Department of Mechanical and Industrial Engineering
Faculty of Engineering and Architectural Science

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COURSE ID:	MEC 734	**SECTION #:**	N/A	**INSTRUCTOR:**	M. F. STEWART
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NAME	**STUDENT ID**	**SIGNATURE***
LUKA SUBOTINCIC	xxxx49428	Luka S.
STEVEN IBRHIM	xxxx73330	Steven Ibrhim
SHOAIB HASAN	xxxx32412	Syed Shoaib Hasan
SUKHMAN BAJWA	xxxx29005	S. Bajwa

(Note: Remove the first 4 digits from your student ID)

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Abstract

This report outlines the Design for Manufacturing and Assembly analysis and redesign process for the Montoy Infrared Sensor Helicopter toy. The following process was performed:

1. The original design was disassembled and assembled several times, and notes and observations were recorded.
2. Surveys and customer satisfaction research were performed to identify issues in the toy and establish requirements.
3. Boothroyd-Dewhurst and Lucas DFMA methods were applied to the original design.
4. A Failure Mode and Effect Analysis was performed on the original design.
5. Based on the mentioned analyses, two revised design concepts were developed.
6. All three designs were evaluated based on the established requirements and it was determined that the final design, which took into account all three analyses, was the best concept.
7. The final design was analysed using the Boothroyd-Dewhurst and Lucas DFMA methods.

The below tables summarize the gains made by the final design against the original design. The body of this report documents the process and explains in it greater detail.

Original Design vs. Redesign - B-D DFA

Design	**Assembly Time (s)**	**Assembly Cost ($)**
Original	423.24	5.53
Redesign	243.36	3.18
Reduction	179.88	2.36
% Reduction - Approx.	43	43

Original Design vs. Redesign - Lucas Analysis

Design	**Handling Score**	**Insertion Score**
Original	39.73	209.9
Redesign	33	79.2
Reduction	6.73	130.7
% Reduction - Approx.	17	62

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1 Introduction

Material and labour costs are one of the largest expenses in any manufacturing process. To help alleviate some of these major expenses, Design for Manufacturing (DFM) and Design for Assembly (DFMA) are used. These two methods combined is called Design for Manufacturing and Assembly (DFMA). These two methods of analysis are vital to any manufacturing operation. Up to 70% of the manufacturing costs are created from manufacturing methods (screwing, snap-fit, etc.) and material selection [1]. The other 30% of the manufacturing costs are created from the other decisions like process planning and tool selection [1]. This report will focus on the former of the two costs - manufacturing methods and process planning.

The product selected to be redesigned is the MonToy Infrared Sensor Helicopter. It is effectively a 1-channel helicopter with controls for only up and down motion. The control element in this toy is the user's hand. When a user moves their hand closer to the infrared sensor it will cause the toy to move up, and vice versa. The helicopter, in its entirety, was dissembled, torn apart and prepared for analysis. Two major methods of analysis were used for this redesign - Lucas Method, and Boothroyd Dewhurst. Other design elements such as Failure Mode Effect Analysis (FMEA), user survey feedback, and common engineering ingenuity were used to help guide the redesign process.

Overall, the redesign that was established in this project was highly effective cutting down 43% of both assembly time and assembly cost. The rest of this document will guide the reader through the exact steps taken to come to the decisions that were made, as well as the rationale behind them.

2 Discussion of Original Design

The design is originally based off a 3-channel R/C helicopter that's been redesigned to be made as cheaply as possible. So instead of using a metal frame, tail rotor, or remote control, an IR sensor uses heat from the palm of the user's hand to increase throttle, and in it's absences, decreases throttle. This means that the toy is effectively a "1 channel helicopter", as the controls are only up and down.

Figure 2.1: Image of the Helicopter

The assembly of the product contains mostly plastic materials that are very flexible and delicate. Assembling the parts of the helicopter are quite difficult due to the small size of many components. Some parts are hard to grasp when assembling, such as attaching the support stabilizer and propeller mount on the blades. Also, a variety of the screw holes are difficult to screw in since they are very small and placed on delicate parts such as the rotor. This is displayed in Figure 2.2, where in order to screw in the propeller mount on the blades, a torque has to be applied on the main shaft, perhaps damaging it. This is in addition to the fact that the hole in both propeller mounts have to be threaded, and that there are no spare propellers provided, so it doesn't make sense to choose screws for serviceability if the user has no course of action in case of an accident. The easy fix for assembly here is to just use snap on fit for the blades.

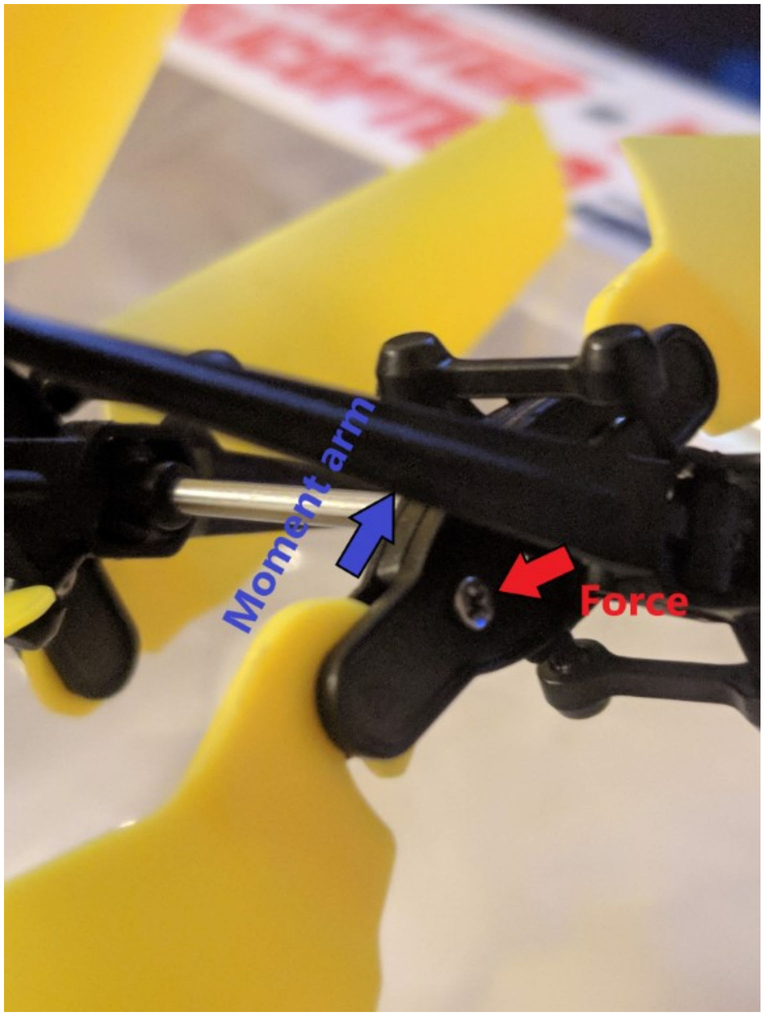

Figure 2.2: Screwing operation on delicate parts

Another big issue is the lack of guided wires, as the body pieces don't have indents to route wires effectively, meaning it has to be pushed down as the other body piece is pushed on. In addition, because of the holes in body piece, likely to save material/weight and not to help with cooling, it's difficult to line up the circuit board assembly, as it has to be fitted underneath the body piece, requiring one to flex the body down in order to get a fit. This kind of issue is not present with the motor, as its encased in a separate assembly and snaps onto the body, likely to reduce lateral stresses given the moving parts. A simple fix in terms of assembly would be to use a slightly larger body piece with indents for electrical parts, and to help with routing the wires. Because of the large amount of cavities in the body piece already, a larger size shouldn't increase the weight drastically. Figure 2.3 shows all of these issues:

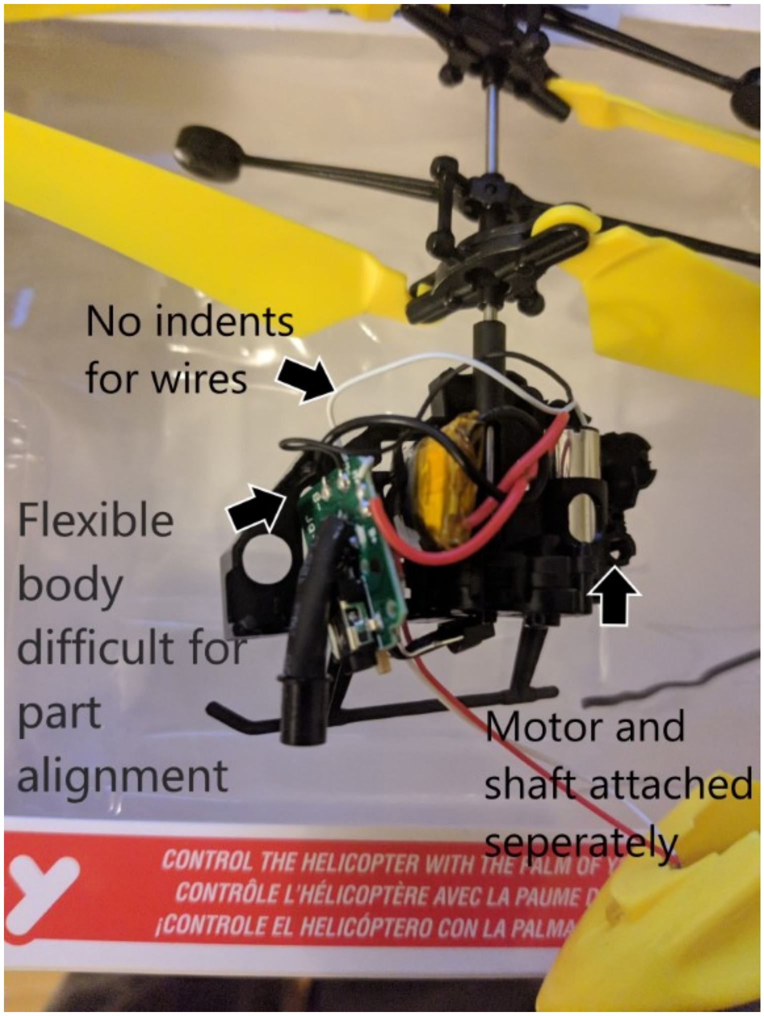

Figure 2.3: Too compact a body size

Any other issues encountered were poor quality control, such as the indent to keep the cockpit cover on being deformed with enough force, or the fact that some models had the circuit board off center, making it difficult for the wire to be plugged in to charge. These issues are likely due to the nature and cost of the product, and were somewhat expected.

In terms of original function, the helicopter doesn't do more than advertised. The throttle is controlled by the palm of the user's hand, it's rechargeable, and it should hover above surfaces, although that's rarely the case. Because there's no speed control gearbox, both rotors that spin opposite to each other do so at almost the same angular velocity. The reason it's not quite the same just comes down to gear losses from the motor to the shaft. This causes each toy to fly off in it's own direction based on gear tolerances, making it difficult to control where the helicopter goes in terms of yaw and pitch. Figure 2.4 shows the original gearbox:

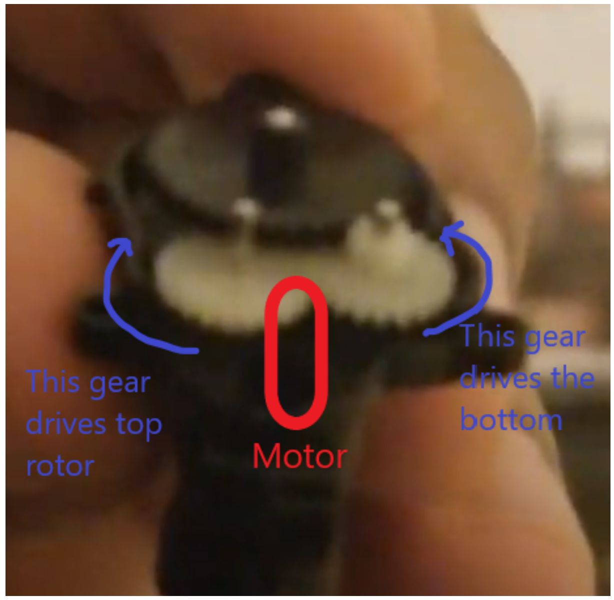

Figure 2.4: Original gearbox

The only way to address this issue is to use a variable gearbox, and while that has been done in the past by using a special dial on top of the rotor (namely Figure 2.5, which shows it on an Air Hogs Reflex helicopter), it'd require special tooling equipment, as other manufacturers ditched this idea in favor of using speed controllers on the transmitter of their toy helicopter. Because this toy doesn't have a transmitter, this can't be implemented, and it's simply not economically feasible to invest in making a small variable.

Figure 2.5: Rotary dial to trim yaw on Air Hogs Reflex [2]

2.1 Product Research

Survey questions regarding the functionality of the toy helicopter were made to understand the users perspective and their satisfaction regarding the product. The following questions are listed below with their answers from 3 different age groups.

2.1.1 Survey Review

1. On a scale of 1-10 , or in a short sentence, how do you rate your experience using the product?
   (a) Harshdeep: The toy was good. It flew in the air but did not have control. 7/10
   (b) Simar: The toy was cool. Went super fast. 9/10
   (c) Jaskaran: 6/10 it was okay.
2. What are your thoughts on the price of the product? Is it expensive, reasonable or cheap?
   (a) Harshdeep: Reasonable for its capabilities.
   (b) Simar: Cheap
   (c) Jaskaran: Cheap
3. Was the setup process difficult?
   (a) Harshdeep: Quite easy.
   (b) Simar: Easy
   (c) Jaskaran: Easy
4. What feature is most important for you in this product?
   (a) Harshdeep: Flying
   (b) Simar: That it is able to fly
   (c) Jaskaran: Sensors
5. If the toy needed fixing, does it seem easy to open and fix?
   (a) Harshdeep: Not really
   (b) Simar: No
   (c) Jaskaran:No
6. What are your thoughts on packaging?
   (a) Harshdeep: Seems recyclable
   (b) Simar: Simple
   (c) Jaskaran: Adequate
7. Would you recommend this product to people?
   (a) Harshdeep:No
   (b) Simar: Yes
   (c) Jaskaran: No

8. Is there something missing you would like to add?
    (a) Harshdeep: Maybe a remote control
    (b) Simar:Controller
    (c) Jaskaran: A remote control and better sensors
9. Did the product have any malfunctions when trying to use it?
    (a) Harshdeep: The product doesn't know where its going
    (b) Simar: It flies everywhere.
    (c) Jaskaran: It has no idea where it is flying. Hit me a couple of times.
10. Are there any parts that are prone to breaking? For example, the skids on the helicopter or the tail of the helicopter?
    (a) Harshdeep: Yes, wings broke off.
    (b) Simar: The tail is broken.
    (c) Jaskaran: Yes, the tail.

2.1.2 Product Reviews

In order to further analyze this product, additional market research was conducted on current customer reviews with regards to similar and current products in the market. Online retailers like Walmart and Amazon, it was possible to look into customer reviews of these sorts of products. To maintain a consistent market analysis from the product reviews, it is important to identify which areas of the product the customers enjoyed the most and areas they disliked. From the filtering suggestion that is available on both websites recommendations on reviews with 5 stars, 3 stars, and 1 star reviews for the products were considered. The positive reviews (5 star) indicated that customer loved the fact that helicopter is able to fly and the cool feature of the helicopter blades. This indicates that for a successful redesign, it is necessary to keep the design of the blades since it will add onto the user experience. The negative reviews (1 star and 3 star) indicated that the product was too small to hold and that the product seems to be cheaply made as some parts broke apart. This implies that it is important to identify which parts can be broken easily or fallen a part when analyzing the components in the design. Also, the design can also possibly be bigger as some users found it difficult to hold the helicopter. These requirements and reviews from the user are critical to the end users satisfaction.

