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AIRBUS HELICOPTER BLADE INSTALLATION CELL REDESIGN

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AIRBUS HELICOPTER BLADE

INSTALLATION CELL

REDESIGN

by

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ABSTRACT

AIRBUS HELICOPTER BLADE INSTALLATION CELL REDESIGN

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Airbus Helicopter is a global company with European roots located in Grand Prairie, TX. They customize helicopters for private customers, such as tourism agencies, law enforcement, and hospitals, as well as assemble the helicopters, install the blades and perform test flights. With the large number of customers they serve, there is a need to decrease the cycle time for the blade installation process and make it safer and more efficient. One way to target this problem is by relocating blade storage or designing an external blade storage. Another way is to redesign Airbus's blade installation cell into a portable station that will accommodate five common helicopters and uphold the safety and comfort of the employees in charge of installation. The DMAIC approach as well as other

Six Sigma and decision analysis tools were used to help present a feasible solution by April 2016 that Airbus can implement and, if successful, expand to other locations.

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CHAPTER 1

INTRODUCTION

1.1 DMAIC Approach

DMAIC is a straightforward approach to address concerns within a business. It is mostly utilized to help understand the current process and find ways not only to improve, but also to sustain it. DMAIC stands for: Define, Measure, Analyze, Improve and Control. These five steps are followed sequentially to help businesses obtain continuous improvement.

The Define phase provides a framework to understand where the area for improvement lies. It also is crucial for understanding customer requirements and the stakeholders that play a role in the project, as well as project goals. This information is typically compiled into a project charter.

The Measure phase is understanding how the process currently performs. Any data collected such as time, dimensions, number of defects or cost of the current process are included.

The Analyze phase identifies several causes of the area of improvement and its main contributors. There are various tools that are used such as a fish bone diagram, which helps portray potential causes to a problem, or the five why's to question why the problems are occurring.

The Improve phase includes coming up with different alternatives, analyzing them and selecting the optimal one. This also includes providing evidence to how sustainable the improvement can be for the company and keeping track of the improvements.

Lastly, the Control phase is the step that ensures that standard operating procedures are set in place so that anyone who comes in contact with the new improvement knows how to operate the system and how to maintain it.

Figure 1.1: DMAIC Methodology

1.2 Problem Identification

Airbus Helicopters receives helicopter blades in two ways: internationally or domestically. Blades are received in storage boxes from international locations. In the domestic case, the helicopters are flown into the facility and de-bladed for maintenance. Upon receipt, blades are transported to and from different buildings within the Airbus facility to perform several operations that will create an aircraft that meets customers' specifications and safety regulations. This project focuses primarily on decreasing the cycle time for the blade installation process.

There are two ways to approach the problem of reducing cycle time for the blade installation activity. The primary way is to make blade storage more convenient. This report dives deeper in the secondary approach, which is to redesign Airbus's blade installation cell into a portable station that will accommodate five common helicopters and uphold the safety and comfort of the employees in charge of the installation.

This project encompasses people and time as crucial components to accomplishing each installation safely, correctly and efficiently. From the beginning, it is important to understand and map the complete blade installation process from the moment it exits the blade shop to the moment the installation is complete, as well as to take time studies for the procedure. Speaking to employees is crucial, since at the end of the day they are the ones conducting each tasks. Therefore, their perspectives and feedback must be taken into account. Upon brainstorming on preliminary ideas and achieving several alternatives for the installation cells, a decision matrix will be constructed to deeply analyze each alternative and select the optimal solution that will help Airbus improve their current state. The final product should present a feasible solution that Airbus can implement and, if successful, perhaps expand to their other locations.

1.2.1 Scope

This project at Airbus Helicopters will involve a redistribution/relocation of resources. The scope involves the following resources: People, Materials, Information, Equipment and Energy.

- People are crucial for the planning, designing and implementing our recommendations. Here is a list of a few of them that directly or indirectly contributed to this project:
    - Senior Director
    - Quality Assurance Engineer

  - Project Supervisor
  - Industrial Engineers
  - Technicians

- Materials for this particular project mainly focus on the helicopter blades and any other resources needed to store, transport and complete installation, such as:

  - Helicopter Blades
  - Pins
  - Bolts
  - Miscellaneous
  - Blade Transportation Carts
  - Blade Storage Racks

- Information needed to achieve blade installation includes the following three items:

  - Schedule: Blade Installation schedule for particular aircraft models
  - Bill of Materials: List of materials needed
  - Standard Operating Procedures: Procedures that all technicians follow consistently.

- Equipment refers to the following list that assists with the installations, blade holders and retrieval of blades, which include:

  - Tools
    - Hand
    - Pneumatic
  - Forklift
  - Crates

- Energy goes hand in hand with people but also any machines that provide some sort of power. These include:

  - Manpower
  - Electricity
  - Pneumatic

1.2.2 Stakeholders

There are multiple stakeholders involved with the Airbus Blade Installation redesign project. The key stakeholders involved in the project are: Technicians, Customers, Quality Assurance Engineers, Investors, and the Senior Director.

- Technicians: The technicians are manually installing the blades onto the rotor while climbing up stairs. This presents an issue of safety and comfort to the employees. The redesigning of the cell will provide safe and efficient methods of installing the blades and will improve the worker's safety.
- Customers: The efficient and safe installation of the blades ensures timely delivery of helicopters to the customers. Customers provide the demand for the product.
- Quality Assurance Engineer: An engineer is required to inspect the blades before and after its installation.
- Investors: Investors are key stakeholders in providing necessary funding to implement the process.
- Senior Director: The project has to be approved by the senior director to be implemented.

1.2.3 Project Charter

AIRBUS HELICOPTERS

DRIVER PROJECT CHARTER

Project Team
David Rock
Miquel Rios
Jasmine Lucero
Sujan Devkota
Tyka Do

Sponsor	Gregg Smith
Site	Grand Prairie
BU	Airbus Helicopters, Inc.
AGB/ABB	Capstone

Project Information

Project Title	Design a blade installation process, work cell and / or fixtures to improve Safety and protect assets
Problem Statement	Blades are currently installed by a team of two technicians using two separate ladders or airstairs. The technicians must simultaneously climb the ladders and then balance themselves while installing the pins in the heavy and awkward blade. Near misses (falls / drops) are common.
Project Scope	Design a blade installation process, fixtures, tools or work stands to improve safety. Cover the common AH models H120, H125, H130, H135, H145.
Project Objective (SMART)	To be set by team
Performance Metrics	Baseline: Cycle time for quotes, planning, and design. Critical Metric: Lost Cycle Time, as defined by the days between PA signing and aircraft start-work. — Target Improvement: Reduce "dead time" by 50%.
Link to Business Unit Strategic Vision (Dashboard, Airbus Group Priorities, etc.)	Supprts AHI dashboard metric on Occupational Safety. Reduces cycle time and cost for blade install. Reduces damage to blades.
Project Deliverables	Designs, layouts and processes as needed. AutoCAD is the preferred format for design.
Project Resource / Budget	TBD

Figure 1.2: Project Charter

As one can see from this project charter, the main goal the customer expects to be completed is to design a blade installation process that will improve safety. The main concentration is on improving the process as a whole by reducing cycle time from the moment the blades are received to the moment the blades are finished being installed.

