NAU NORTHERN ARIZONA UNIVERSITY
Mechanical Engineering

Team 19F11
Micro Aero - Prop Dogs

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Subject: Implementation 2 Memo

0 Introduction

The purpose of our senior capstone is to design and manufacture a small fixed-wing aircraft that can compete in the SAE Aero Micro competition. The most difficult engineering requirements to complete were to create an aircraft that can fit in the correct volume of a storage box, and assembling the aircraft in the time requirement of three minutes. The objectives of this memo are to provide a detailed description of our manufacturing process from week 7 to week 11. This memo also contains a detailed description of the manufacturing steps taken, design changes, standards, codes, and regulations that the team must adhere to in order to fulfill the engineering requirements of the competition, and finally a risk mitigation analysis. These topics will detail why we manufactured a certain way and how we anticipated design failures.

1 Implementation – Weeks 7-11

The implementation process from mid February to late March essentially revolved around completing the aircraft completely. This entails finishing the final design of the aircraft as well as completing all the necessary testing procedures. The majority of the manufacturing for the project occurred during the weeks prior to this, so the design changes will include additional information regarding proposed future design changes. During the specified weeks the group focused on the testing procedures and the presentation that was due during week 8. The manufacturing process ended prior to spring break because we were waiting for the parts that were ordered to arrive, and then we were unable to meet and repair the aircraft.

1.1 Manufacturing

The final components of the manufacturing process that we needed to complete were the finalized rudder/empennage design and finalizing the application of a thin film over the exterior of the aircraft in order for a lift force that can be applied to the undercarriage of the aircraft. This process based on the brand we used will be referenced as Monokoting. The empennage is connected to the carbon fiber rod and the tail wing by several M3 bolts. All the bolts for the construction of the aircraft are the same diameter, but different lengths due to how it's utilized. Some bolts are inserted through a thin layer of balsa wood, i.e. the tail wing, but for the carbon fiber rod the bolt is through two layers of ABS and a 3/8th inch carbon fiber rod. This simplifies the assembly time because each team member will have their own bolts that are the same size, but not necessarily the same length; this limits the amount of error while assembling.

Figure 1: Completed Assembly

1.2 Design Changes - Weeks 7-11 & Future Design Changes

In the weeks 7-11 there were little design changes because the finalized design for the first complete iteration was concluded. Besides small experimental tests that concluded that monokoting would work on the balsa wood and boring holes in the rudder and empennage design to simplify the construction of the aircraft for the M3 bolts.

1.2.1 Design Iteration 1: Change in Monokoting discussion

When conducting the research on how to apply the Monokote to different materials there were several "how to" videos, but we realized that nothing applied to our case, which was laying a layer of the film over the entire outer surface of the aircraft. This included suspending the film over a two inch gap where the ribs of the wing segments were located. The realization of a problem occurred when first applying a sheet.

We first attempted a top and bottom coat of Monokote around the wing segments, but this could become futile if the two sheets of film did not meld together. It is significantly easier to iron two sides to blend the edges together than trying to do that twice on different parts of the wing segment. The Tail Edge (TE) of the airfoil of the wings, shown in Figure 2, were constructed, so there was a solid component between the ribs that the Monokote could tack onto.

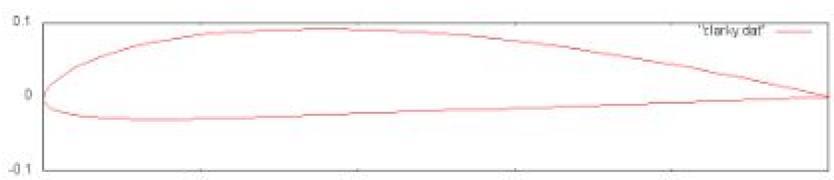

Figure 2: Clark Y Airfoil Image

That is where the start and the end of the Monokote segment was in relation to the wing segment. This simplified the process because aftering ironing the first beginning segment of the Monokote down, then after wrapping the film around the entirety of the aircraft and tightening it significantly then the final edge would be tacked down in the same location, which turns out to be the flattest part of the airfoil . This was a lot more ergonomic than the previous method because in order for the majority of the Monokoting work to be accomplished only two edge would need to be tacked down to one location rather than cutting out two different sheets and tacking down four separate edges, hoping that the plastic film would bind together.