2.2 Product Design Specification

2.2.1 Design characteristics

1. The helicopter must be light.

(a) The helicopter must be at a weight that is appropriate for it to be lifted by children and teens. It must be suitable for children at the age of 6 or older.

(b) The helicopter must be at a weight that is appropriate for it to be lifted by the motor and battery. The battery and motor are small so it must be sized for them to lift the whole weight of the helicopter.

2. The helicopter must be safe.

   (a) The helicopter must be safe for children and teens to use and play with because they are the primary users. The product must be safe for use and not dangerous for the primary users.

3. The helicopter must be assembled easily.

   (a) The helicopter must be assembled easy because it is a toy that is recommended for children. It should not be something complicated, but something simple where children can easily function with this product.

4. The helicopter must be durable.

   (a) The helicopter must be able to withstand wear, pressure, or damage because it is a children's toy. This type of user group will most likely not take care of the product, thus leading to bad conditions.

   (b) The item must be able to withstand damage from walls or objects in households as well because it will be hovering in the air and likely to bump into a structure.

5. The helicopter must be aesthetically pleasing.

   (a) The product must be presentable to young children and young teens, so that the product catches their eyes. This will lead to better sales as they will be more attracted to wanting this product.

6. The helicopter must be appropriately sized.

   (a) Since the toy helicopter will be for ages 6 and up, mainly targeting young children. The toy must be an appropriate size for them to hold by hand.

7. The helicopter must be sustainable.

   (a) The helicopter must be maintained at a certain rate or level because it will be used over and over again by kids. The helicopter quality must be functional so it lasts for a long period of time.

8. The helicopter must be affordable.

   (a) The helicopter pricing must be reasonable as it is made for kids. Also, due to its basic functions it should be affordable to most family classes.

9. The helicopter must be ergonomic.

    (a) The helicopter must be ergonomic because kids want something that feels comfortable to hold and play with. This way they will play with it longer and have more fun.

2.2.2 Functional Requirements

1. The product must be able to fly.
    (a) A function of the helicopter is that it flies off the ground when it is powered on by shifting the power slider.
2. The product must be easy to use.
    (a) Since the toy is meant for ages 8 and up it must be easy to use as children will be playing with this product. It should not be difficult to operate.
3. The product must be able to power on.
    (a) The product is an electrical toy that flies and in order for it to fly, power must be generated.
4. The product must be rechargeable.
    (a) The product consists with a battery that charges the toy and gives it power. One of the functions of the battery is that it is rechargeable so it can be used again for use.
5. The product must be able to balance itself.
    (a) The product must be able to sit comfortably by itself when placed on a table or the ground. The helicopter should not tip over or fall down.
6. The product must be able to hover above objects.
    (a) One of the functions of the helicopter is that it has control to hover over objects when it is flying in the air.
7. The product must have moving parts such as a moving blade.
    (a) The product must contain moving parts. The blades, gears, and shafts are the moving parts in the product.
8. The product's shafts must rotate.
    (a) For the product to operate, the shafts must rotate for it to fly.
9. The product's gears must rotate.
    (a) For the product to operate, the gears must rotate for it to fly.

2.2.3 Physical Constraints

1. The helicopter must fly at maximum 2 meters above the surface.
   (a) The helicopter should be at maximum approximately 2 metres above the ground surface. This distance is the average the toy helicopter flies above the ground.
2. The helicopter must fly in the upwards and downward direction.
   (a) The helicopter is only capable of flying in the upwards and downwards direction when powered on because of its infrared sensor being located at the bottom of the helicopter belly.
3. The helicopter must be able to spin in the air.
   (a) The helicopter has the ability to spin 360 degrees while flying since it has rotational shafts.
4. The helicopter blades on the on the top must rotate in the different direction as the helicopter blades on the bottom.
   (a) In order for the helicopter to fly the bladed must rotate in different directions, hence one pair going in the clockwise direction and the other set going in the counter-clockwise direction.
5. The LED light must display a white colour.
   (a) To indicate the helicopter is powered on or is fully charged the LED light must display a white colour.
6. The helicopter must be able to detect surfaces near its surroundings.
   (a) The infrared sensor should detect objects that are near the helicopter when they are near, approximately 10cm to 15 cm away.
7. The motor and battery must be capable of lifting the whole weight of the helicopter.
   (a) The weight of helicopter should be minimum in order for the battery and motor to hold and lift the helicopter to fly.

2.2.4 Performance Metric

1. The helicopter should be light weight.
   (a) The product should not weigh more than 50 grams.
2. The size of the helicopter should be appropriate for easy handling for kids.
   (a) The height of the helicopter should be between 10cm to 15cm.
   (b) The length of the helicopter should be between 15cm to 18cm.

(c) The depth of the helicopter should be between 3cm to 6cm.

3. The product should not have any sharp edges and all the edges should be a round shape.
4. Speed of helicopter must be slow enough for preventing hazardous play.
5. Rotary blades of helicopter.
6. The height of the helicopter when flying should be appropriate.
   (a) The maximum height of the helicopter from the ground surface should be 2 metres.
7. The total parts for the assembly should not be complex and the total amount of the parts should not exceed 30 parts.

2.2.5 Pairwise Comparison

Table 2.1: Pairwise Comparison Matrix

Product Characteristic		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Total**	**Weight**	**Rank**
Safety	**A**		A	A	A	A	A	A	A	7	25%	1
Functionality	**B**			BC	BD	E	B	B	B	5	17.9%	2
Costs	**C**				C	C	C	C	C	5	17.9%	2
Sustainability	**D**					D	D	D	D	4	14.3%	3
Manufacturability	**E**						E	E	E	4	14.3%	3
Aesthetics	**F**							G	F	1	3.5%	4
Durability	**G**								H	1	3.5%	4
Ease of Assembly	**H**									1	3.5%	4
Total										28	100%	

2.2.5.1 Safety

- Safety is ranked the highest in the chart because this is a toy intended for children. The toy must be suitable for children to play safely without the risk of getting hurt from choking hazards or sharp objects. It is our responsibility to insist that the design safety is the number one priority over all the other characteristics.

2.2.5.2 Functionality and Cost

- Functionality and cost were ranked second in the chart because it is important the product produced must work and be functional at an acceptable cost. They are both weighed the same because we need to make sure that the costs are low to produce enough products and cover all the expenses that satisfy the customer needs and manufacturing cost needs (Break-Even).

2.2.5.3 Sustainability and Manufacturability

- These two characteristics were ranked third in the chart because it is important in today's world to manufacture an environmentally friendly product that is sustainable and consists of recyclable materials throughout. This goes with the concept of manufacturability because we need to make sure that the product can be manufactured at an appropriate and efficient expense and process along with it. Overall, it is important that we use sustainable materials that are manufacturable.

2.2.5.4 Ease of assembly, Durability, and Aesthetics

- These product characteristics are ranked last in the chart. Ease of assembly is one of our goals for this product but all other product characteristics must be ranked higher in order to ensure the product is successful. Durability is also an important product characteristic since the children will be using it to fly and possibly bump into objects. So, the product must be able to withstand rough conditions causing it not to break. Lastly, aesthetics are important because children will need to enjoy and appeal to a good looking toy that catches their eye instead of a boring toy. However, this is not ranked higher than safety, functionality, and sustainability.

2.2.5.5 Old Design vs. PDS

The original design does meet all the PDS requirements, but does so just barely. For example, the design constraint of the helicopter being safe is true only to an extent. The helicopter won't fly into the user, provided the toy is above them and the IR sensor detects them. If the toy and the user are at the same elevation, then there is a chance that the rotor's might hit the user, provided that they don't get out of the way. Additionally, the functional requirement of the toy being able to hover is true only to an extent; it remains stationary only if one measures the distance between the toy and the user's moving hand, and that the user tries their best to keep that distance constant. If left alone, the toy will just oscillate in elevation, and veer slightly towards whatever direction the wind blows. To it's credit, that spinning motion by the wind does satisfy the physical constraint that the helicopter be able to rotate 360 degrees. Lastly, the sustainability of the helicopter is only valid as long as the lithium ion battery lasts. Because of Electrolyte Oxidation Pathways in Lithium-Ion batteries, the soldered on battery would eventually not hold a charge anymore, and because it's not replaceable (unless you solder a new one on) the whole toy would have to be discarded.

To it's credit, however, the toy meets all the other PDS requirements listed; its appropriately sized, it's affordable, it can even fly slightly above 2 meters if the user can get that high. This makes it a very good redesign from the other RC helicopter models like the Syma, as it retains most of the PDS characteristics found in them, with the exception of remote control.

3 Lucas Method Analysis - Original Design

The Lucas Assessment provides the ability to explore the manufacturing of the product in an entirely visual format. This method of analysis provides a very subjective approach towards determining whether or not the assembly process is of a good design. Typically, this method of analysis will showcase the flaws of the manufacturing process in relation to “vertical assembly” - an assembly method in which the product has parts that build on to each other, rather than requiring sub-assemblies to be pieced together. This section will provide an in-depth analysis of the product using the Lucas Method, and it will also discuss some of the short comings of using this method of analysis.

3.1 Handling and Insertion Analysis

The Handling and Insertion Analysis is an objective analysis that is carried out through the Lucas Method Analysis. It’s main goal is to analyze how well individual components are designed in terms of handling and inserting each part. Each part goes through a series of questions in which each question has a value attached to it. The higher the value, the harder it is to handle or insert the part. The overall handling score comes out to be 39.73 and the overall insertion score comes out to be 209.9.

The individual parts were very hard to handle due to nature of its design. Many of the parts, especially near to the end of the assembly, are very small and delicate causing several gripping problems. This was especially apparent in the screwing operations due to the screws being very small and having to be inserted in holes that were very difficult to find. Many of the screwing operations required to hands to guide the screw in to the correct hole. IN addition to that, two hands were required to screw the parts as the helicopter was very small and fragile and thus required more support when screwing. The Handling and Insertion worksheet that was tabulated by the team can be found in Appendix C.

3.2 Assembly Structure Flowchart

With the values generated from the Handling and Insertion Analysis, the team was able to conduct an Assembly Structure Flow Chart. This flowchart allowed the team to get a visual representation of the entire manufacturing process, what sub-assemblies are required to be made, and the order in which parts are inserted. The original design, in theory, was a very good one. The flowchart was very “vertical” meaning that the assembly didn’t require many sub-assemblies and that pieces can be added on to the helicopter piece by piece, very similar to how Lego’s are assembled. The vertical nature of the manufacturing process translates to a very efficient manufacturing process on paper - however the reality of the situation was much different when the team was able to really explore the design further comparing the handling analysis to the Assembly Structure Flowchart.

As discussed in the previous section, the parts were very small and difficult to handle. So while the manufacturing process may seem very good on the surface, in reality it is very difficult to assembly which explains the relatively high scores of handling and insertion. The Assembly Structure Flow chart for the original design can be found in Appendix D.

3.3 Design Efficiency

Part of the Lucas Method is to also understand the design efficiency of a product. The design efficiency indicates how efficient as a design is in terms of how many essential vs. non-essential parts there are. The more essential parts (or "A" parts as defined in the Lucas Analysis) there are in an assembly, the more efficient the design will be. There are several criteria for determining whether or not a part is considered essential, such as relative movement, material selection, etc. All this criteria is provided by the Lucas Analysis itself. In this particular product, the design efficiency was found to be approximately 36% with 14 essential parts in the overall design. The formula to obtain this value can be seen in equation (1).

$$\text{Design Efficiency} = \frac{\text{``A'' Parts}}{\text{Total Parts}} \tag{1}$$

4 Failure Mode and Effect Analysis (FMEA)

To help understand the design better and anticipate potential issues, an FMEA will be conducted on the original design, and it's issues will be compared to the redesign to see if it's been addressed. Before conducting the actual FMEA, the design will first be split up into systems and it's subsequent components, listed in Figure 4.1:

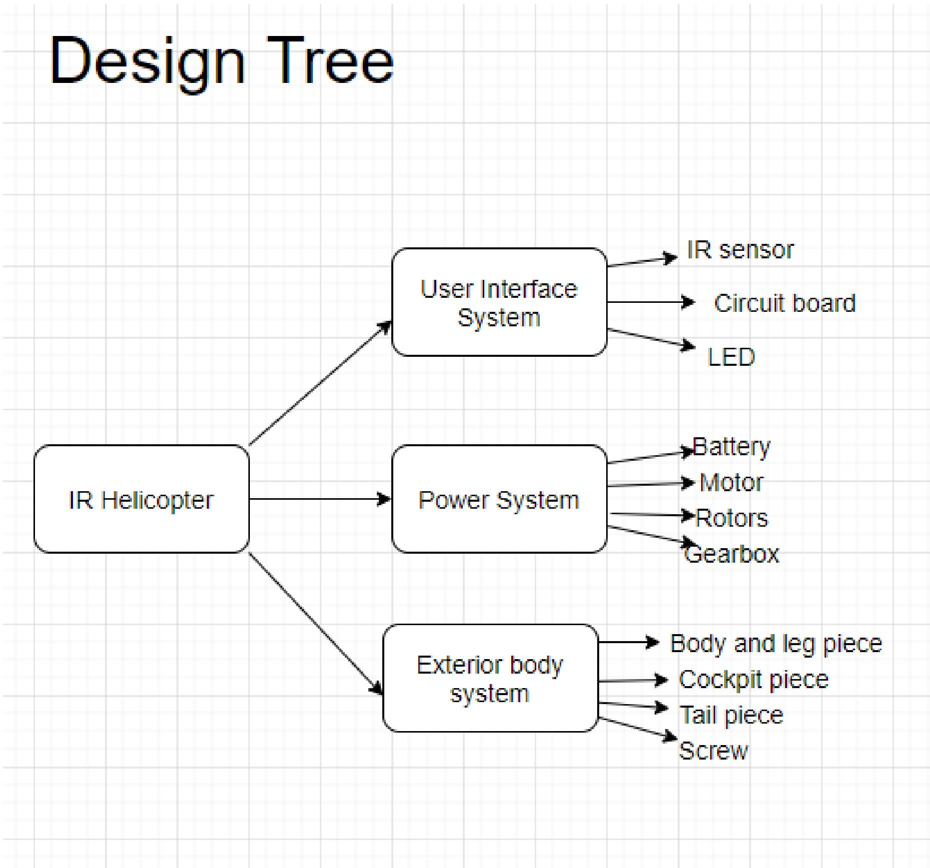

Figure 4.1: Design tree

Then, a function tree for the overall design, its system, and its subsequent components are made, listed in Figure 4.2 and 4.3