CHAPTER 2

MEASURE

2.1 Current Process

In order to understand the process of blade installation on the helicopters, a process map of Airbus' current state, from the time the helicopter blades arrive at the hangar to the time the helicopter is ready for flight testing, was mapped out. This was made possible thanks to the information provided by the respective personnel and our observations of the process. The current process involves obtaining blades and the helicopters to Airbus domestically or internationally. The main difference between the two is that international delivery ships the blades and helicopter by cargo in separate boxes and domestic helicopters fly into the hangar.

If the helicopter arrives domestically, it comes into the flight hangar, and an empty box is retrieved from storage and brought to the hangar with the use of a forklift. The helicopter is then de-bladed and the blades are boxed and taken to storage. Fifty percent of these domestic blades need to be painted and customized before they are installed back in the helicopter. The blades that need to be painted are taken from the storage location to the blade shop according to a set schedule. The blades are taken out from the boxes and stored on the blade staging area to wait for their turn, and the empty box is taken back to storage. After the blades are painted and customized, an empty box is retrieved from storage and the blades are boxed again to be taken back to the storage location, unless they are scheduled to be installed. Whenever blades are scheduled for installation, they are taken to the hangar. The hangar is the area where maintenance and blade installation is done. It also protects the aircraft from direct sunlight and extreme weathers and serves as a holding area for completed helicopters awaiting customers' pick up. The blades are inspected in the hangar and installed on the helicopters. The blades along with the rotor are inspected after the installations to ensure everything is on spec. The helicopter is then ready for flight testing.

The other method of receiving blades and helicopters is by cargo internationally. The boxed blades are taken to the storage area. The blades may or may not be customized. If they need to be customized and painted, they are taken to the blade shop and then taken out of the boxes to accomplish the task. The empty boxes are taken back to the storage location, and the blades are left in the blade staging area. After the blades are customized, depending on the blade installation work schedule, they are taken to either storage or the flight hangar for installation. Once the blades make it to the flight hangar, they are inspected and installed onto the helicopter. The blades along with the rotor are inspected after the installation and the helicopter is ready for flight testing. This process is outlined in the appendix.

2.2 Time Study

A time study was completed for an EC-145 helicopter blade installation as shown in Table 2.1.

Table 2.1: Time Study for EC-145 Blade Installation

Time (AM)	Time Lapse (min)	Comments
10:39		Cannot locate blades in the storage location because of missing label on the blade box and boxes stacked on top of each other
10:58	19	Blade #1 Observations: 1. Set up two ladders at certain distances away from the helicopter 2. Two workers obtained blades from the box with the blades for this specific aircraft 3. Both workers climbed ladders at a steady pace. Once the employee closest to the aircraft was high enough, he rotated the rotor to insert the blade in an exact location and pushed it in 4. The employee on the other end held the blade and wobbled it a bit, to assist with the installation 5. Immediately, the worker next to the helicopter added bolts and screws loosely
11:03	5	Blade #2 Observations: • Had to position himself on top of the helicopter on tiptoes to put bolts
11:06	3	Blade #3 Observations: • Worker on the other end wiggled the blade to allow pins to go through the holes more easily • Worker on the helicopter attached bolts loosely and rotated blade along to move on
11:10	4	Blade #4 Observations: • Worker next to aircraft struggled to push the blade into the hub • Started to turn along with the rotor, but caught his balance
11:13	3	Installation complete
Total time:	34 minutes	

On this occasion, the worker only illustrated the process from when blades were already at the station up until putting the bolts in loosely, but the complete process, from the moment technicians obtain a forklift to when they pick up the blades from the current storage location, bring to the hangar for installation, and finish the installation takes about 45 minutes. If one considers variation, one can add about one extra hour due to fluctuations in time for finding a forklift and accessing the blades in the storage location.

2.3 Storage Space

Having blades right when you need them and the way you need them is crucial for determining when blade installation begins. Some questions asked after completing the time study included, "Why did it take the personnel twenty minutes to locate blades in the first place?" "Where are the blades being stored?" and "How are they being transported back and forth?"

Each blade storage box contains a set of blades for a particular helicopter model. Some aircrafts require three blades while others require four. If the box is empty, it is labeled empty, as in the picture shown below.

Figure 2.1: Blade Storage Boxes with Labels

Figure 2.1 shows an unlabeled box in the bottom left corner. This demonstrates how a technician will have trouble knowing what aircraft the blades belong to and they will have to do additional movement to check what is inside the unlabeled box. This also helps answer the first question asked earlier as to why locating the blades took twenty minutes. The blade box they needed was stored behind another one, and the paper with the ship number was missing, similar to what is shown in Figure 2.1.

Figure 2.2: Blade Storage Area

Figure 2.2 is a snapshot of the current Blade Storage Area and how the blade boxes are stored on top of cantilever racks. In this storage space, there are four cantilever racks that reach five high. The floor space is 30’X38’3.’’

In summary, the current storage location is not only in a separate building, but it is also disorganized, which makes it difficult to retrieve the blades in an efficient manner.

Sometimes the blade boxes have missing labels, and sometimes there is clutter in the floor space and/or boxes are stacked on top of each other or next to each other, therefore increasing non-value added time.

2.3.1 Blade Box Measurements

There are three types of boxes -- yellow, white and wooden -- that correspond to the different sizes of blades. Therefore, measurements were taken for the different blade boxes. The dimensions in inches are as follows:

a. Wooden Box: 211.75''x 37'' x 25''
b. Yellow Box: 191.5'' x 19.75'' x 15''
c. White Box: 219.5'' x 21.5'' x 25.75''

These box dimensions were important to measure because early brainstorming sessions brought considerations of either bringing the blade storage into the flight hangar, for easier access of blades, or creating an off-site blade storage location, to save space. Knowing the blade box measurements would assist with determining an approximate size for the new storage space.

