-3: Lockheed Martin Aeronautics was visited by the Danish Minister of Industry, Business and Financial Affairs. The visit included a private 30 minute meeting with the Danish engineering interns.
Copyright: Lockheed Martin Photo

Figure 4-4: The Danish interns at Sheppard Air Force base visiting the Danish fighter pilot students at the NATO Joint Jet Pilot Training Program. The training is carried out in the T-38 Talon jet trainer of which one is seen in the background.

4.4 Life in Texas

Everything is bigger in Texas. That is common knowledge, and going here has only confirmed the stereotype. Texas is the biggest state in the United States, Texans drive big pickup trucks, and they live in large homes. When Airforce Plant 4 that now houses Lockheed Martin Aeronautics Co. was built, it was designed to feature a 1 mile long factory floor. This was similar to other planned factories around the United States. However, since everything had to be bigger in Texas, the local community raised funds locally to build the factory 20 feet longer than any other plant, or so the story goes, at least.

Marquis at Stonegate

The interns have for many years lived in an apartment complex near South Hulen Street, called Marquis at Stonegate, see Figure 4-5. Conveniently located only a 10 minute drive from Lockheed Martin Aeronautics, it makes commuting easy. The three apartments are also located in the very same building, one on each floor. This has contributed to the very good coherency of the group and a feeling of camaraderie. The pool area and outdoor grill, being a welcome addition to what you usually find in Denmark, has been frequently used. Texan weather being much better and warmer than Danish weather, has also invited for the use of both of these facilities. Generally, living in the large, luxurious apartments at Stonegate has been a very good experience.

Cars and Coffee

Americans love their cars, and they have a great car culture. Cars tend to be larger, have larger engines and be more powerful. Engines with 6 cylinders ordinary, and V8's are commonplace. Since Denmark has a 25% sales tax, a 150% state registration fee and gasoline is 3 times as expensive as in Texas, these type of characteristics appear very exotic. Point in case: among the most sold cars in Denmark in 2017 were the micro-compact car Peugeot 208, while in the United States the large, powerful Ford F-150 pick-up truck year after year consistently sells more than any other car.

Every first Saturday of the month, the petrol heads of the Dallas-Fort Worth metroplex meet from 6.30 pm to 11.00 in the carpark of the Plano BMW dealership to show off their beautifully maintained and tricked out exotics, classics, hyper and muscle cars, pickup trucks, hot rods and motorcycles. From all different motoring fields all at once, they all enjoy a shared interest in cars. The BMW dealership clears out the parking lot free of charge, to fit the more than 1000 privately owned exhibition worthy cars and more than 2000 visitors. The spirit of the event is amazing. The soundscape of high performance engines and the excited cheering of the crowd is an experience not soon forgotten. The event concept is not exclusive to Dallas-Fort Worth nor to Texas, but is nationwide and known under the name: Cars and Coffee.

NASCAR

Another popular motoring event is the NASCAR races, see Figure 4-6. The Texas Motor speedway oval circuit is located half a half hour drive north of Dallas-Fort worth. With its sheer size, it is an attraction in itself. The speedway can seat up to 180.000 spectators, making it far larger than anything in Denmark. However, the cars themselves are real attraction. With high octane V8 engines that output more than 850 bhp, the stock cars can reach speeds of more than 200 mph (around 300 km/h). The roar of 43 of these stock cars when they pass all at once after safety car laps is deafening. You can literally feel earth rumble as the lineup passes. Not bringing ear protection for a NASCAR race is a rookie mistake, that some of the interns did. However, most importantly, the interns did remember to bring beer for so called tailgating, the party in the parking lot sitting out of the tailgate of the cars,

Fast Food

The food culture in Texas is based around the Mexican food culture of jalapenos, beans and flatbread tortillas, the Texan Tex-Mex is thus a spicy food culture. It is delicious. Owing to the Fort Worth heritage of cattle breeding, and the name Cow town, steaks are better in Fort Worth, Texas than anywhere in the world. All Texans will tell you this, and I am willing to agree. Classic BBQ such as seen in Figure 4-7, is also popular. However, as is the case of most of the United States, the food eaten is rarely home cooked. Texas, as most Americans, eat at restaurants or at fast food vendors for most meals. Wendy's, Burger King, What-A-Burger and the like are everywhere, but especially Chick-Fil-A became a favorite for the Danish interns. The best food however, comes out of "hole in the wall" places. The small, not always sanitary looking places often offers the best taste and often at the same time at the best price.