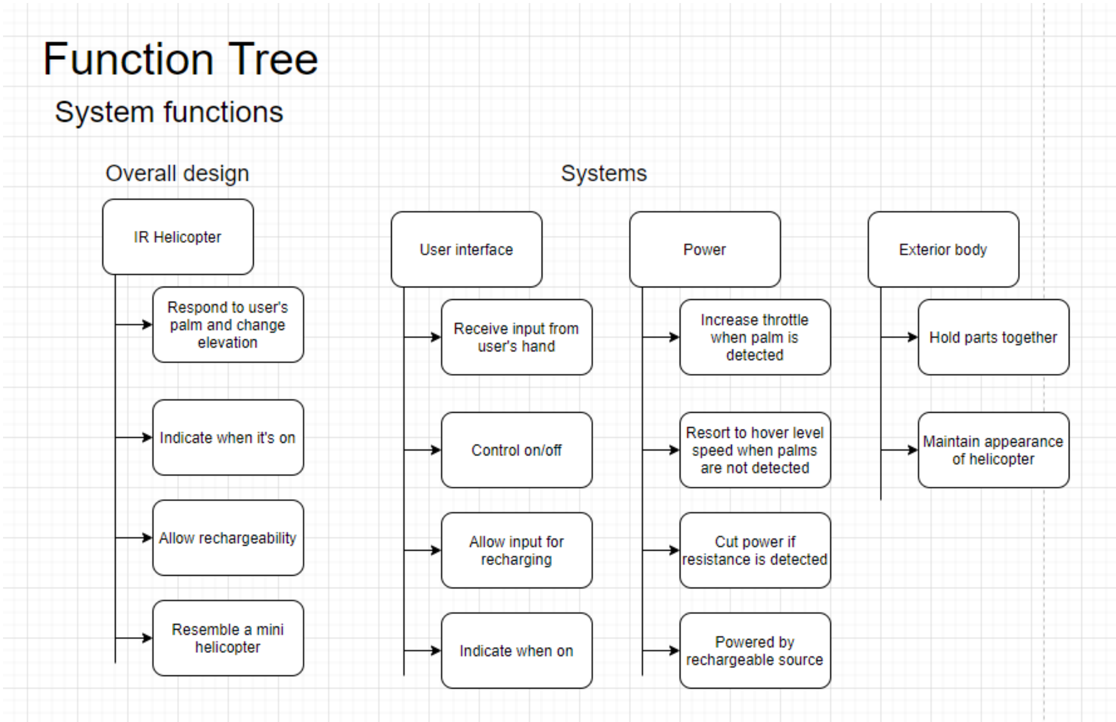

Figure 4.2: Function tree for System

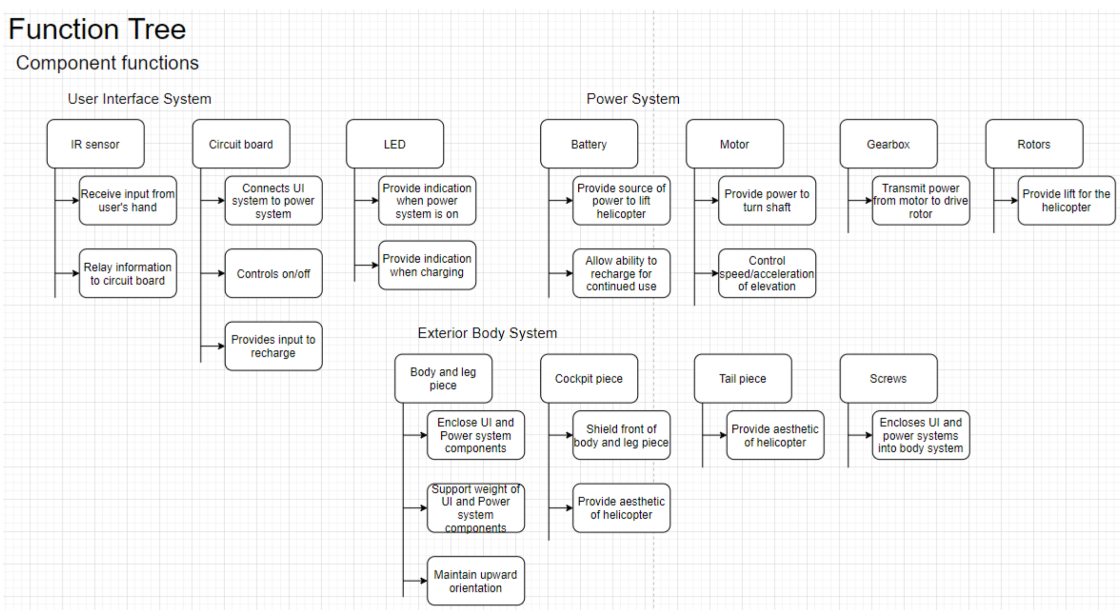

Figure 4.3: Function tree for Components

Now that there's a clear understanding of the functions of the product's system and it's components, it's time to relate these functions into the overall design by a function tree, as seen in Figure 4.4:

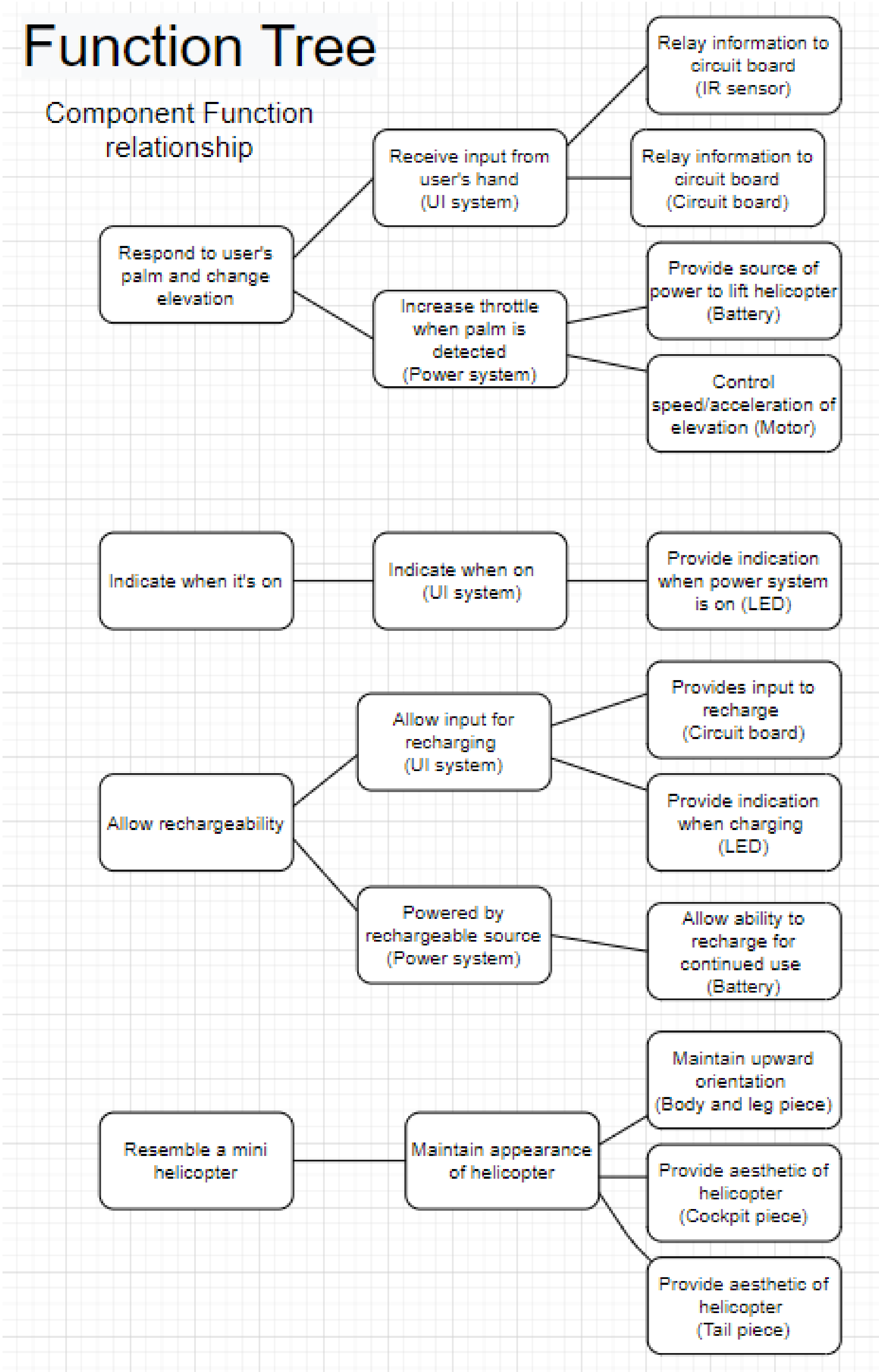

Figure 4.4: Component function relationship

With the functions well defined, we can now discuss failures at each level and show how they are related. First, the overall failures, or the effects of failure modes, are what the end user experiences. Figure 4.5 shows these failures from the overall design:

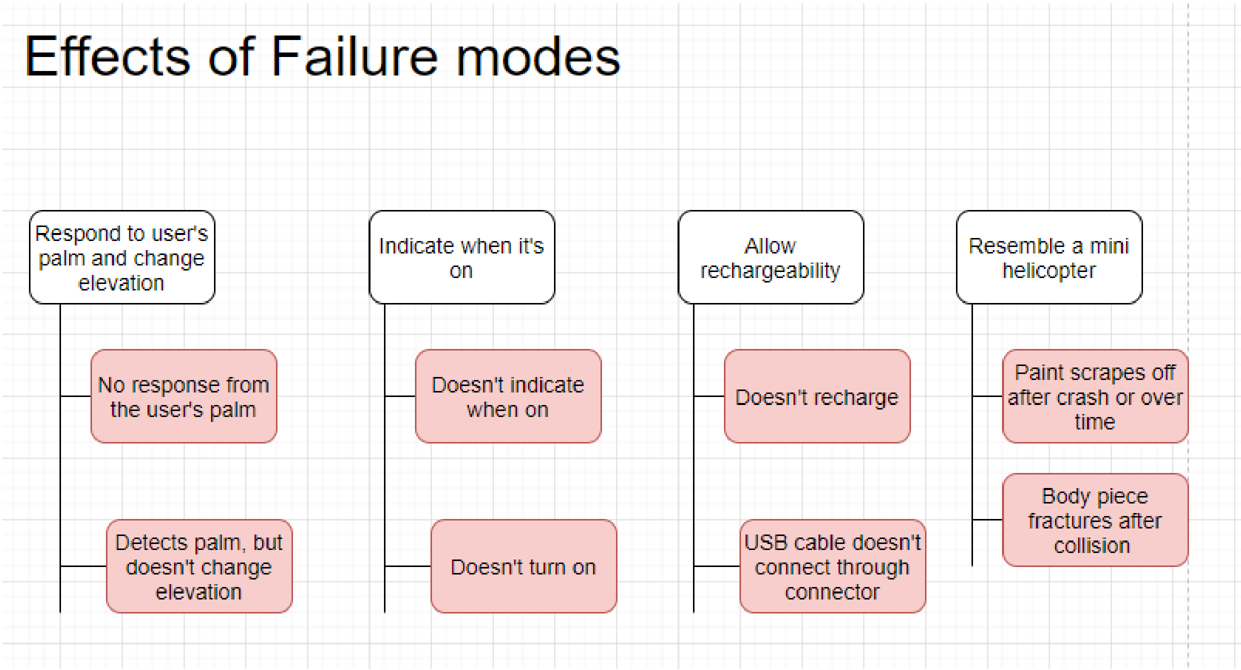

Figure 4.5: Effects of failure modes

Now system failures can be looked at, called the failure modes of each system, as shown in Figure 4.6:

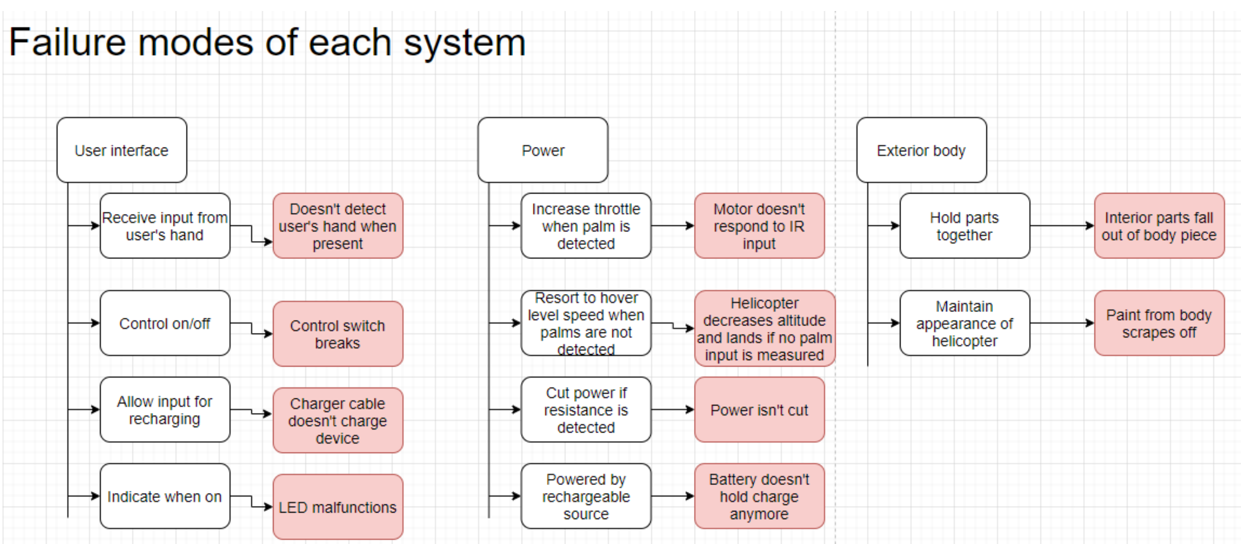

Figure 4.6: Failure modes of each system

Finally, failure at the component level can be looked at, called causes of failure modes, which is where the focus of the design actions will be. Figure 4.7

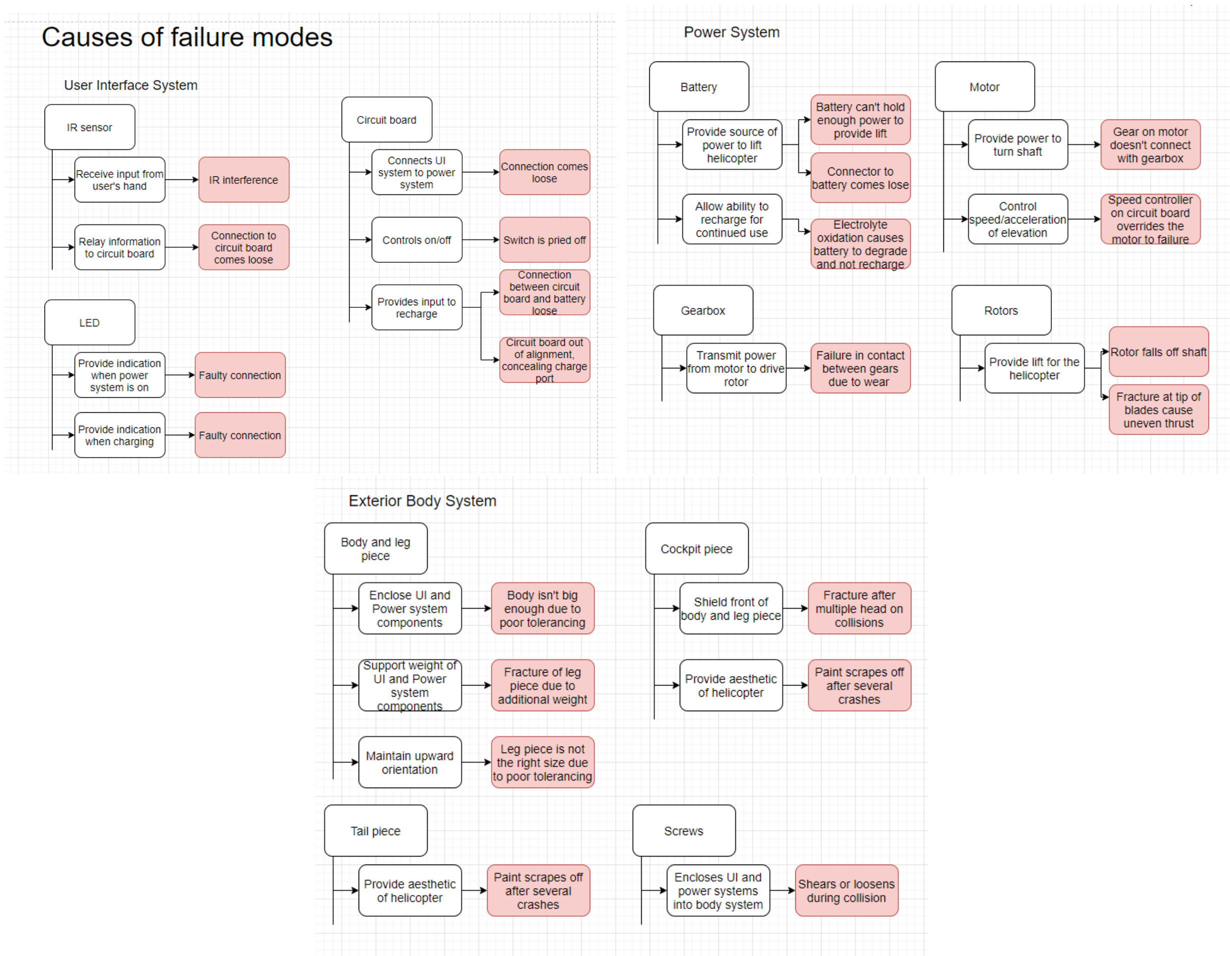

Figure 4.7: Failure modes of each component

As it would be a lot of work to go through each and every failure case, only the large failures from effects of failure mode will be studied, namely the issues of: no response from the user's palm, not being able to recharge, elevation not responding to user's palm, and body piece fractures. As these are taken from the overall design function, they would give the most necessary failures to be addressed.