2.4 Distance between Buildings

The buildings that this project focuses on include: Blade Installation area, also known as the hangar; Blade/Paint shop (where the blades are painted, balanced, bonded, and repaired); and lastly the Storage Area, which is a small area of their maintenance hangar.

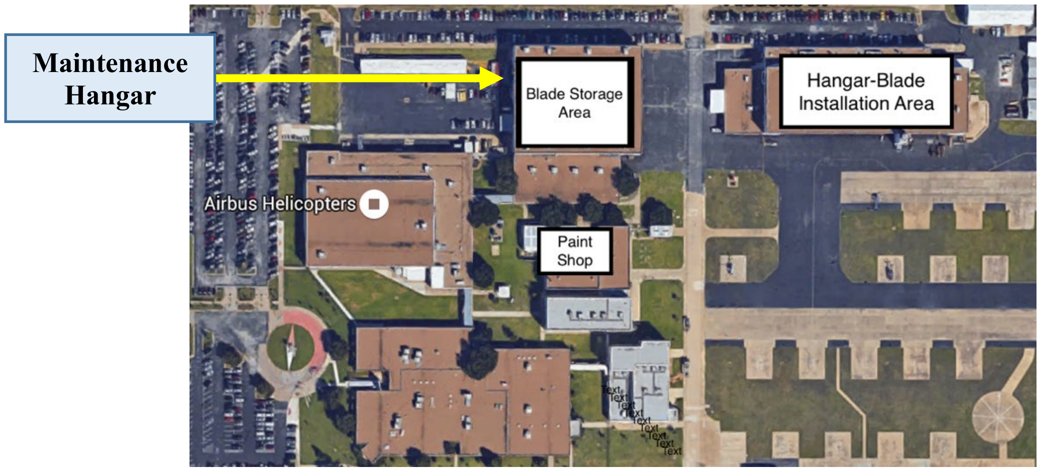


Figure 2.3: Aerial View of Airbus Helicopters

The walking distance between the Blade Storage Area to the Flight hangar is approximately 431 ft. and 10 inches. The walking distance from the hangar to the Paint Shop is approximately 545 ft. These measurements were important, in considering how much employees are travelling as they transport blades to and from buildings.

Since the hangar is one of the main buildings we are looking into, an AutoCAD file of the floor layout is provided in the Appendix to illustrate how it is currently laid out.

2.5 Airbus Helicopter Models

Each aircraft model that goes through the blading / de-blading process has unique dimensions. The Airbus Industrial Engineering department provided us schematics of each targeted model. This drawing reflects the EC-145 helicopter, which was the one we observed in more detail during the blade installation process.

Figure 2.4: EC-145

The complete list of these drawings for the remaining helicopters is found in the Appendix.

The variation between each model highlights an inherent difficulty in the process because the operations for four different helicopter models will need to be standardized in order to design an improved blade installation method.

CHAPTER 3

ANALYZE

In this section, more in-depth analysis was done to understand the causes of the problem. As mentioned earlier, the original problem statement included finding a more ergonomic way to accomplish blade installation, but because risk is a complex factor to measure and to attribute to cost, reducing installation time became a more practical problem statement to present. Reducing installation time translates to reducing cycle time, which will eventually also be equivalent to saving money. However, the ergonomic issue is not disregarded, and still remains as a secondary major concern. My contribution was mostly concentrated on the safety aspect of blade installation

3.1 Ishikawa Diagram-Root Cause Analysis

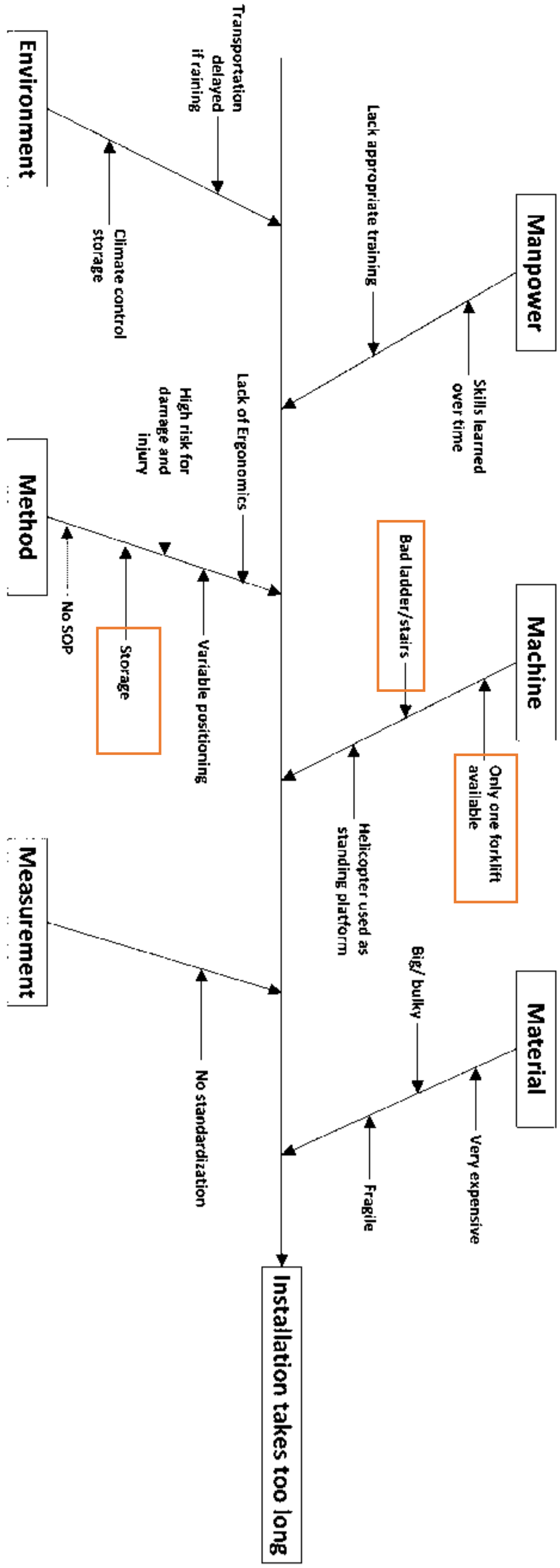


Figure 3.1: Fishbone Diagram

Based on the fishbone diagram, the three main areas that this project focuses on include Stairs, Storage and Transportation. Each issue and its alternatives are discussed in more detail

3.1.1. Bad Ladder/Stairs

The current process for blade installation includes utilizing stairs that are more than ten years old, unstable and unfit for the blade installation task, which increases the potential for an injury or a fall. Since safety is one of the focus areas, we came up with three alternatives that can be used instead of their current stairs, which include: maintenance stands (or new maintenance stairs), ladders or a hoist.