2 Standards, Codes, and Regulations

For this project there are codes and standards that are necessary to be practiced to ensure safety. The first code listed below in Table 3 is provided by the Academy of Model Aeronautics (AMA). The code is titled Devices Academy of Model Aeronautics National Model Aircraft Safety Code and lays out basic safety regulations including; not flying in a careless or reckless manner, flying over unprotected people, vehicles, and occupied structures, etc. The second code on Table 3 provided by the Society of automotive engineers (SAE) is the 2020 SAE Aero design rules. This rule book is the backbone of our design and by following all of the rules which are our customer requirements the team will be successful when it comes to the time of competition. The last code on the list comes from the International Electrotechnical Commission (IEC). This code gives basic safety guidelines when using lithium batteries such as making sure to test batteries for over discharge to avoid explosion. By following each of these standards and codes the team will not only be successful in competition but ensure safety throughout the duration of the project.

2.1 Standards applied to project

Table 1: Standards

Standard Number or Code	Title of Standard	How it applied to Project
AMA	Devices Academy of Model Aeronautics National Model Aircraft Safety Code	Helps in ensuring safety while flying and prepping the plane before flight. Referenced during test flight.
SAE	2020 Collegiate Design Series SAE Aero Design Rules	All rules and regulations for competition.
IEC 60086-4 Ed. 5.0 b:2019	Primary Batteries - Part 4: Safety Of Lithium Batteries	Gives precautions to ensure safety while using lithium batteries.

3 Risk Analysis and Mitigation

The purpose of this section is to describe how our team mitigated potential failures based on design and manufacturing decisions. In this section, several failure modes from the fall and spring semesters are identified and analyzed using a failure modes and effects analysis (FMEA). Finally, this section explains how the identified failure modes were mitigated in the manufacturing process.

3.1 Potential Failures Identified Fall Semester

Given the final aircraft design from Fall 2019, a complete and comprehensive list of 40 potential failure modes were identified and analyzed using an FMEA system. Our team identified failure modes by separating each mode into groups based on subsystems. For instance, 10 potential failures were identified for the drive subsystem. Next, each failure mode was rated from 1-10 (10 being the greatest) in terms of severity, likelihood of occurrence, and lack of detection. The severity, occurrence, and detection scores were multiplied together for each mode to yield the risk priority number (RPN). Finally, the top 10 RPN scores defined the critical failure modes of the plane. The critical failure modes gathered from the FMEA are shown below in Tables 2 and 3. The complete FMEA is found in Appendix Table A1.

Table 2: Critical Failures FMEA (Part 1)

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure
Landing Gear Frame	Buckling	Shrapnel flying when landing	5	Length of landing gear is too long for loading
Motor	Improper Discharge	Aircraft falling out of the sky	5	Motor is too powerful for the battery
Propeller	Buckling of Landing Gear	Shrapnel flying when landing	5	Landing gear buckles enough for the prop to break
Ailerons	Wiring Connection Failure	Aircraft falling out of the sky	4	Assembly/Building Errors
Rudder	Wiring Connection Failure	Aircraft falling out of the sky	4	Assembly/Building Errors
Battery	Improper Discharge	Aircraft falling out of the sky	3	Overcharged battery
Main Cabin to landing gear connector	Fastener failure	Debris falling from the sky	3	Tolerance Buildup
Propeller	Crack	Aircraft falling out of the sky	3	Tolerance Buildup
Empennage	Fracture	Aircraft falling out of the sky	3	Tolerance Buildup
Tail Dragger and front landing gear	Failure to withstand landing force	Shrapnel flying when landing	3	Flexion to do placement of aluminum connectors

Table 3: Critical Failures FMEA (Part 2)