Note that some changes have been made to the FMEA document from the one posted on D2L; the first two columns have been changed from item and function to system/function, and potential failure mode. The third column has then been changed to potential effects of failure mode, as those represent the overall design. Lastly, there was no RPN column, nor a new RPN column after listing the actions to be taken, so the original RPN column is listed, just to show the most pressing issues. The resulting FMEA document can be found in Appendix D.

5 Redesign Process

5.1 DFMA Changes

Boothroyd-Dewhurst DFMA software was used to analyze the original design, and produced an assembly time of 423.24 seconds and an assembly cost of 5.53$. The software also produces suggestions for redesign in order to reduce this time and cost (available in Appendices B and F). The principal solutions were as follows:

- Remove screws as much as possible.
  - This includes the propeller screws and the body screws.
- Remove parts which are used only as connectors.
  - The small shafts do not move relative to their gears, for example.
  - The stabilizer supports were also mentioned.
    - However, though they are connectors, they serve as part of a linkage and cannot simply be removed.
  - The propeller mounts are also candidates under this category.
- Remove parts which present handling difficulties.
  - These were principally the small shafts and the wires.
  - The LED in the front of the helicopter also presents handling difficulties.

A Lucas assembly analysis was also performed in two parts - a Handling + Insertion analysis and an Assembly Structure Flowchart (both available in appendices). This report will consider their implications separately. First, the Handling + Insertion worksheet lead to the following conclusions.

- The largest offenders, by far, were the screws.
  - This was partially due to sheer quantity, and partially due to their nature as small parts.
- The stabilizer supports were also prominently featured.
  - However, this is largely due to there having been four. Individually, their impact is not massive.
  - As discussed above, they cannot be simply removed from the linkage.
- The propeller mounts were the next largest problem.
  - Eliminations is feasible for at least some of them.
- The last large issue shown by the chart is the small shafts.

– They are very small, difficult to grip, and slippery.
– Elimination would be a large benefit to ease of assembly.

The Assembly Structure Flowchart leads to the following points:

- The current design makes some use of snaps and press fits already.
  – This leads to a fairly clean assembly process.
- The screwing operations cause a massive impact on assembly time.
  – Their elimination would be a large benefit.

The Lucas method process and implications for the original design are discussed in greater detail in Section 3.

The combined Boothroyd-Dewhurst and Lucas analyses lead to the following proposed design changes to improve manufacturing and assembly cost (sketches are shown within relevant bullet points):

- Screws should be removed from the body halves.
  – Instead, the body halves should be fastened together with snaps, as the gearbox cover is.
- The propeller mounting should be modified to remove the two top propeller mounts.

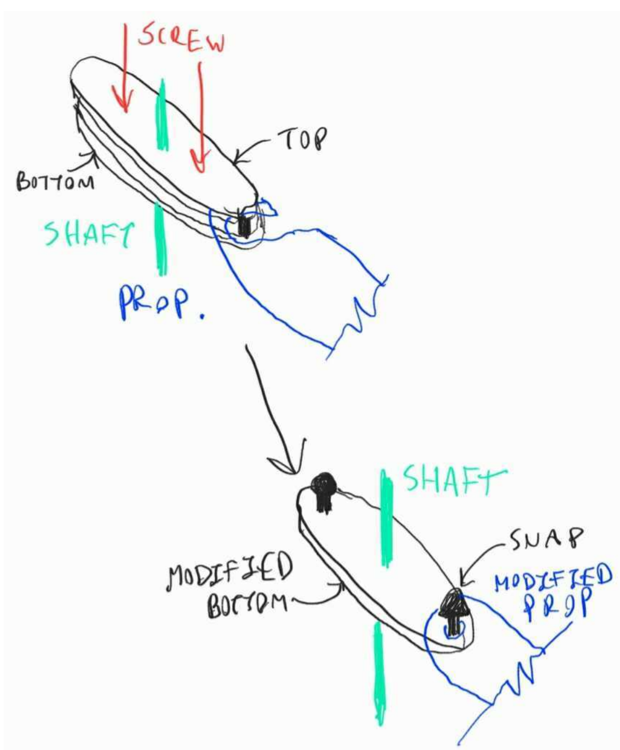

Figure 5.1: Sketch of the Propeller Mounting Modification

  - The propeller design would be slightly modified in order to push onto snaps in modified bottom mounts.
  - This leads to removing four more screws as well, as they are no longer needed to hold the top and bottom mounts together.

- The two small shafts should be integrated into the small gears.

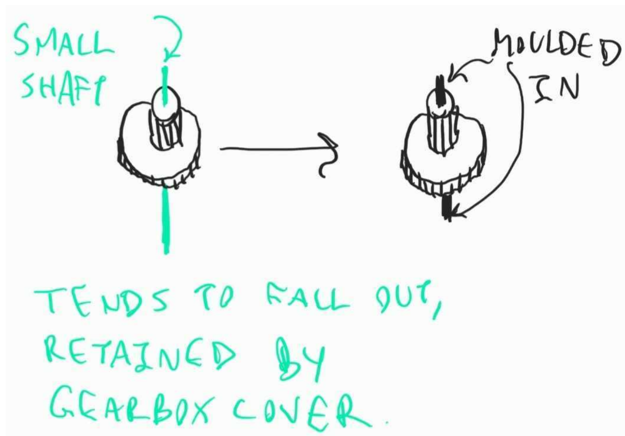

Figure 5.2: Sketch of the Small Shaft and Gear Modification

  - Currently, they simply slide into the centers of the gears.
    * This leads to them easily falling out.
  - Critically, these shafts also present a significant handling challenge as they are small and slippery.
  - Since they do not move relative to the gears, they can be injected directly by the same mould.
    * Due to the lower strength and wear resistant of plastic, their size should be slightly improved.
  - Since the shafts can no longer fall out, the bottom of the gearbox may now be unnecessary to retain them.
    * The bottom of the gearbox, however, also provides some alignment of the gears.
      · Testing is required to validate its removal with the new design.
      · Alignment features could also be included directly in the body halves if testing shows issues.

- The back support should be integrated directly into the right body half.

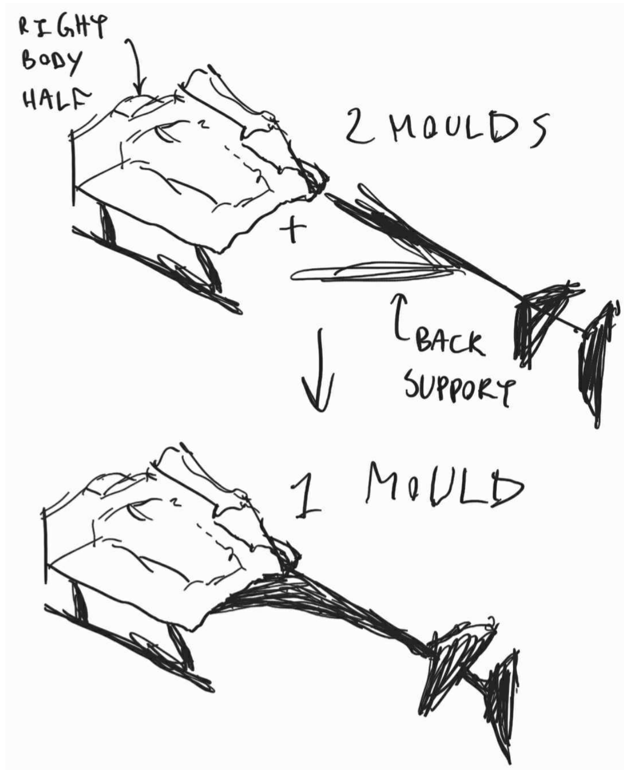

Figure 5.3: Sketch of the Back Support Modification

- The fit and finish of the part indicates it is not dimensionally critical.
- Testing of the helicopter indicates that it acts principally as a counterweight.
  - This, combined with its necessity as a visual cue for "helicopter" means it should not be outright removed, but rather integrated.
- Its elimination as a separate part also leads to the removal of a significant assembly issue of two screws.
  - Currently, it must be inserted between the body halves before closing and then screwed to their outsides, which is onerous.

- The LED in the front of the helicopter should be mounted directly to the board on its original, unclipped stiff leads.

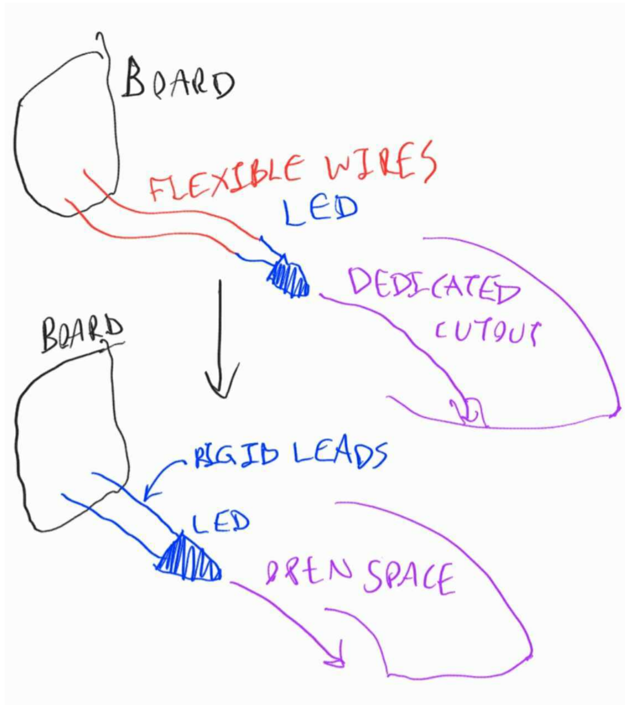

Figure 5.4: Sketch of the LED Mounting Modification

  - This removes the flexible wires currently being used to connect it.
  - The cutout in the cockpit cover that accepts it should also be enlarged.
    * This means that the LED no longer needs to be manually positioned in the cockpit cover, a tedious process.
    * The LED is now mostly removed as an assembly and handling concern.

5.2 FMEA Changes

A Failure Mode and Effect Analysis of the toy was also conducted, the processes and results of which are discussed in Section 4 and Appendix E. This lead to the following further proposed design changes:

- A potentiometer should be added to the control board to allow the user to adjust the strength of the reaction to an input if needed.
  - Many of the helicopter were purchased for the purpose of writing this report.
    * Several models flew directly into the ceiling the moment a user's hand approached the sensor.
    * Several models responded weakly to an approaching hand.
  - An adjustment potentiometer would allow either the supplier or end users to ameliorate this inconsistency.

- Snaps should be designed to minimize stress risers and should be added in sufficient quantity.
  - Screws are stronger than plastic snaps, therefore care should be taken in implementation to avoid introducing regressions to the design.
- The slot in the body halves which holds the IR transmitter in the correct position should be moved forwards.
  - Depending on the particulars of assembly, it can block access to the charging port in its current position.

5.3 Selection of Design

5.3.1 Design Concepts

1. Concept 0 - Original Design
2. Concept 1 - DFMA Improved Design
3. Concept 2 - DFMA and FMEA Improved Design

5.3.2 Weighted Decision Matrix

Table 5.1: Weighted Decision Matrix for Design Concept Selection

		Concepts					
Product Characteristic	**Wgt (%)**	**Concept 0 Rating**	**Score**	**Concept 1 Rating**	**Score**	**Concept 2 Rating**	**Score**
Functionality	17.90%	0	0	0	0	2	0.358
Costs	17.90%	0	0	2	0.358	1.5	0.2685
Sustainability	14.30%	0	0	1.5	0.2145	1.5	0.2145
Manufacturability	14.30%	0	0	2	0.286	2	0.286
Ease of assembly	3.50%	0	0	2	0.07	2	0.07
Safety	25%	0	0	0	0	1	0.25
Aesthetics	3.50%	0	0	0	0	0	0
Durability	3.50%	0	0	-1	-0.035	1	0.035
Total		0	0	6.5	0.8935	11	1.482
Rank		3		2		1	

Scale: Rating values from 2 (Good) and -2 (Bad). The values for weights are derived in table 2.1. The following points justify the assigned ratings:

1. Concept 0

(a) All (0): Concept 0 is the reference design, therefore it is considered to be a 0.
   - Other concepts are rated relatively to it.

2. Concept 1
   (a) Functionality (0): No changes were made which should affect functionality.
   (b) Costs (2): Costs are vastly reduced by the reduction in part count.
   (c) Sustainability (1.5): Sustainability is also improved by the reduction of part count, and therefore of process and material usage.
   (d) Manufacturability (2): Manufacturability is greatly improved by the reduction in part count, and the associated reduction in processes needed.
   (e) Ease of Assembly (2): Ease of Assembly is greatly increased by the simplified and eliminated parts.
   (f) Safety (0): No changes were made which should affect Safety.
   (g) Aesthetics (0): No changes were made which should affect Aesthetics.
   (h) Durability (-1): Durability is slightly affected by the use of snaps rather than screws. However, it is considered a low-weight aspect of this analysis, as the reference design is low cost and not designed to be durable.