3.1.1.1 Maintenance Stands or Stairs

One alternative for maintenance stands was to purchase from a company called Allmetal Maintenance Stands. The first idea was to purchase a sturdier and wider stand, but unfortunately it would only fit one type of helicopter model and would have a large storage footprint. The second idea was to have Allmetal customize the platform to permit adjustable heights, but the cost would be almost doubled and storage footprint would still be an issue.

3.1.1.2 Ladders

Ladders were a second alternative to utilize for blade installation. Two companies were researched: LocknClimb and Heliladders. Their overall ladder structures were very similar, but with slightly different physical features such as the position of the tool trays, color, hand rail design, etc. Once we talked to one of the managers, a different perspective was brought into place, which included considering the comfort of the employees as they climb a ladder with an 80-90-pound blade on their shoulder. Ladders brought about several safety concerns: lack of platform support on either side, narrow climbing space, and height constraint.

3.1.1.3 Hoist

Another method to install blades included using a machine to facilitate lifting blades towards the helicopter rotor. One alternative is by using a smart rig crane which is highly mobile, useful for other applications, and has a small storage footprint. The main disadvantage to this product is the high initial cost. Another alternative is to utilize a mobile gantry crane, which is cheaper than the smart rig crane, but it only has a one directional movement, and cannot be 'broken down' for storage.

Overall each of these three different alternatives for the safety aspect, maintenance stands, ladders, and hoist, had its pros and cons, but to determine which alternative would help meet our goal of improving safety for the blade installation process, a risk analysis and a trade study was conducted in the Improve Section to help with our decision.

3.1.2 Storage

Storage space became a major concern after realizing that Airbus's current blade storage location was not placed at the blade installation's point of use nor being used effectively. We considered to bring the blade storage to the flight hangar area for easier blade retrieval. Based on conversations with engineers, floor storage was not a path Airbus wanted to take at all, especially because of their limited space in the flight hanger. Therefore, if we were to bring blade storage to the hangar, we would have to utilize overhead storage to clear space on the floor. Utilizing automated carousels or lifting racks would be ideal for overhead storage, but high costs for this equipment and construction in a busy location were an issue and caused us to consider another alternative.

The second alternative for storage was to create an external building for blade storage only. This would also mean considering obtaining more optimal blade storage racks and new transportation carts to take blades from building to building instead of using a forklift. Even though the blades would still be in a separate building from the flight hangar, this new location would be spacious enough to fit more blades and organized in a way that allows for easier blade retrieval. Since the new storage location would be designed in a more organized way, it would eliminate non-value added activities such as waiting for a forklift to transport blade boxes, get rid of obstructions that are misplaced in the blade storage area, and minimize potential error for retrieving the wrong blades.

3.1.2.1 Transportation

The option of having a separate storage facility has to take means of transportation into account because the blades would need to be transferred to the flight hangar for installation. As shown earlier in this report, once the blades exit the blade shop, they are transported by boxes that pertain to a particular aircraft. One alternative for transporting blades is to utilize existing transfer carts that Airbus currently has in a different building. These type of carts will transport three blades at a time.

Figure 3.2: Current Blade Transportation Carts

An upgrade to this alternative would be something that can hold more blades, similar to a blade rack from a company called Spika.

Figure 3.3: Spika Blade Transportation Carts

Another alternative would be to utilize something similar to Figure 3.3 to decrease the storage footprint, transport at least one to two sets of blades per trip, and remove the need to wait around for forklifts and blade boxes.

Figure 3.4: Collapsible Blade Transportation Carts

With the analysis of the two primary concerns, reducing cycle time and improving employee safety for blade installation, we were able to come up with a few alternatives, but deeper analysis and constant communication with Airbus is still underway.

CHAPTER 4

IMPROVE

The improve phase is the part where we suggest the optimal solution. In this section, there is a more in-depth analysis for the ergonomic alternatives through a risk analysis and a trade study that I assisted with the most. A risk assessment matrix is a project management tool that allows a quick view of the probable risks evaluated in terms of the likelihood or probability of the risk and the severity of the consequences. Trade studies help assess the requirements that stakeholders find crucial for decision making and also weigh the criteria to support the selection process. A trade study in general offers the best or most balanced solution.

4.1 Risk Analysis

The four ergonomic alternatives that this section focuses on includes keeping the current stairs, changing to new improved maintenance stands or stairs, changing to ladders or using a hoist. A risk analysis was conducted for personnel who conduct blade installation and for the aircraft blades involved in the process. Therefore a few definitions are considered for people and for the aircraft blades themselves, which are at risk. Four possible opportunities may occur such as a fall, slip, drop or bump. A more detailed table with definitions is shown in Table 4.1.

Table 4.1: Definitions for Probability/Impact Grid

Definitions for Probability/Impact Grid		
Possible Occurrences	Person	Aircraft
Fall	The moment the employee is no longer on the platform and reaches the ground	----
Slip	An incomplete fall. The moment the employee loses balance or gets a minor injury, but does not touch the ground	----
Drop	----	When the blade hits the floor
Bump	----	When the blade touches against anything on its way up to being installed

To assess these possible occurrences, a scale from 1 to 5 was created to represent the probability of a fall, a slip, a drop or a bump to occur. A score of 5 would indicate something very likely to happen, and a score of 1 would indicate a rare occurrence. Impact was also ranked from 1 to 5, with a score of 1 meaning an insignificant effect, a score of 3 meaning a moderate effect (such as an injury for employee or damage to the blade) and a score of 5 meaning a severe effect on an employee or blade. Quantifying the risk is simply probability times impact. For example, considering Table 4.2, if falling was very likely to happen it would be given a score of 5 and if the impact for falling was severe it would also be given a score 5. Risk in this case would equal 25, which indicates an 'extreme' score of risk and the current situation/process should be addressed and altered immediately.

Table 4.2: Probability/ Impact Grid

Probability/Impact Grid						
Probability	Impact	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Severe (5)
	Very Likely (5)	Moderate	High	High	Extreme	Extreme
	Likely (4)	Moderate	Moderate	High	High	Extreme
	Possible (3)	Low	Moderate	Moderate	High	Extreme
	Unlikely (2)	Low	Moderate	Moderate	Moderate	High
	Rare (1)	Low	Low	Moderate	Moderate	High

The two tables below (4.3 and 4.4) indicate a Personnel and Aircraft Blade Risk Analysis. The table labeled personnel implies that we are focusing on the employees doing blade installation. The other table focuses on the blades themselves only. Both tables have the same alternatives which are keeping the current stairs, using customized and improved stairs, ladders and or a hoist.