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Figure 4-5: Apartment complex Marquis at Stonegate, Fort Worth, Texas [6]

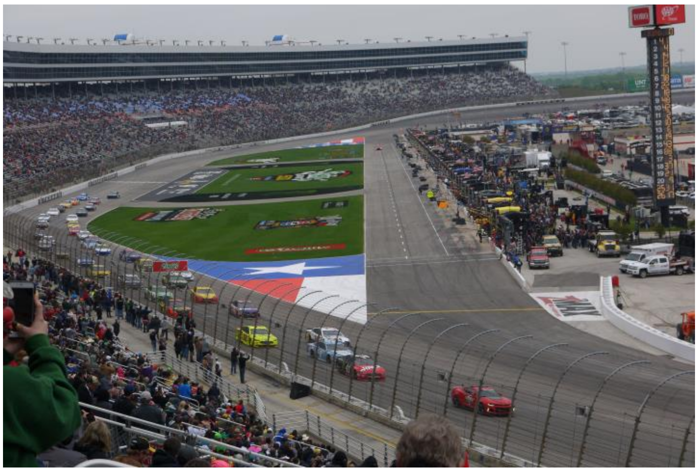

Figure 4-6: Texas Motor Speedway at the O'Reilly Auto Parts 500 NASCAR stock car race.

Figure 4-7: Hill B-B-Q outside of Austin, Texas. Home of the best BBQ in Texas, and on account of the owner a favourite of President George W. Bush Sr.

4.5 Travelling

A big part of the internship has been travelling, and using the long weekends allowed by the 9/80 schedule. This has taken the group all across Texas, and some people have gone as far as New York, Washington D.C. and Arizona. In travelling you get an understanding of why many Americans have never been out of the United States. Even in Texas, all kinds of climates and terrains can be found. Everything from forests, deserts, beaches, prairies and farmland are within the state borders. Florida and California are suited for beach vacations with great weather, while Wyoming and Colorado offers excellent skiing in the Rocky Mountains.

San Antonio

The first trip went to San Antonio. Close to the Mexican border, the city is most known for the battle of the Alamo that took place in 1836. This battle was instrumental to the formation for the Texas Revolution. The city features a Riverwalk with restaurants and bars, where people can cool off shaded from the Texas sun.

Arizona Airshows /

By luck, this year he marine core airshow at Marine Core Air Station Yuma and the air force airshow at Luke Air Force Base were scheduled for the same weekend, Saturday and Sunday respectively. This meant that a long weekend trip was possible to go see all the aircraft on display from the two branches of the US military.

At the Yuma airshow, the main attractions were air displays of the marine core only Bell-Boeing V-22 Osprey, the Harrier Jump jet and of course the F-35B Lightning II showing the its STOVL capabilities. An air force Lockheed Martin F-22 Raptor air superiority fighter also made an unexpected but welcome appearance, see Figure 4-8.

The airshow at Luke AFB focused on air force aircraft. On air display where among other the iconic A-10 Warthog and the C-130J Hercules. Ground displays included the F-16 Fighting Falcon and Lockheed Martin C-5 Galaxy cargo plane, meaning that all of the Lockheed Martin lineup excluding the U-2 Dragon lady spy plane, the T-50 trainer jet and the P-3 Orion had been seen.

Pima Space and Air museum

This air museum is the world's largest non-government funded aerospace museums. With 300 aircraft placed on 80 acres of land, most all of the American and European iconic aircraft are parked either in their hangars or outside under the Arizona sun, see Figure 4-9. Among the most iconic aircraft on display is the SR-71 Blackbird, the world’s fastest production aircraft, capable of outrunning surface-to-air missiles and also a Lockheed innovation. Yet another is the Lockheed Constellation a beautiful piston engine airliner from 1943 featuring a design much ahead of its time.

Aircraft Boneyard Tour

A true singular experience however, was the Pima guided tour to the neighbouring Davis-Monthan Air Force Base, see Figure 4-10. Home to the Air Force Materiel Command's 309th Aerospace Maintenance and Regeneration Group (AMARG), better known as The Aircraft Boneyard. At this facility all decommissioned or store aircraft from all branches of the US military is stored in the Arizona desert. The dry heat of the desert naturally prevents corrosion on the aircraft. Furthermore, the hard soil makes it possible to move aircraft around without having to pave the storage areas. Here, thousands of different aircraft models ranging from F-16 Falcon fighter aircraft, over helicopters and B-52 bombers to heavy airlifter C-5 Galaxy aircraft will be held for later recommission or disassembly for years or even decades. The sheer size of the operation was breath taking and unlike anything else on earth.