3. Concept 2
   (a) Functionality (2): The Functionality is greatly ameliorated by adding a potentiometer to adjust the helicopter's response to inputs.
   (b) Costs (1.5): A potentiometer does slightly increase Costs.
   (c) Sustainability (1.5): Sustainability is similar to Concept 1.
   (d) Manufacturability (2): Manufacturability is similar to Concept 1.
   (e) Ease of Assembly (2): Ease of Assembly is similar to Concept 1.
   (f) Safety (1): Safety is slightly improved by the ability to adjust the helicopter's response to reduce erratic movement.
   (g) Aesthetics (0): No changes were made which should affect Aesthetics.
   (h) Durability (1): The redesigned snaps should increase Durability. Also, the ability to adjust the response should reduce collisions and therefore increase Durability.

5.3.3 Final Design Chosen

The final design chose, as outlined above, was Concept 2 - which integrated changes driven both by DFM/DFA concerns and FMEA concerns. As shown in table 5.1, it has a clear and quantifiable lead against both the reference design (Concept 0) and the DFM/DFA-only design (Concept 1).

5.3.4 Discussion of DFMA Improvements

To conclude the redesign process, DFM/DFA analyses were once again performed on the chosen design. A comparison of Boothroyd-Dewhurst results is shown in table 5.2. As can be easily seen, the redesign lead to cost and assembly time reductions of 43%.

Table 5.2: Original Design vs. Redesign - B-D DFA

Design	**Assembly Time (s)**	**Assembly Cost ($)**
Original	423.24	5.53
Redesign	243.36	3.18
Reduction	179.88	2.36
% Reduction - Approx.	43	43

The results of the two Lucas analyses are summarized in table 5.3. Once again, large improvements are evident. This is discussed in further detail in Section 6

Table 5.3: Original Design vs. Redesign - Lucas Analysis

Design	**Handling Score**	**Insertion Score**
Original	39.73	209.9
Redesign	33	79.2
Reduction	6.73	130.7
% Reduction - Approx.	17	62

6 Lucas Method Analysis - Redesign

As discussed previously in this report, the original design overall was not horrible when analyzed in respect to the Lucas Method. Small changes were made to the design, however, these small changes directly translated to dramatic decreases in handling and insertion scores, design efficiency, as well as the overall visual appeal of the Assembly Structure Flowchart. More importantly, the physical assembly also becomes much easier as shown in the previous section through a great decrease in the assembly time. The updated Assembly Structure Flow Chart can be found in Appendix H.

6.1 Handling and Insertion Analysis

The selected redesign had a major improvement on the handling score of the parts. The redesigned handling score of 33 - approximately a 17% improvement. This data showcases that the changes that were made improved the overall ease of handling during assembly. Insertion was also greatly improved to a score of 79.2 - approximately a 62% reduction. The redesign Handling & Insertion worksheet can be found in Appendix G.

6.2 Design Efficiency

With the removal of non-essential parts, like the screws, the team able to streamline and simplify the design. Additionally, several changes were made so that a few of the parts can be integrated together, such as the tail and body pieces, as well as the top and bottom propeller mounts. These changes, while minor on the surface, translated to a design efficiency of nearly 44% - an 8% increase compared to the original design. The differences are even more profound when the physical assembly is taken into place, with a very easy assembly process.

7 Conclusion and Recommendations

This report outlines the DFMA and FMEA based redesign of the Montoy Infrared Sensor Helicopter toy using the Boothroyd-Dewhurst method, the Lucas method, and the FMEA process.

Through this, combines with user feedback research and surveys, a new design was produced to ameliorate all identified issues with the existing one. The complete process is outlined in detail in the previous sections, and summaries of the DFM/DFA gains obtained are available in tables 5.2 and 5.3.

To ensure that the design is implemented successfully and the resulting product is optimal, the following next steps are recommended:

1. Prototypes of the new design should be produced.
2. The prototypes should be tested for possible mechanical issues.
   (a) Particularly, the snaps should be tested, as well as the new small gears, as outline in Section 5.
3. Once the design is mechanically validated, it should be tested by users.
4. User surveys should be conducted to identify possible issues with the new design.
5. The design should be revised to ameliorate these issues.

The above process should be repeated to the greatest degree allowed by financial and time constraints in order to yield the best possible product once production is started.

Bibliography

[1] "The importance of design for manufacturing," Markforged, [Online]. Available: https://markforged.com/resources/blog/importance-of-dfm (visited on 12/03/2020).

[2] (Mar. 2007). "Air hogs: Reflex helicopter," RCMania, [Online]. Available: http://www.rcmania.com/reviews/air-hogs-reflex-helicopter/ (visited on 11/29/2020).

[3] "DFMA® - Cutting Billions in Manufacturing Costs Since 1983 — Boothroyd Dewhurst, Inc.," [Online]. Available: https://www.dfma.com/software/dfma.asp (visited on 12/09/2020).

[4] Lucas Engineering and Systems Ltd., *Lucas Method Reference Material*. Hull, UK: University of Hull, 1994.

A Product Decomposition Worksheet

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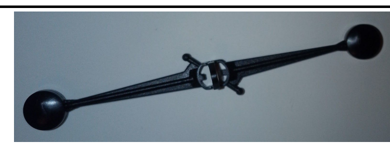
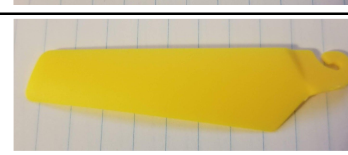
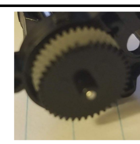
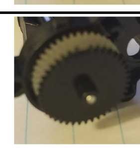
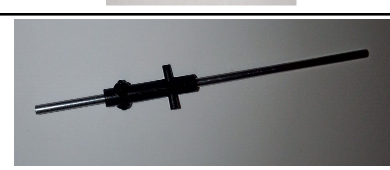
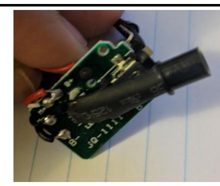
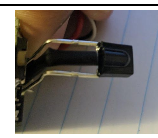
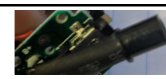
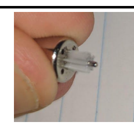
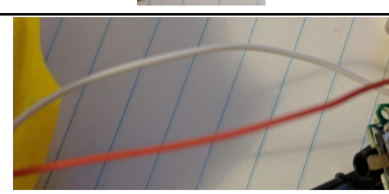
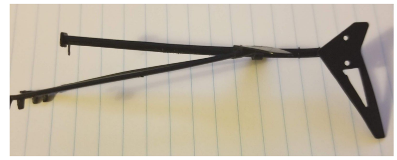
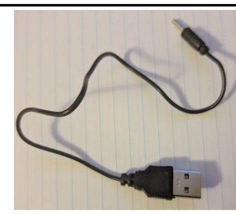
MEC734 **Product Decomposition**						
Product Decomposed:					**DATE: 16/11/2020**	
Functional Description:						
PARTS OF PRODUCT						
Part #	**Part Name**	**# Req'd**	**Material**	**Mfg Process**	**Dimensions (cm)**	**Image**
1	CockPit Cover	1	Plastic	Injection Moulding	7 x 3 x 2.8	
2	Stabilizer Support	4	Plastic	Injection Molding	1.35 x 0.4 x 0.4	
3a	Propeller Mount (Top)	2	Plastic	Injection Moulding	3.2 x 0.9 x 0.3	
3b	Propeller Mount (Bottom)	2	Plastic	Injection Moulding	3.2 x 1.8 x 0.3	
4	Stabilizer (Top)	1	Plastic	Injection Moulding	9 x 1.3 x 1	
5	Stabilizer (Bottom)	1	Plastic	Injection Moulding	9 x 1.3 x 0.3	
6	Blades (Left)	2	Plastic	Injection Moulding	7.2 x 2 x 0.5	
7	Blades (Right)	2	Plastic	Injection Moulding	7.2 x 2 x 0.5	

8	Screws	9	Steel	Lathe	0.5 x 0.25	
9	Left Body Piece	1	Plastic	Injection Moulding	6 x 4 x 2	
10	Right Body Piece	1	Plastic	Injection Molding	6 x 4 x 2	
11	Gear Box Cover	1	Plastic	Injection Molding	2 x 1.8 x 0.9	
12	Small Shaft	2	Steel	Cold Rolling	0.95 x 0.05	
13	Small Gear	2	Plastic	Injection Molding	0.8 x 0.35	
14a	Large Gear - inner	1	Plastic (black)	Injection Molding	1.9 x 0.5	
14b	Large Gear - outer	1	Plastic (white)	Injection Molding	1.9 x 0.5	
15	Shaft Housing	1	Plastic	Injection Molding	3.5 x 2 x 3.5	
16	Exterior Propellor Shaft	1	Steel & Overmolded Plastic		6.7x0.9	

17	Interior Propellor Shaft	1	Steel & Overmold ed Plastic		8.8x9.5	
20	LED light	1	-	-	0.4 x 0.4	
21	Battery	1	Lithium		2.3 x 0.7 x 1.5cm	
22	Circuit board	1	glass fiber reinforced (fiberglass) epoxy resin		3 x 1.5 x 1.5cm	
22a	IR receiver	1	Plastic		2.7 x 0.6 x 0.2cm	
22b	IR transmitter	1	Plastic		2.7 x 0.6 x 0.2cm	
24	Motor	1	Steel		2.3 x 0.8cm	
25	Motor gear	1	Plastic		0.35 x 0.4cm	
26 a/b	Wires	2/2	Copper		From board to LED. / From board to battery. Board to motor wires are integrated into motor.	

					Diameter: 0.2cm Length: 5.5-6.5cm each	
27	Back support	1	Plastic		11 x 2.5 x 3.5cm	
28	USB wire	1	Copper		0.7 x 0.5 x 29	
29	Plastic tray	1	Plastic		22 x 15.5 x 4	
30	Cardboard box	1	Cardboard		23 x 16 x 4.5	

B B-D DFMA Charts - Original Design

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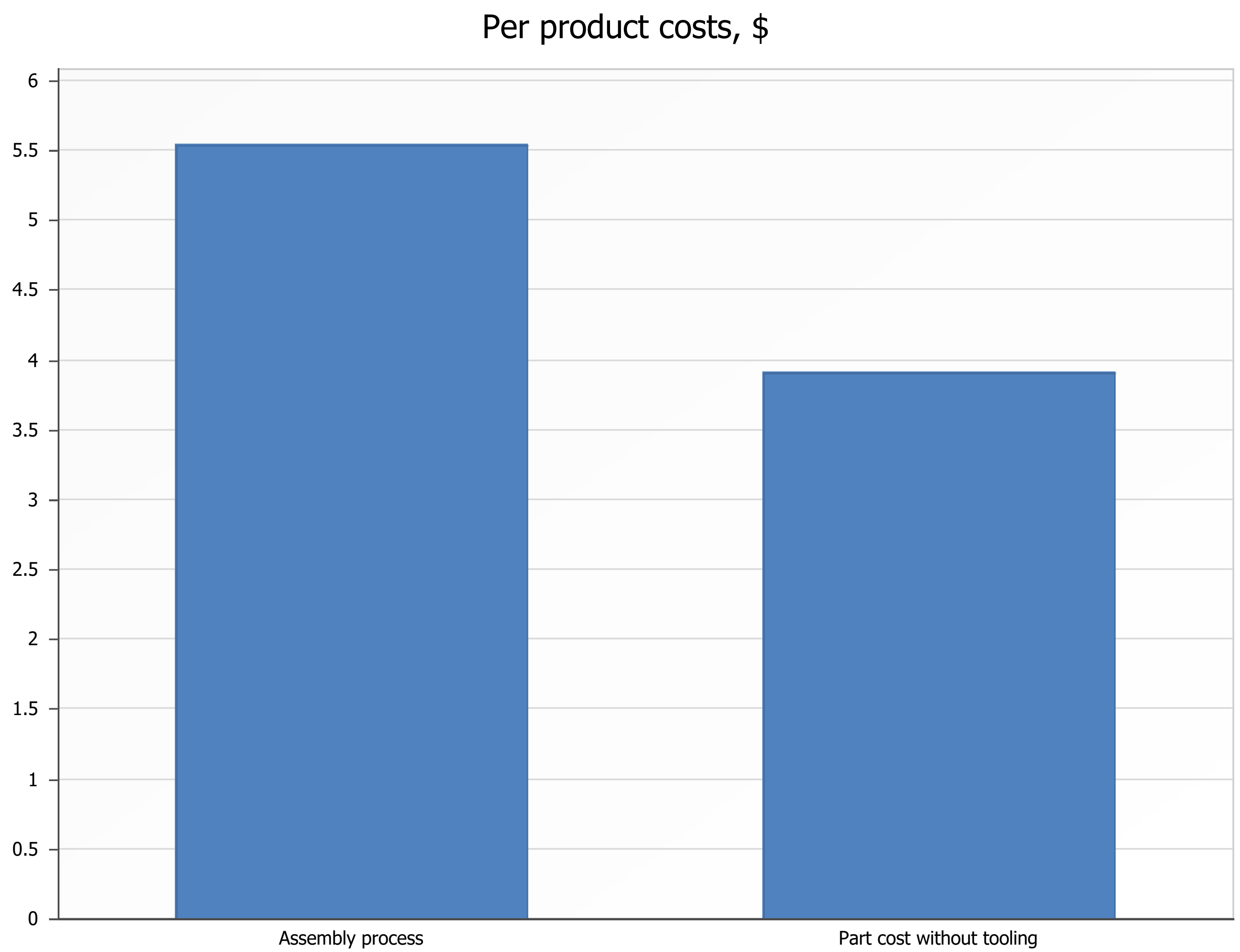
Analysis Totals for Design for Manufacture and Assembly (DFMA)

December 9, 2020

IR helicopter.dfax

Per product costs, $	Original
Assembly process	5.53
Part cost without tooling	3.91
Total cost without tooling	9.44

Production life data and weight	
Life volume	300,000
Total weight, kg	0.51



DFMA® - Boothroyd Dewhurst, Inc.