Table 4.3: Personnel Risk Analysis

Personnel	Risk Analysis							
		FALL			SLIP			TOTAL
	Alternatives	Probability	Impact	RISK=(P*I)	Probability	Impact	RISK=(P*I)	RISK per
	Current Stairs	3.5	5	17.5	5	3	15	32.5
	Improved Stairs	2		10	3		9	19
	Ladders	3		15	2		6	21
	Hoist/Crane	1		5	1		3	8

Table 4.4: Aircraft Blade Risk Analysis

Aircraft Blade	Risk Analysis							
		DROP			BUMP			TOTAL
	Alternatives	Probability	Impact	RISK=(P*I)	Probability	Impact	RISK=(P*I)	RISK per
	Current Stairs	3	5	15	4	3	12	27
	Improved Stairs	2		10	3		9	19
	Ladders	3		15	3		9	24
	Hoist/Crane	1		5	2.5		7.5	12.5

At the end of this risk analysis, each alternative's risk from each table was totaled together to obtain one value. The higher the sum value, the higher the risk and the less favorable the alternative becomes. The results for the alternatives from lowest to the highest risk came to be the hoist, customized stairs, ladders, and lastly the current stairs. This shows that a hoist has the least amount of risk for both dropping and bumping a blade as well as for employees falling or slipping. The highest risk falls under what Airbus is currently using. The trade study analysis was completed to further investigate each alternative.

4.2 Trade Study

To have support for the decision-making process, a trade study was conducted. Based on our conversations with the project champion and information from the project charter, we were able to come up with several different requirements that drive management's decision. This includes cost, the total risk factor and flexibility. Cost and risk are pretty easy to measure, but for flexibility we had to quantify it. Based on my observations, I defined flexibility as: "*Flexibility in terms of the product includes its ability to be Maneuverable, Foldable, and Adjustable in height and with a small storage footprint. Ideally it is important that the product has all or some of these qualities to improve storage space and make it easy to move around.*" The appendix shows how each alternative was scored for flexibility.

Table 4.5: Data for Each Alternative

Data for each alternative	Cost (On average)	Total Risk Factor	Flexibility
Current Stairs	$0	59.5	1
Improved Stairs	$9,300.00	38	1
Ladders	$2,480.00	45	3
Hoist/Crane	$10,500.00	20.5	4

Table 4.6: Trade Study Scoring Guide

Scoring Guide	Score	Risk Factor	Cost	Flexibility
4	Excellent	20-33	$0-$2600	4
3	Good	34-47	$2601-$5201	3
2	Fair	48-61	$5202-$7802	2
1	Poor	62+	$7803-$10,500	1

After the data was collected, it was compared to Table 4.6, the Trade Study Scoring Guide, to see what range the risk factor, cost and flexibility lied under, to determine scores. For example, since the price of keeping the current stairs is $0, you look at Table 4.6 and match this data to the range of cost in between $0-$2600, which receives a score of 4 and so forth.

Additionally, a major consideration for the trade study analysis is to weigh each requirement to show what Airbus values more. For the sake of this portion of the project, the risk factor is ranked the highest, followed by flexibility and then by cost. All three requirements are important, but upholding the safety of the employees is one of the principal objectives, followed by the other requirements.

Table 4.7: Trade Study Analysis with Weights

Requirements	Analysis Rank	nverted Rank	Weight	Current Stairs	Improved Stairs	Ladders	Hoist
Risk Factor	1	3	0.5	2	3	3	4
Flexibility	2	2	0.33	1	2	3	4
Cost	3	1	0.17	4	1	4	1
Sum	*6*		*1*				
			Weighted Sum	2.00	2.33	3.17	3.50

Table 4.7 simply compiles all the scores for the four alternatives that corresponds to each requirement. The weighted sum is then calculated for each alternative and the one that yields the maximum total performance value should be the alternative to choose, which in this case, is the hoist.

4.2.1 Trade Study Analysis

We analyzed our trade study results to see if purchasing a hoist would the optimal solution. When one considers the effect a hoist would have on Airbus's current blade installation process, one realizes that safety training would be needed, a learning curve would have to be met, setup time would increase and so would the amount of labor. Labor would increase because there are more tasks involved. Having a hoist would require a technician to set up the hoist, maneuver it and place the blade on a clamp. A hoist would also require someone to control its movement with a remote, and someone else to do the actual blade installation. Overall, using a hoist would have extra steps that would essentially kill cycle time. The second highest score were the ladders followed by customized stairs.

4.2.1.1 Sensitivity Analysis

Since setup time was not originally considered in the first trade study analysis, it was added to determine if our decision would change. The rankings for flexibility and setup time were switched, making setup time to be ranked as number two since safety and cycle time are important aspects of this project.

Table 4.8: Trade Study Sensitivity Analysis – Addition of Setup Time and Ranked #2

Sensitivity Analysis							
Requirements	Rank	Inverted Ran	Weight	Current Stairs	Improved Stairs	Ladders	Hoist
Risk Factor	1	4	0.4	2	3	3	4
Setup Time	2	3	0.30	3	3	4	1
Flexibility	3	2	0.20	1	2	3	4
Cost	4	1	0.10	4	1	4	1
Sum	10		1				
			Weighted Sum	2.30	2.60	3.40	2.80

Performing this sensitivity analysis changed our decisions to choosing ladders over a hoist. Since we disregarded the idea of purchasing a hoist, we compared ladders against improved stairs. In the end, our optimal solution was to choose purchasing customized stairs. With the new customized stairs, a safer and more ergonomic work cell for the technicians would be provided. This alternative should help reduce the risk of bodily injury for the technicians as well the risk of blade damage.

4.3 Work Injury Cost Analysis

New customized stairs will be able to provide a safer and more ergonomic work cell for the technicians in charge of blade installation. The cost for two new customized stairs is approximately $19,000. As shown on Table 4.8, one can see that the cost of bodily injury ranges from $39,801 to $960,310 depending on type of injury. With that said, the new customized stairs will save the company the expenditure associated with potential accidents.