Hops and Props

With its rich aviation heritage being home to companies such as General Dynamics, Consolidated Vultee, Aircraft Corp./Convair, Bell Helicopters and Lockheed Martin Aeronautics, Fort Worth of course also has an aviation Museum of its own. In addition, Fort Worth also has many good local breweries that all produce excellent beer. This all comes together in a beautiful union at the Hops and Props event that takes place every spring. This offers a great opportunity to go and taste the all the different brews, at the same time that you can enjoy iconic aircraft such as the locally built F-111 Aardvark and Bell 206 JetRanger. The local helicopter school was also present selling roundtrips over downtown Fort Worth. It did not require many minutes of thought, before I had my first flight of over Fort Worth in a Robinson R-44 Raven helicopter on a beautiful, clear spring day.

Figure 4-8: The F-22 Raptor air force demonstration team at the Yuma Marine Core Air Station air show.

Figure 4-9: Inspecting the air intake of a former Navy Blue Angels F/A-18 Hornet for FOD at the Pima Air and Space Museum, Tucson, Arizona. Most of the aircraft on display were parked outside under the burning Arizona desert sun. .

Figure 4-10: The characteristic white coating serving to protect the aircraft from the heat, sun and dust of the Arizona desert, on a decommissioned F-16 Fighting Falcon at the AMARG at Davis Monthan Air Force base. Most of the decommissioned F-16 aircraft will be converted into remote controlled target drones for F-35 live targets.

5 Conclusion

The Suite of Drones concept, including the Suite of Sensors has been laid out. A detailed explanation of how project fits into the overall vision for the future of the inspection process and the Inspector of The Future project as applied to the manufacturing operations carried out at Lockheed Martin Aeronautics has been given. The mechanical platform, drivetrain, controls and active stabilization system for the Roller Drone Version 3 prototype has been finished and demonstrated. The project is at a point where full operational functionality will be added with autonomous navigation, a FOD identification capability, and FOD retrieval system. There are suggestions and designs laid out for these, however, not given in this report. With these systems the first proof-of-concept of the autonomous FOD identification and retrieval system can be made.

The recommendations for tools and capabilities additions for the new drone laboratory has been given. These include adding further electronics manufacturing and 3D printing capabilities for the Quality Technologies Drone Laboratory for faster rapid prototyping of new drone platforms to further the Suite of Drones project.

Lastly, an account of the personal experiences made is given. Specifically how it has been working at Lockheed Martin Aeronautics, working in the aerospace and defense industry, focused storytelling about living in Texas and the United States and how this is different from life in Denmark and Europe has been told. Particular the task of representing Denmark to Lockheed Martin both directly and indirectly has been a learning experience, epitomized by the visit of the Danish Minister of Finance, Business and Industry at the manufacturing plant of the F-35 Lightning II. This shows the importance and visibility this internship has both at Lockheed Martin in the United States and in Denmark in relation to the F-35 Joint Strike Fighter Program.

It has been an incredible experience working for five months at Lockheed Martin Aeronautics, Fort Worth, Texas in the United States. The insights gained about the aerospace industry, the familiarity with large international corporations, and the F-35 Joint Strike fighter program are invaluable to an engineering student and extremely relevant to Danish industry. It has truly been a once in a lifetime experience!

References

[1] Lockheed Martin Corporation, "Locations," [Online]. Available: http://www.lockheedmartin.com/us/aeronautics/locations.html. [Accessed 29 September 2017].

[2] Lockheed Martin Corporation, "Top 35 F-35 Photos," 24 June 2014. [Online]. Available: http://www.lockheedmartin.com/us/news/features/2014/top-35-f35-photos.html. [Accessed 15 October 2017].

[3] "phys.org," [Online]. Available: https://phys.org/news/2014-01-soft-robotics-technology-spawns-products.html. [Accessed June 2018].

[4] "Kurzweilai.net," [Online]. Available: http://www.kurzweilai.net/a-gripper-using-soft-robotics. [Accessed June 2018].

[5] N. Grumman, "northrupgrumman.com," June 2018. [Online]. Available: https://news.northropgrumman.com/news/releases/northrop-grumman-completes-center-fuselage-for-first-f-35-aircraft-to-be-assembled-in-japan.

[6] CWS Apartments, "Photo Gallery for Marquis at Stonegate," [Online]. Available: https://www.cwsapartments.com/apartments/tx/fort-worth/marquis-stonegate/photos. [Accessed 16 October 2017].