Design for Assembly
Product Worksheet

Original

December 9, 2020

IR helicopter.dfax

Name	Part number	Repeat count	Total count	Minimum items	Minimum part criteria
IR helicopter			51	14	
Main body		1	1		
Cockpit cover	1	1	1	1	Assembly
Shaft assembly		1	1		
Shaft housing	15	1	1	1	Base part
Large gear - inner shaft	14a	1	1	0	Connector
Large gear - outer shaft	14b	1	1	0	Connector
Small gear	13	2	2	0	Connector
Small Shaft	12	2	2	0	Connector
Gear box cover	11	1	1	0	Fastener
Exterior propellor shaft	16	1	1	1	Movement
Interior propellor shaft	17	1	1	1	Movement
Stabilizer support	2	4	4	0	Connector
Propellor mount top	3a	2	2	0	Fastener
Propellor mount bottom	3b	2	2	0	Fastener
Stabilizer (top)	4	1	1	1	Assembly
Stabilizer (bottom)	5	1	1	1	Assembly
Blades (left)	6	2	2	2	Different material
Blades (right)	7	2	2	2	Different material
Electronics + body assembly		1	1		
Circuit board assembly		1	1		
Circuit board	22	1	1	0	Connector
Wires - board to battery	26a	2	2	0	Connector
Wires - board to LED	26b	2	2	0	Connector

Design for Assembly
Product Worksheet

Original

December 9, 2020

IR helicopter.dfax

Name	Process time per entry, s	Process time per product, s	Process cost per product, $	Piece part cost per item, $	Piece part cost per product
IR helicopter		423.24	5.53		3.91
Main body	3.54	3.54	0.05	0.00	0.00
Cockpit cover	4.95	4.95	0.06	0.06	0.06
Shaft assembly	3.54	3.54	0.05	0.00	0.00
Shaft housing	3.54	3.54	0.05	0.07	0.07
Large gear - inner shaft	5.83	5.83	0.08	0.05	0.05
Large gear - outer shaft	5.83	5.83	0.08	0.05	0.05
Small gear	17.53	17.53	0.23	0.05	0.11
Small Shaft	27.60	27.60	0.36	0.52	1.05
Gear box cover	4.92	4.92	0.06	0.05	0.05
Exterior propellor shaft	7.22	7.22	0.09	0.78	0.78
Interior propellor shaft	7.22	7.22	0.09	0.52	0.52
Stabilizer support	18.68	18.68	0.24	0.02	0.06
Propellor mount top	22.56	22.56	0.29	0.02	0.04
Propellor mount bottom	22.56	22.56	0.29	0.03	0.06
Stabilizer (top)	4.67	4.67	0.06	0.09	0.09
Stabilizer (bottom)	4.67	4.67	0.06	0.04	0.04
Blades (left)	21.70	21.70	0.28	0.17	0.34
Blades (right)	21.70	21.70	0.28	0.17	0.34
Electronics + body assembly	3.54	3.54	0.05	0.00	0.00
Circuit board assembly	3.54	3.54	0.05	0.00	0.00
Circuit board	7.97	7.97	0.10	0.00	0.00
Wires - board to battery	17.87	17.87	0.23	0.00	0.00
Wires - board to LED	17.87	17.87	0.23	0.00	0.00

Original

December 9, 2020 IR helicopter.dfax

Name	Total cost per product without tooling, $	Assembly tool or fixture cost, $	Manufacturing tooling investment, $	Manufacturing tooling cost per item, $	Item cost per item, $
IR helicopter	9.44	0.00	607670.00		
Main body	0.05	0.00	0.00	0.00	0.00
Cockpit cover	0.12	0.00	28034.00	0.09	0.15
Shaft assembly	0.05	0.00	0.00	0.00	0.00
Shaft housing	0.11	0.00	13399.00	0.04	0.11
Large gear - inner shaft	0.13	0.00	39113.00	0.13	0.18
Large gear - outer shaft	0.13	0.00	39113.00	0.13	0.18
Small gear	0.34	0.00	78226.00	0.13	0.18
Small Shaft	1.41	0.00	18311.00	0.03	0.55
Gear box cover	0.12	0.00	39113.00	0.13	0.18
Exterior propellor shaft	0.87	0.00	6838.00	0.02	0.80
Interior propellor shaft	0.62	0.00	9155.00	0.03	0.55
Stabilizer support	0.31	0.00	17408.00	0.01	0.03
Propellor mount top	0.34	0.00	17528.00	0.03	0.05
Propellor mount bottom	0.35	0.00	18940.00	0.03	0.06
Stabilizer (top)	0.15	0.00	30526.00	0.10	0.19
Stabilizer (bottom)	0.10	0.00	21015.00	0.07	0.11
Blades (left)	0.63	0.00	18293.00	0.03	0.20
Blades (right)	0.63	0.00	18293.00	0.03	0.20
Electronics + body assembly	0.05	0.00	0.00	0.00	0.00
Circuit board assembly	0.05	0.00	0.00	0.00	0.00
Circuit board	0.10	0.00	0.00	0.00	0.00
Wires - board to battery	0.23	0.00	0.00	0.00	0.00
Wires - board to LED	0.23	0.00	0.00	0.00	0.00

Original
December 9, 2020 IR helicopter.dfax

Name	Item cost per product, $	Total cost, $	Notes
IR helicopter	5.93	11.46	
Main body	0.00	0.05	
Cockpit cover	0.15	0.22	
Shaft assembly	0.00	0.05	
Shaft housing	0.11	0.16	
Large gear - inner shaft	0.18	0.26	
Large gear - outer shaft	0.18	0.26	
Small gear	0.37	0.60	
Small Shaft	1.11	1.47	
Gear box cover	0.18	0.25	
Exterior propellor shaft	0.80	0.90	
Interior propellor shaft	0.55	0.65	
Stabilizer support	0.12	0.36	
Propellor mount top	0.10	0.40	
Propellor mount bottom	0.12	0.41	
Stabilizer (top)	0.19	0.25	
Stabilizer (bottom)	0.11	0.17	
Blades (left)	0.40	0.69	
Blades (right)	0.40	0.69	
Electronics + body assembly	0.00	0.05	
Circuit board assembly	0.00	0.05	
Circuit board	0.00	0.10	
Wires - board to battery	0.00	0.23	
Wires - board to LED	0.00	0.23	

Original

December 9, 2020

IR helicopter.dfax

Name	Part number	Repeat count	Total count	Minimum items	Minimum part criteria
Motor	24	1	1	1	Movement
Motor gear	25	1	1	0	Connector
LED	20	1	1	1	Different material
Battery	21	1	1	1	Different material
Left body piece	9	1	1	0	Fastener
Right body piece	10	1	1	0	Fastener
Back support	27	1	1	1	Assembly
Screws	8	9	9	0	Fastener
USB wire	28	1	1	0	Connector

DFMA® - Boothroyd Dewhurst, Inc.
Design for Assembly
Product Worksheet

Original

December 9, 2020 IR helicopter.dfax

Name	Process time per entry, s	Process time per product, s	Process cost per product, $	Piece part cost per item, $	Piece part cost per product
Motor	8.22	8.22	0.11	0.00	0.00
Motor gear	8.73	8.73	0.11	0.00	0.00
LED	8.18	8.18	0.11	0.00	0.00
Battery	6.93	6.93	0.09	0.00	0.00
Left body piece	6.19	6.19	0.08	0.03	0.03
Right body piece	6.19	6.19	0.08	0.03	0.03
Back support	9.72	9.72	0.13	0.13	0.13
Screws	89.03	89.03	1.16	0.00	0.00
USB wire	21.00	21.00	0.27	0.00	0.00

Original

December 9, 2020 IR helicopter.dfax

Name	Total cost per product without tooling, $	Assembly tool or fixture cost, $	Manufacturing tooling investment, $	Manufacturing tooling cost per item, $	Item cost per item, $
Motor	0.11	0.00	0.00	0.00	0.00
Motor gear	0.11	0.00	0.00	0.00	0.00
LED	0.11	0.00	0.00	0.00	0.00
Battery	0.09	0.00	0.00	0.00	0.00
Left body piece	0.11	0.00	76403.00	0.25	0.29
Right body piece	0.11	0.00	76403.00	0.25	0.29
Back support	0.26	0.00	41559.00	0.14	0.27
Screws	1.16	0.00	0.00	0.00	0.00
USB wire	0.27	0.00	0.00	0.00	0.00

Original

December 9, 2020 IR helicopter.dfax

Name	Item cost per product, $	Total cost, $	Notes
Motor	0.00	0.11	
Motor gear	0.00	0.11	
LED	0.00	0.11	
Battery	0.00	0.09	
Left body piece	0.29	0.37	
Right body piece	0.29	0.37	
Back support	0.27	0.39	
Screws	0.00	1.16	
USB wire	0.00	0.27	

C Handling & Insertion Analysis - Original Design

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LUCAS METHOD

Design For Assembly Worksheet

Product: IR Helicopter

	HANDLING ANALYSIS						INSERTION ANALYSIS							
ITEM #	**Component Name**	**A**	**B**	**C**	**D**	**Handling Sum**	**# of Items**	**A**	**B**	**C**	**D**	**E**	**F**	**Insertion Sum**
1	Cockpit Cover	1	0.6	0.1	0.2	1.9	1	2	0.1	0.7	0	0	0	2.8
2	Stabilizer Support	1.5	0.2	0.1	0.2	2	4	1.3	0.1	0.7	0	0.7	0.6	3.4*4=13.6
3a	Propellor Mount (Top)	1.5	0.2	0.1	0.1	1.9	2	2	0	1.2	1.5	0.7	0	5.4*2=10.8
3b	Propellor Mount (Bottom)	0.1	0.1	0.1	0.1	1.9	2	2	0	1.2	1.5	0.7	0	5.4*2=10.8
4	Stabilizer (Top)	1	0.2	0.1	0	1.3	1	1.3	0	0.7	1.5	0	0.6	4.1
5	Stabilizer (bottom	1	0.2	0	0	1.2	1	1.3	0	0.7	1.5	0	0.6	4.1
6	Blades (Left)	1	0.6	0.5	0.4	2.5	2	2	0	1.2	1.5	0.7	0	5.4
7	Blades (Right)	1	0.6	0.5	0.4	2.5	2	2	0	1.2	1.5	0.7	0	5.4
8	Screws	1.5	0.2	0.1	0	1.8	9	4	0.1	0	1.5	0.7	0.6	6.9*9=62.1
9	Left Body Piece	1	0.2	0.5	0.2	1.9	1	1.3	0.1	0.7	1.5	0	0.6	4.2
10	Right Body Piece	1	0.2	0.5	0.2	1.9	1	1.3	0.1	0.7	1.5	0	0.6	4.2
11	Gear Box Cover	1	0.2	0.1	0.2	1.5	1	1.3	0	0	1.5	0	0.6	3.4
12	Small Shaft	1.5	0.2	0	0	1.7	2	1	0	0	1.5	0.7	0	3.2*2=6.4
13	Small Gear	1.5	0.2	0.1	0	1.8	2	1.3	0	0	0	0	0.6	1.9*2=3.8

Product: IR Helicopter

		HANDLING ANALYSIS					***INSERTION ANALYSIS***							
ITEM #	**Component Name**	**A**	**B**	**C**	**D**	**Handling Sum**	**# of Items**	**A**	**B**	**C**	**D**	**E**	**F**	**Insertion Sum**
14	Large Gear	1	0.2	0.5	0.4	2.1	2	1.3	0	0	0	0	0.6	1.9*2=3.8
15	Motor Gear	1.5	0.2	0	0	1.7	1	2	1.3	0	0	0	0.6	1.9
15	Shaft Housing	1	0.2	0.5	0.4	2.1	1	2	0.1	1.2	0	0.7	0	4
16	Exterior Propellor Shaft	1	0.2	0.5	0	1.7	1	1	0	0	0	0	0	1
17	Interior Propellor Shaft	1	0.2	0.5	0	1.7	1	1	0	0	0	0	0	1
20	Electronics	1.5	0/8+0.7=1.5	0.5	0.4	3.9	1	2	1.6	1.2	1.5	0.7	0	7
21	Back Support	1	0.6	0.1	0.2	1.9	1	4	0.1	0.7	1.5	0.7	0	7
TOTAL						**39.73**								**209.9**

D Assembly Structure Flowchart - Original Design

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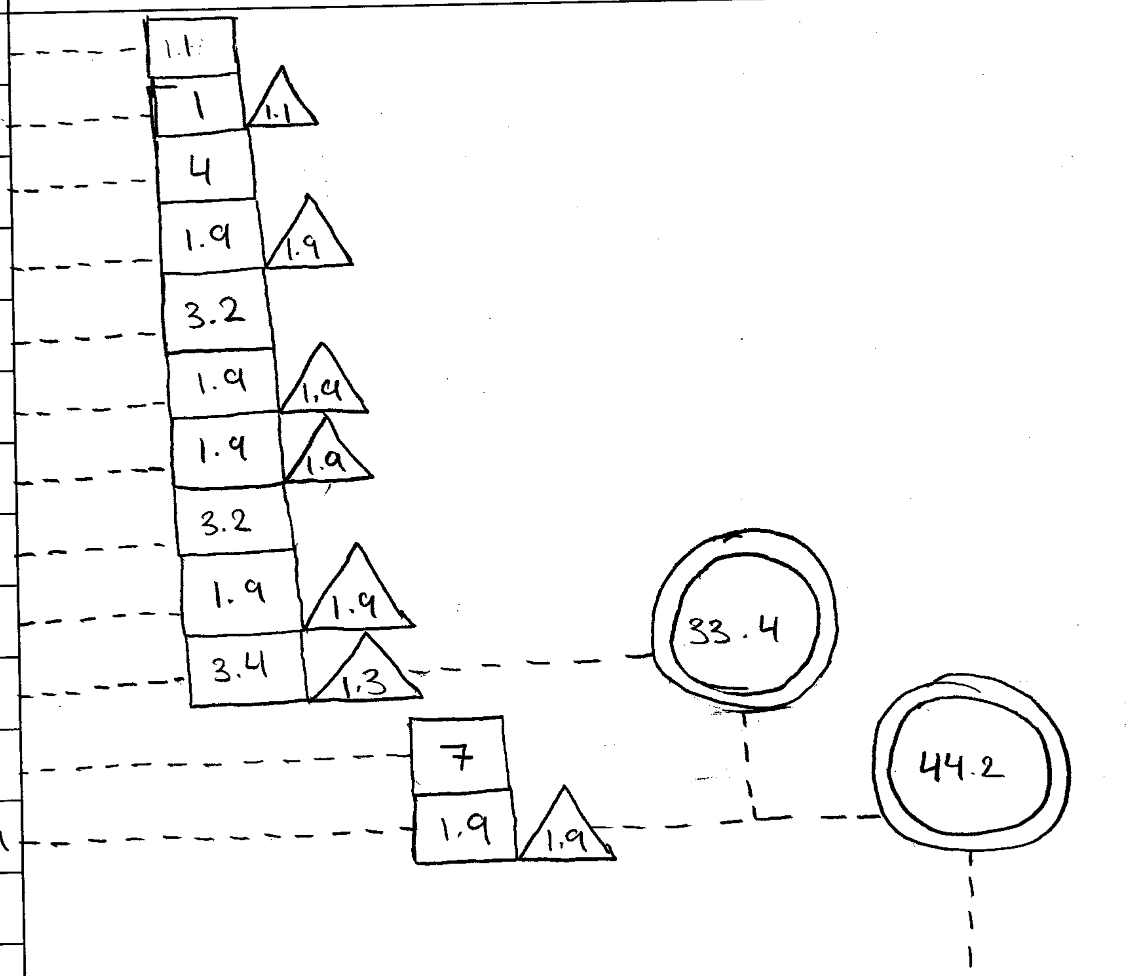
DESIGN FOR MANUFACTURE AND DESIGN FOR ASSEMBLY ANALYSIS CHART (AAC) / ASSEMBLY STRUCTURE FLOWCHART (ASF)

Product: IR Helicopter **System/Assembly:** Full Assembly

Repeated Process · Work Holding Process · Insertion Process · Non Assembly Process · Disassemble Or Remove Tool · Reassemble or Insert Tool · Sub Assembly Total · Assembly Total

Item #	Component Description	Quantity	Poka Yoke (Y/N)	Part Type (A/B)	Handling Analysis	NOTES
17	Interior Propellor Shaft	1	N	A	1	
16	Exterior Propellor Shaft	1	Y	A	1	Simillar to snap fit operation but not as difficult.
15	Shaft Housing	1	N	B	4	
14	Large Gear	1	Y	A	1.9	Gear is press fit to shaft
12	Small Shaft	1	N	B	3.2	
13	Small Gear	1	Y	A	1.9	Gear is press fit to shaft
14	Large Gear	1	Y	A	1.9	Gear is press fit to shaft
12	Small Shaft	1	N	B	3.2	
13	Small Gear	1	Y	A	1.9	Gear is press fit to shaft
11	Gearbox Cover	1	N	B	3.4	Gearbox Cover is snapfitted into place.
20	Electronics	1	N	A	7	
25	Motor Gear	1	N	A	1.9	Motor Gear is press fit to electronics.