Table 4.9: Work Injury Cost Estimates

Body Injury			
	Direct*	Indirect	Total Cost (Direct and Indirect)
Concussion	$ 60,770.00	$ 66,847.00	$ 127,617.00
Fracture	$ 48,492.00	$ 53,341.00	$ 101,833.00
Sprain	$ 28,866.00	$ 31,752.00	$ 60,618.00
Foreign Body	$ 18,953.00	$ 20,848.00	$ 39,801.00
Laceration	$ 19,059.00	$ 20,964.00	$ 40,023.00
Fatality	---	---	$ 960,310.00
Blade Damage			
	Quantity	Cost	
Minor	1	$ 20,000.00	
Major	1	$ 100,000.00	

CHAPTER 5

CONTROL

5.1 Future Implementation and Control

In order to create a safer environment for the technicians installing the blades, we ultimately decided to work with vendors to price a custom-made stair assembly. The initial thought was to purchase a crane so that it would take charge of lifting the blade instead of using manpower. However, this would take an extra person to operate, increase setup time, and interrupt the current flow, since the technicians would have to learn a different way to accomplish their task. We then compared stairs and ladders and realized that stairs would work better because of its safety enclosures and stable platform, which give ease of walking up to the top.

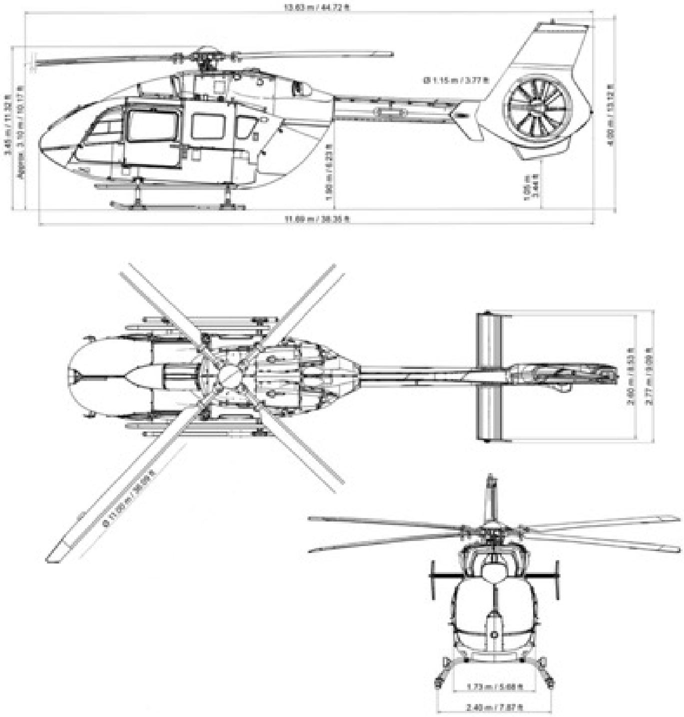
Despite the stairs' larger storage footprint when compared to the hoist and ladders, they have the least learning curve, are more stable and have enough room for technicians to maneuver during operations as they hold 80-90 pound blades on their shoulders.

Designs for customized stairs are forthcoming as we work with AllMetals Company to help design stairs that are adjustable in height, will accommodate different helicopters, decrease the storage footprint and provide physical attributes valuable for technicians. Continuing our communication with AllMetals and ensuring we are all on the same page, will facilitate the implementation of an ergonomic solution superior to Airbus's current blade installation process.

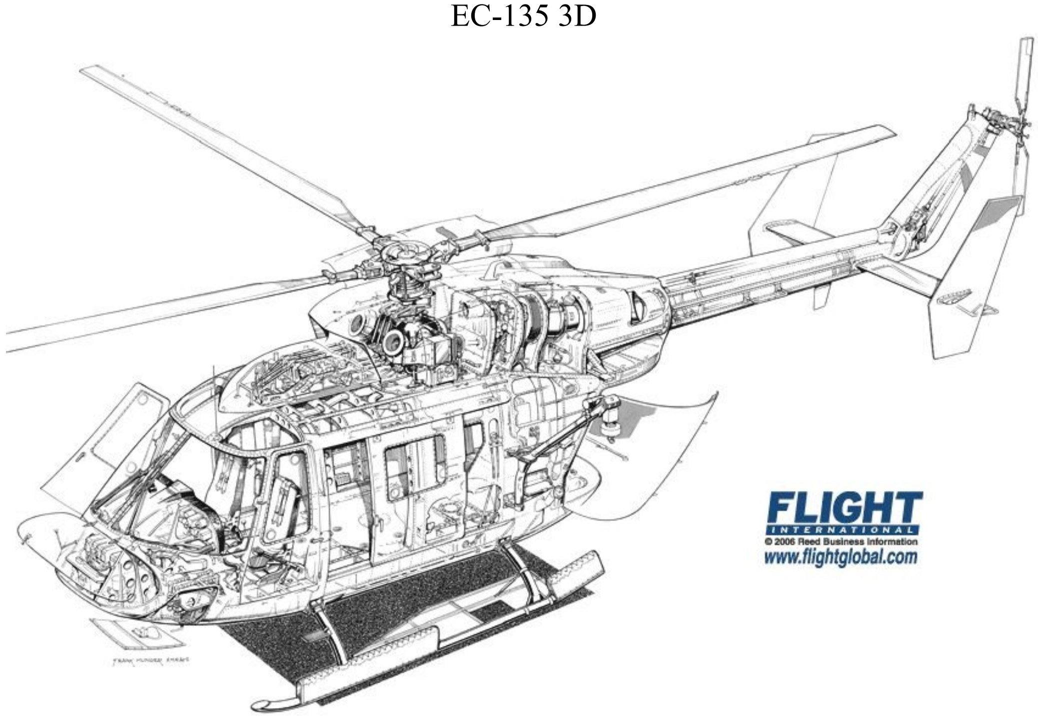
APPENDIX A

OTHER AIRBUS HELICOPTER MODELS

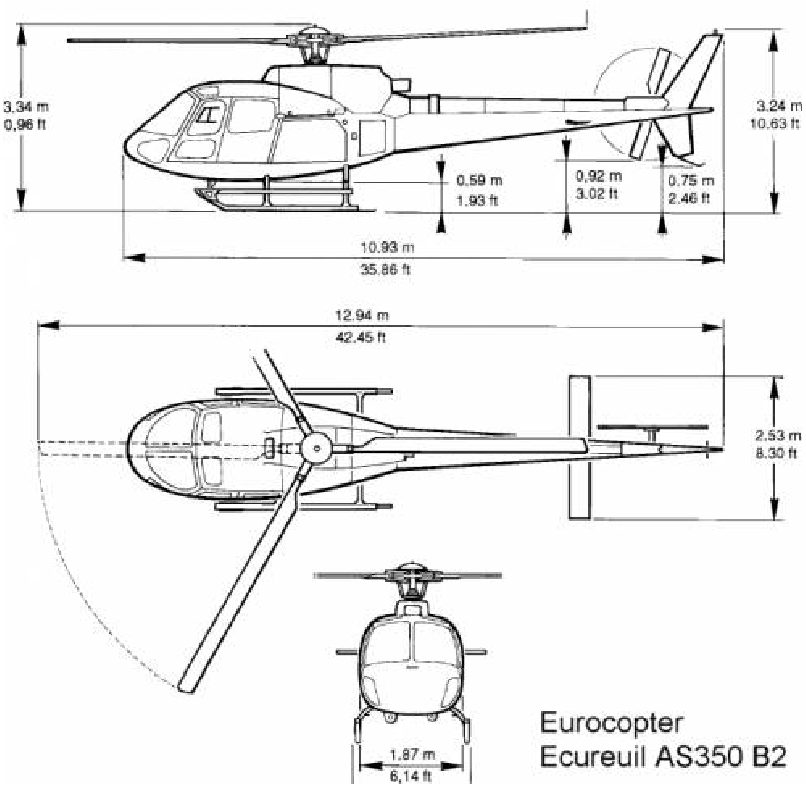
EC-145



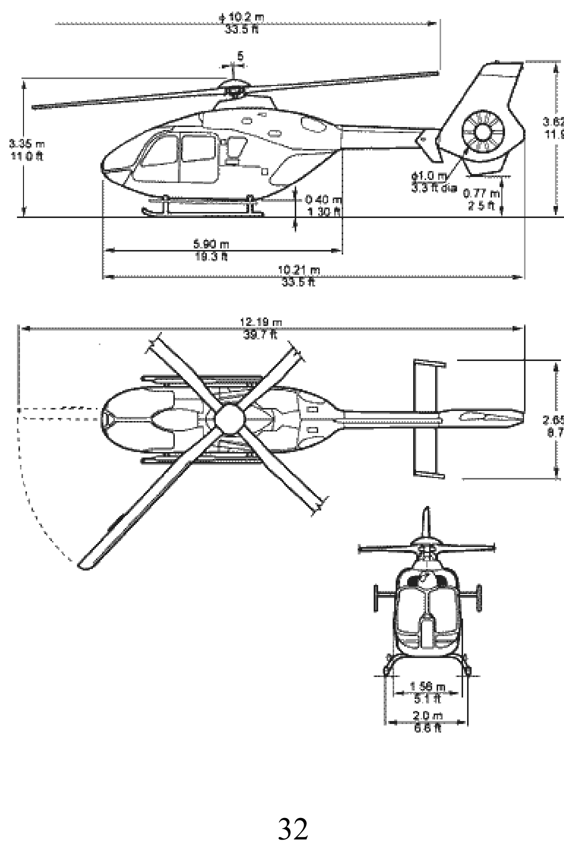
EC-135 3D



AS 350


3,34 m
0,96 ft
3.24 m
10.63 ft
0,59 m
1.93 ft
0,92 m
3.02 ft
0.75 m
2.46 ft
10.93 m
35.86 ft
12.94 m
42.45 ft
2.53 m
8.30 ft
1,87 m
6,14 ft
Eurocopter
Ecureuil AS350 B2