Design Efficiency = 'A' Components / Total Components x 100% =

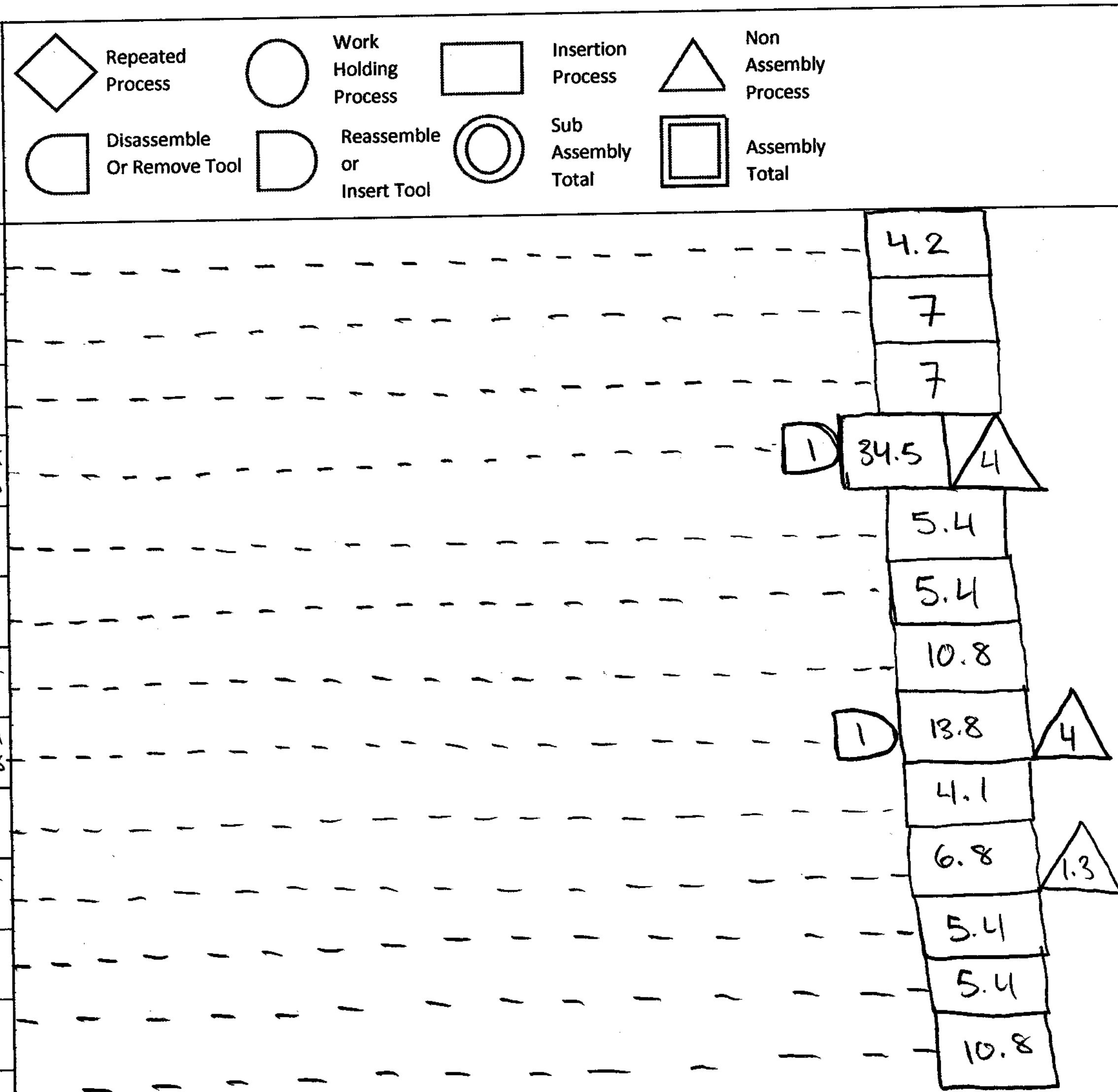


DESIGN FOR MANUFACTURE AND DESIGN FOR ASSEMBLY ANALYSIS CHART (AAC) / ASSEMBLY STRUCTURE FLOWCHART (ASF)

Product: 1R Helicopter **System/Assembly:** Full Assembly

Item #	Component Description	Quantity	Poka Yoke (Y/N)	Part Type (A/B)	Handling Analysis
9	Left Body Piece	1	N	B	4.2
21	Back Support	1	N	B	7
10	Right Body Piece	1	N	B	7
8	Screws	5	N	B	5x6.9 =34.5
3b	Propellor Mount (Bottom	1	N	B	5.4
3a	Propellor Mount (TOP)	1	N	B	5.4
7	Blades (Left)	2	N	A	5.4x2 =10.8
8	Screws	2	N	B	2x6.9 =13.8
5	Stabilizer (Bottom)	1	N	A	4.1
2	Stabilizer Support	2	N	B	3.4x2 6.8
3b	Propellor Mount (Bottom)	1	N	B	5.4
3a	Propellor Mount (TOP)	1	N	B	5.4
7	Blades	2	N	A	10.8

Design Efficiency = 'A' Components / Total Components x 100% =



NOTES

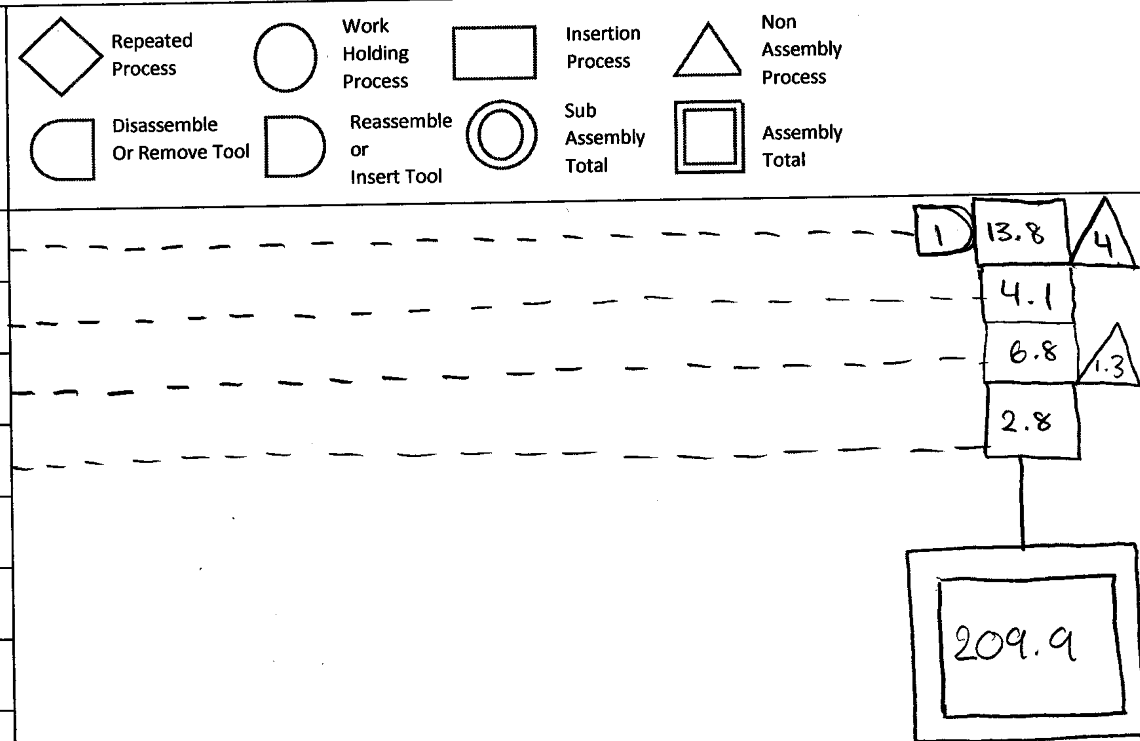
Stabilizer support snap fits to secure.

DESIGN FOR MANUFACTURE AND DESIGN FOR ASSEMBLY ANALYSIS CHART (AAC) / ASSEMBLY STRUCTURE FLOWCHART (ASF)

Product: IR Helicopter **System/Assembly:** Full Assembly

Item #	Component Description	Quantity	Poka Yoke (Y/N)	Part Type (A/B)	Handling Analysis
8	Screws	2	N	B	13.8
4	Stabilizer (Bottom)	1	N	A	4.1
2	Stabilizer Support	2	N	B	6.8
1	Cockpit Cover	1	N	B	2.8

Design Efficiency = 'A' Components / Total Components x 100% =



NOTES

E FMEA Analysis Worksheet

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Failure Mode and Effect Analysis Worksheet

System/ Function	Potential Failure Mode	Potential Effects of Failure Mode	Severity	Potential Causes of Failure	Occurrence	Current Controls (Prevention Steps)	Current Controls (Detection Steps)	Detection	Actions to Be Taken	RPN
UI/receive input from user's hand	Doesn't detect user's hand	No response from the user's palm	8	IR interference, or IR sensor became loose from circuit board	3	Assess QC steps, in relation to soldering or testing interference levels	Sample testing for IR sensors for interference	1	-Supplier visit -Quality testing -New supplier	24
UI/allow input for recharging	Charger cable doesn't charge device	USB cable doesn't connect through connector, or it does but battery doesn't charge	8	Circuit board out of alignment, concealing charge port, or connection between circuit board and battery loose.	2	Assess assembly steps in relation to soldering or inspection processes	Automated vision system detecting charge port visibility	3	-Talk to workers on the shop floor about soldering techniques	48
Power/ Increase throttle when palm is detected	Motor doesn't respond to IR input	Detects palm, but doesn't change elevation	8	Speed controller on circuit board overrides the motor to failure	3	Strain gage testing on circuit board, and power testing on motor	Short fuses on circuit board to limit power	4	-Stress test more motor components, and talk to supplier about QC issues	96
Exterior Body/ Hold parts together	Interior parts fall out of body piece	Body piece fractures after collision, leaving interior parts exposed	7	Screws shears or loosens during collision	3	Assessing screwing operations during assembly	Small drop or impact test on a sample	5	Design body piece with less cavities to prevent fracture, consider other methods of enclosure like snap on fitting	105

NOTES: 1. Identify at least 3 potential Failure Modes for your product **2.** Complete the table rows for those 3 Failure Modes

F B-D DFMA Charts - Redesign

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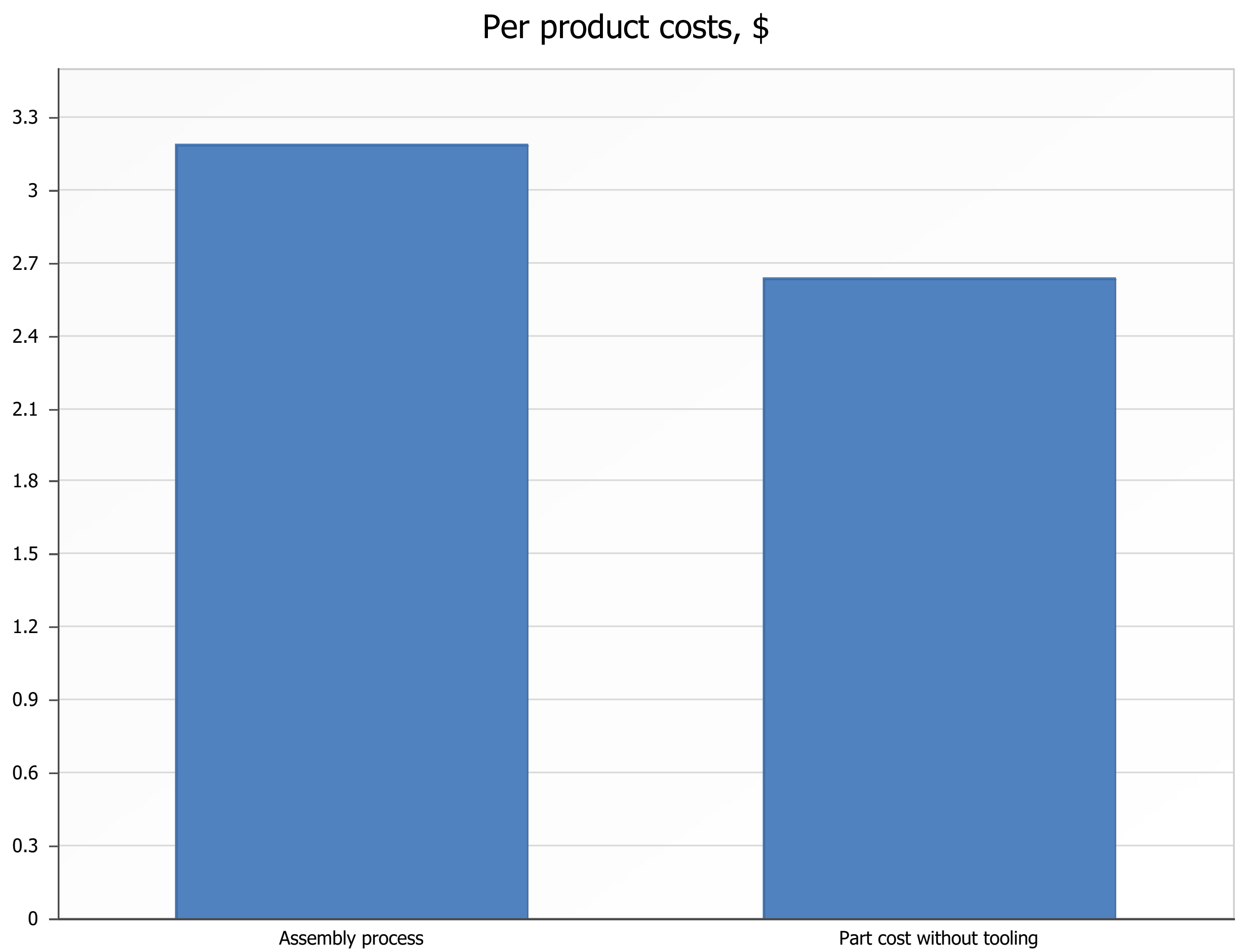
Analysis Totals for Design for Manufacture and Assembly (DFMA)

December 9, 2020

IR helicopter - redesign.dfax

Per product costs, $	Original
Assembly process	3.18
Part cost without tooling	2.63
Total cost without tooling	5.81

Production life data and weight	
Life volume	300,000
Total weight, kg	0.37



DFMA® - Boothroyd Dewhurst, Inc.

Design for Assembly
Product Worksheet

Original

December 9, 2020

IR helicopter - redesign.dfax

Name	Part number	Repeat count	Total count	Minimum items	Minimum part criteria
IR helicopter			33	12	
Main body		1	1		
Cockpit cover	1	1	1	1	Assembly
Shaft assembly		1	1		
Shaft housing	15	1	1	1	Base part
Large gear - inner shaft	14a	1	1	0	Connector
Large gear - outer shaft	14b	1	1	0	Connector
Small gear	13	2	2	0	Connector
Exterior propellor shaft	16	1	1	1	Movement
Interior propellor shaft	17	1	1	1	Movement
Stabilizer support	2	4	4	0	Connector
Propellor mount bottom	3b	2	2	0	Fastener
Stabilizer (top)	4	1	1	1	Assembly
Stabilizer (bottom)	5	1	1	1	Assembly
Blades (left)	6	2	2	2	Different material
Blades (right)	7	2	2	2	Different material
Electronics + body assembly		1	1		
Circuit board assembly		1	1		
Circuit board	22	1	1	0	Connector
Wires - board to battery	26a	2	2	0	Connector
Motor	24	1	1	1	Movement
Motor gear	25	1	1	0	Connector
Battery	21	1	1	1	Different material
Left body piece	9	1	1	0	Fastener

Name	Process time per entry, s	Process time per product, s	Process cost per product, $	Piece part cost per item, $	Piece part cost per product
IR helicopter		243.36	3.18		2.63
Main body	3.54	3.54	0.05	0.00	0.00
Cockpit cover	4.95	4.95	0.06	0.06	0.06
Shaft assembly	3.54	3.54	0.05	0.00	0.00
Shaft housing	3.54	3.54	0.05	0.07	0.07
Large gear - inner shaft	5.83	5.83	0.08	0.05	0.05
Large gear - outer shaft	5.83	5.83	0.08	0.05	0.05
Small gear	17.53	17.53	0.23	0.05	0.11
Exterior propellor shaft	7.22	7.22	0.09	0.78	0.78
Interior propellor shaft	7.22	7.22	0.09	0.52	0.52
Stabilizer support	18.68	18.68	0.24	0.02	0.06
Propellor mount bottom	22.56	22.56	0.29	0.03	0.06
Stabilizer (top)	4.67	4.67	0.06	0.09	0.09
Stabilizer (bottom)	4.67	4.67	0.06	0.04	0.04
Blades (left)	21.70	21.70	0.28	0.17	0.34
Blades (right)	21.70	21.70	0.28	0.17	0.34
Electronics + body assembly	3.54	3.54	0.05	0.00	0.00
Circuit board assembly	3.54	3.54	0.05	0.00	0.00
Circuit board	7.97	7.97	0.10	0.00	0.00
Wires - board to battery	17.87	17.87	0.23	0.00	0.00
Motor	8.22	8.22	0.11	0.00	0.00
Motor gear	8.73	8.73	0.11	0.00	0.00
Battery	6.93	6.93	0.09	0.00	0.00
Left body piece	6.19	6.19	0.08	0.03	0.03

DFMA® - Boothroyd Dewhurst, Inc.
Design for Assembly
Product Worksheet

Original

December 9, 2020 IR helicopter - redesign.dfax

Name	Total cost per product without tooling, $	Assembly tool or fixture cost, $	Manufacturing tooling investment, $	Manufacturing tooling cost per item, $	Item cost per item, $
IR helicopter	5.81	0.00	491159.00		
Main body	0.05	0.00	0.00	0.00	0.00
Cockpit cover	0.12	0.00	28034.00	0.09	0.15
Shaft assembly	0.05	0.00	0.00	0.00	0.00
Shaft housing	0.11	0.00	13399.00	0.04	0.11
Large gear - inner shaft	0.13	0.00	39113.00	0.13	0.18
Large gear - outer shaft	0.13	0.00	39113.00	0.13	0.18
Small gear	0.34	0.00	78226.00	0.13	0.18
Exterior propellor shaft	0.87	0.00	6838.00	0.02	0.80
Interior propellor shaft	0.62	0.00	9155.00	0.03	0.55
Stabilizer support	0.31	0.00	17408.00	0.01	0.03
Propellor mount bottom	0.35	0.00	18940.00	0.03	0.06
Stabilizer (top)	0.15	0.00	30526.00	0.10	0.19
Stabilizer (bottom)	0.10	0.00	21015.00	0.07	0.11
Blades (left)	0.63	0.00	18293.00	0.03	0.20
Blades (right)	0.63	0.00	18293.00	0.03	0.20
Electronics + body assembly	0.05	0.00	0.00	0.00	0.00
Circuit board assembly	0.05	0.00	0.00	0.00	0.00
Circuit board	0.10	0.00	0.00	0.00	0.00
Wires - board to battery	0.23	0.00	0.00	0.00	0.00
Motor	0.11	0.00	0.00	0.00	0.00
Motor gear	0.11	0.00	0.00	0.00	0.00
Battery	0.09	0.00	0.00	0.00	0.00
Left body piece	0.11	0.00	76403.00	0.25	0.29

DFMA® - Boothroyd Dewhurst, Inc.

Design for Assembly
Product Worksheet

Original

December 9, 2020 | IR helicopter - redesign.dfax

Name	Item cost per product, $	Total cost, $	Notes
IR helicopter	4.27	7.45	
Main body	0.00	0.05	
Cockpit cover	0.15	0.22	
Shaft assembly	0.00	0.05	
Shaft housing	0.11	0.16	
Large gear - inner shaft	0.18	0.26	
Large gear - outer shaft	0.18	0.26	
Small gear	0.37	0.60	
Exterior propellor shaft	0.80	0.90	
Interior propellor shaft	0.55	0.65	
Stabilizer support	0.12	0.36	
Propellor mount bottom	0.12	0.41	
Stabilizer (top)	0.19	0.25	
Stabilizer (bottom)	0.11	0.17	
Blades (left)	0.40	0.69	
Blades (right)	0.40	0.69	
Electronics + body assembly	0.00	0.05	
Circuit board assembly	0.00	0.05	
Circuit board	0.00	0.10	
Wires - board to battery	0.00	0.23	
Motor	0.00	0.11	
Motor gear	0.00	0.11	
Battery	0.00	0.09	
Left body piece	0.29	0.37	

Name	Part number	Repeat count	Total count	Minimum items	Minimum part criteria
Right body piece	10	1	1	0	Fastener
USB wire	28	1	1	0	Connector

Name	Process time per entry, s	Process time per product, s	Process cost per product, $	Piece part cost per item, $	Piece part cost per product
Right body piece	6.19	6.19	0.08	0.03	0.03
USB wire	21.00	21.00	0.27	0.00	0.00

Original

December 9, 2020

IR helicopter - redesign.dfax

Name	Total cost per product without tooling, $	Assembly tool or fixture cost, $	Manufacturing tooling investment, $	Manufacturing tooling cost per item, $	Item cost per item, $
Right body piece	0.11	0.00	76403.00	0.25	0.29
USB wire	0.27	0.00	0.00	0.00	0.00

Name	Item cost per product, $	Total cost, $	Notes
Right body piece	0.29	0.37	
USB wire	0.00	0.27	

G Handling & Insertion Anaylsis - Redesign

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LUCAS METHOD

Design For Assembly Worksheet

Product: IR Helicopter Redesign

SHEET 1 of 1

		HANDLING ANALYSIS					INSERTION ANALYSIS							
ITEM #	**Component Name**	**A**	**B**	**C**	**D**	**Handling Sum**	**# of Items**	**A**	**B**	**C**	**D**	**E**	**F**	**Insertion Sum**
1	Cockpit Cover	1	0.6	0.1	0.2	1.9	1	2	0.1	0.7	0	0	0	2.8
2	Stabilizer Support	1.5	0.2	0.1	0.2	2	4	1.3	0.1	0.7	0	0.7	0.6	3.4*4=13.6
3	Propellor Mount	1	0.0	0	0	1.0	2	1	0	0	0	0	0	1*2=2
4	Stabilizer (Top)	1	0.2	0.1	0	1.3	1	1.3	0	0.7	1.5	0	0.6	4.1
5	Stabilizer (Bottom)	1	0.2	0	0	1.2	1	1.3	0	0.7	1.5	0	0.6	4.1
6	Blades (Left)	1	0.6	0.5	0.4	2.5	2	2	0	1.2	1.5	0.7	0	5.4*2=10.8
7	Blades (Right)	1	0.6	0.5	0.4	2.5	2	2	0	1.2	1.5	0.7	0	5.4*2=10.8
8	Left Body Piece w/ Integrated Back Support	1	0.2	0.5	0.2	1.9	1	1.3	0.1	0.7	1.5	0	0.6	4.2
9	Right Body Piece w/ Integrated Back Support	1	0.2	0.5	0.2	1.9	1	1.3	0.1	0.7	1.5	0	0.6	4.2
10	Gear Box Cover	1	0.2	0.1	0.2	1.5	1	1.3	0	0	1.5	0	0.6	3.4
11	Small Gear w/ Shaft Moulded In	1.5	0.2	0.1	0	1.8	2	1	0	0	0	0	0	1*2=2

Product: IR Helicopter

		HANDLING ANALYSIS					*INSERTION ANALYSIS*							
ITEM #	**Component Name**	**A**	**B**	**C**	**D**	**Handling Sum**	**# of Items**	**A**	**B**	**C**	**D**	**E**	**F**	**Insertion Sum**
12	Large Gear	1	0.2	0.5	0.4	2.1	2	1.3	0	0	0	0	0.6	1.9*2=3.8
13	Motor Gear	1.5	0.2	0	0	1.7	1	2	1.3	0	0	0	0.6	1.9
14	Shaft Housing	1	0.2	0.5	0.4	2.1	1	2	0.1	1.2	0	0.7	0	4
15	Exterior Propellor Shaft	1	0.2	0.5	0	1.7	1	1	0	0	0	0	0	1
16	Interior Propellor Shaft	1	0.2	0.5	0	1.7	1	1	0	0	0	0	0	1
17	Electronics	1.5	0/8+0.7=1.5	0.5	0.4	3.9	1	1	1.6	0.7	1.5	0.7	0	5.0
TOTAL						**33**								**79.2**

H Assembly Structure Flowchart - Redesign

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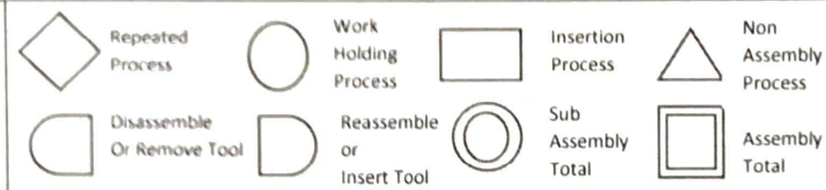
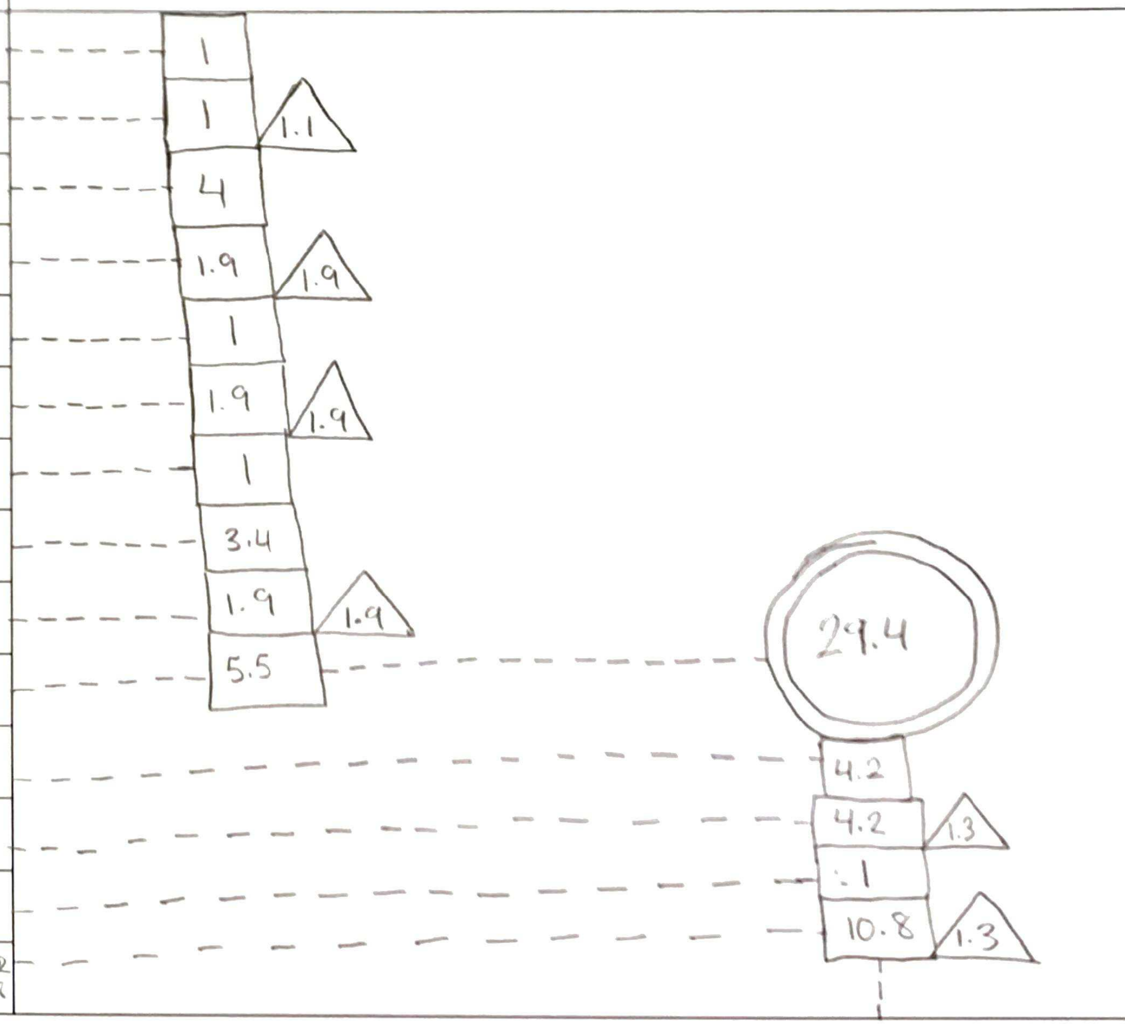
DESIGN FOR MANUFACTURE AND DESIGN FOR ASSEMBLY ANALYSIS CHART (AAC) / ASSEMBLY STRUCTURE FLOWCHART (ASF)

Product: IR Helicopter (Redesign)   System/Assembly: Full Assembly



Item #	Component Description	Quantity	Poka Yoke (Y/N)	Part Type (A/B)	Handling Analysis
16	Interior Propeller Shaft	1	N	A	1
15	Exterior Propeller Shaft	1	Y	A	1
14	Shaft Housing	1	N	B	4
12	Large Gear	1	Y	A	1.9
11	Small Gear	1	Y	A	1
12	Large Gear	1	Y	A	1.9
11	Small Gear	1	Y	A	1
10	Gear box Cover	1	N	B	3.4
13	Motor Gear	1	N	A	1.9
17	Electronics	1	N	A	5.5
8	Left Body Piece	1	N	B	4.2
9	Right Body Piece	1	N	B	4.2
3	Propeller Mount	1	N	B	1
6	Blades (Left)	2	N	A	5.4x2 =10.8



NOTES

DESIGN FOR MANUFACTURE AND DESIGN FOR ASSEMBLY ANALYSIS CHART (AAC) / ASSEMBLY STRUCTURE FLOWCHART (ASF)

Product: IR Helicopter (Redesign)   System/Assembly: Full Assembly

Item #	Component Description	Quantity	Poka Yoke (Y/N)	Part Type (A/B)	Handling Analysis	NOTES
5	Stabalizer (Bottom)	1	N	B	4.1	
2	Stabalizer Support	1	N	B	3.4x2 =6.8	
3	Propellor Mount	1	N	B	1	
7	Blades Right	1	N	B	5.4x2 =10.8	
4	Stabalizer (Top)	1	N	B	4.1	
2	Stabalizer Support	2	N	B	3.4x2= 6.8	
1	Cockpit Cover	1	N	B	2.8