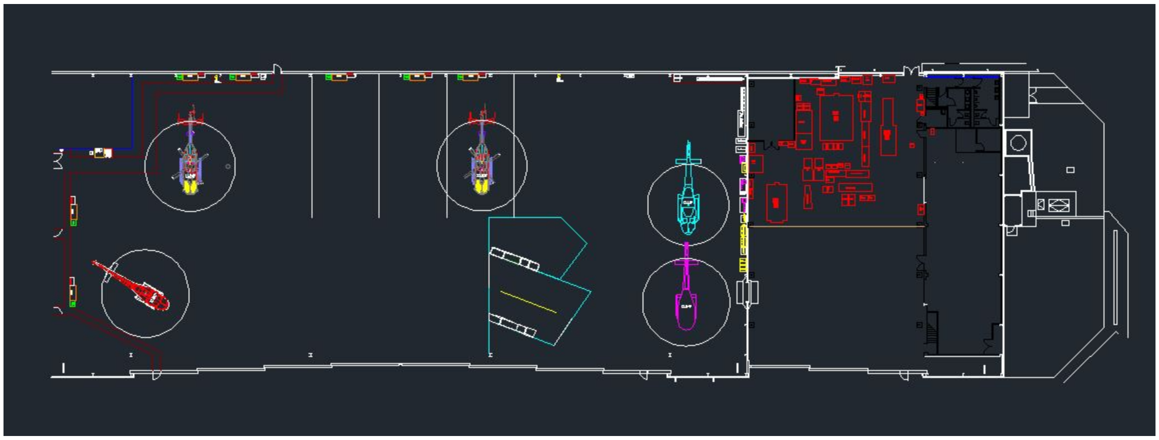
H-135

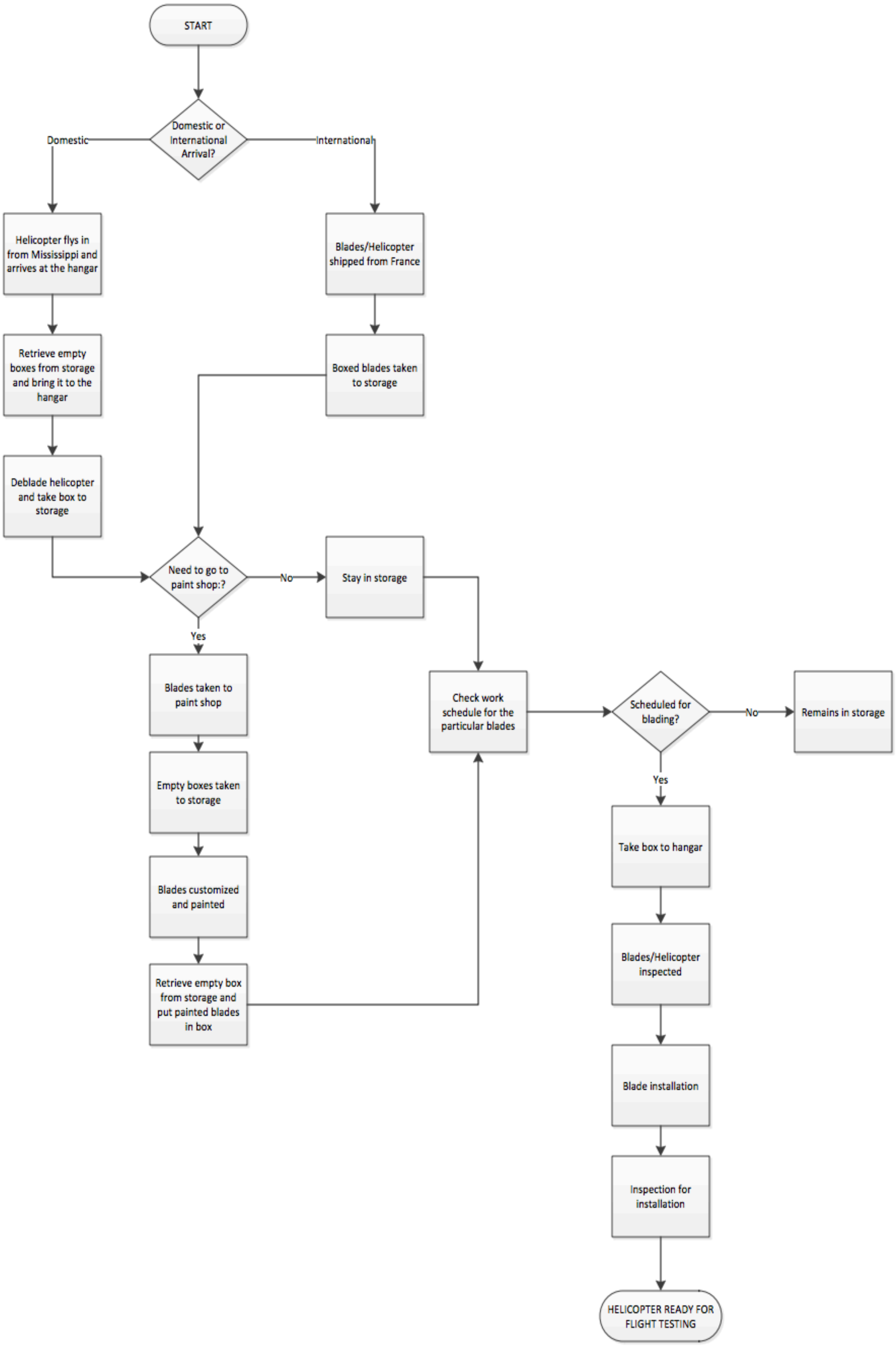

ϕ10.2 m
33.5 ft
5
3.35 m
11.0 ft
3.62 m
11.9 ft
ϕ1.0 m
3.3 ft dia
0.77 m
2.5 ft
0.40 m
1.30 ft
5.90 m
19.3 ft
10.21 m
33.5 ft
12.19 m
39.7 ft
2.65 m
8.7 ft
1.56 m
5.1 ft
2.0 m
6.6 ft

APPENDIX B

CURRENT BLADE INSTALLATION FACILITY

OVERVIEW AND PROCESS MAP




START
Domestic or International Arrival?
Domestic
International
Helicopter flys in from Mississippi and arrives at the hangar
Blades/Helicopter shipped from France
Retrieve empty boxes from storage and bring it to the hangar
Boxed blades taken to storage
Deblade helicopter and take box to storage
Need to go to paint shop:?
No
Stay in storage
Yes
Blades taken to paint shop
Check work schedule for the particular blades
Scheduled for blading?
No
Remains in storage
Empty boxes taken to storage
Yes
Take box to hangar
Blades customized and painted
Blades/Helicopter inspected
Retrieve empty box from storage and put painted blades in box
Blade installation
Inspection for installation
HELICOPTER READY FOR FLIGHT TESTING

APPENDIX C

TRADE STUDY FLEXIBILITY CHART AND

SETUP TIME SCORING GUIDE

Flexibility Scoring Guide for Trade Study Analysis

Alternatives	Maneuverable	Foldable	Storage Space (Small storage footprint?)	Adjustable Height	SCORE (# of yes)
Current	Yes	No	No	No	1
Customized Stairs	Yes	No	No	Yes	2
Ladders	Yes	yes	Yes	No	3
Hoist	Yes	Yes	Yes	Yes	4

Setup Time Scoring Guide for Sensitivity Analysis

	Alternatives			
Setup Time Scoring	current stairs	improved stairs	ladders	hoist
Very High (1) High (2) Medium(3) Low (4)	3	3	4	1

REFERENCES

"400 Series Helicopter Work Stands." *400 Series Helicopter Work Stands*. MP Industries, Inc. Web. 11 Apr. 2016.

Allmetal Maintenance Stands, Antoine. "Pricing and Information Inquiry." Telephone Interview. 11 Apr. 2016.

Graves, Allen. Digital image. *Six Sigma Daily*. U.S.News University Connection. 2012. Web.

Green, Jeffrey. "Airbus A320/321 MRO Ergonomic Safety Ladder System. *"Ergonomic Ladders for MRO Service and Safety*. LockNClimb, LLC, 2015. Web and Telephone Interview 11 Apr. 2016.

Hamdan, Maysaa. "DMAIC." 2014. Microsoft PowerPoint Presentation

Heliladder Neubauer, Dale. "Pricing and Information Inquiry." Web and Telephone interview. 11 Apr. 2016

"NIOSH Fatal Occupational Injury Cost Fact Sheet: Warehousing and Storage (NAICS 493)." NIOSH Fatal Occupational Injury Cost Fact Sheet: Warehousing and Storage. National Institute for Occupational Safety and Health Education, 06 June 2014. Web.

Thakur, Sidharth. "A Critical Tool for Assessing Project Risk." *Bright Hub Planning Management*. Bright Hub Inc, 13 June 2015. Web

"The Helicopter Industry Leader." *Buy or Purchase Airbus Helicopters*. 2014. Web. 11 Apr. 2016

“Portable Pick and Carry Mini Cranes." *Smart-Rig Portable Cranes*. Smart Rig Cranes, 2016. Web.

United States Department of Labor." OSHA's Safety Pays Program. OSHA, n.d. Web.

BIOGRAPHICAL INFORMATION

Jasmine Lucero has been pursuing her Honors Bachelors of Science in Industrial, Manufacturing and Systems Engineering from the University of Texas at Arlington since 2012. She is a first-generation college student and has two younger brothers. She has been a part of the Society of Hispanic Professional Engineers throughout her college career and hopes to continue her involvement in the years to come to inspire other younger Hispanics to pursue a career in STEM. Additionally, she hopes to support nonprofit organizations such as INROADS that aim to help underprivileged students gain access to corporate America, therefore creating opportunities and supporting professional and personal development. She is currently working towards obtaining a position in the supply chain and logistics industry. Jasmine's future career plans include obtaining an MBA and perhaps becoming a motivational speaker for organizations, companies or schools. She is very grateful to the people who have left a positive imprint in her life and attributes her success to her mentors, colleagues and family, who have provided her with encouragement, support and inspiration to move on forward and be the best she can be.