Part # and Functions	Occurance (O)	Detection (D)	RPN	Rank	Recommended Action
Landing Gear Frame	6	4	120	1	Brace landing gear
Motor	3	7	105	2	Limit throttle to 75%
Propeller	5	4	100	3	Replace propeller
Ailerons	4	6	96	4	Use servo wire connectors
Rudder	4	6	96	5	Use servo wire connectors
Battery	3	7	63	6	Limit throttle to 75%
Main Cabin to landing gear connector	4	4	48	7	Bolted connection
Propeller	4	4	48	8	Replace propeller
Empennage	3	5	45	9	Monokote empennage
Tail Dragger and front landing gear	3	5	45	10	Oversize landing gears

As shown above in Tables 2 and 3, some of the critical failure modes result in the plane breaking upon landing. The other critical failures will result in the aircraft falling out of the sky, which is even more catastrophic. To mitigate these failures, the reasons for failure and design recommendations were identified. Through research, each of the critical failure mechanisms, or the reason for each failure, were applied to each mode. Given these mechanisms for failure, a recommended course of action was applied to each failure mode. These design recommendations will help to mitigate failures from occurring. Despite design changes made during the manufacturing process, no new failure modes were identified prior to the final product completion and conducting tests on the plane.

3.2 Risk Mitigation

Previously mentioned above, a recommended action to address each critical failure was identified. In order to mitigate failures, some of the recommended actions were followed. First, to prevent the front and rear landing gears from failing (rank 1 and 10 in Table 3), the landing gears were designed at 1.5 times the original size. The trade off with bracing the front landing gear was that the propeller was more likely to contact the brace. So, in order to mitigate the front and rear landing gear failures, both landing gears were oversized. Furthermore, a bolted connection was applied to both landing gears to ensure the connection between the plane and landing gears did not fail (rank 7). The three landing gear critical failures were mitigated, shown in Figure 3.

Figure 3: Oversized Landing Gears with Bolted Connections

Next, to prevent the motor and battery from failing (rank 2 and 6 in Table 2), the throttle must be limited to 75% when flying. The trade off with limiting the throttle to 75% is that the thrust and lift are also limited. However, limited thrust is acceptable, given the battery and motor would catch on fire if overloaded. If the motor is limited to 75% throttle, the battery discharge is well below the 70C rating. The battery and motor loading conditions are shown below in Table 4.

Table 4: Battery Loading

Battery	
Load:	24.15 C
Voltage:	10.04 V
Rated Voltage:	11.10 V
Energy:	19.98 Wh
Total Capacity:	1800 mAh
Used Capacity:	1530 mAh
min. Flight Time:	2.1 min
Mixed Flight Time:	4.7 min

Third, two forms of propeller failure exist due to crack propagation and contact with the ground/landing gear (rank 3 and 8 in Table 3). The recommended action for this failure mode was to simply replace the propeller because propellers are easy to replace and low cost. No trade offs or risks are associated with this action.

Fourth, the ailerons and rudder critical failures (rank 4 and 5 in Table 3) were caused due to wiring connections. Servo wire connectors were used to mitigate this failure. The servo wire connectors are shown in Figure 3 above. Finally, the empennage failure mode was addressed by monokoting the tail wing, which is also shown in Figure 3. No trade offs or risks are associated with servo wire connectors and monokoting the tail wing.

4 Appendices

4.1 Appendix A: FMEA

Table A1: Full FMEA

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Detection (D)	RPN
Subsystem 1: Drive							
ESC	Improper Transfer of Voltage/Current	Aircraft falling out of the sky	2	Wiring issue	2	8	32
Propeller	Crack	Aircraft falling out of the sky	3	Tolerance Buildup	4	4	48
Propeller	Shaft Displacement	Aircraft falling out of the sky	2	Propeller rotates too fast	2	3	12
Propeller	Fracture	Aircraft falling out of the sky	2	Tolerance Buildup	4	3	24
Battery	Improper Discharge	Aircraft falling out of the sky	3	Overcharged battery	3	7	63
Motor	Deforms Propeller	Aircraft falling out of the sky	4	ESC transfer error to the motor	2	2	16
Motor	Improper Discharge	Aircraft falling out of the sky	5	Motor is too powerful than the battery	3	7	105
Wiring	Connection failure	Aircraft falling out of the sky	4	User error	2	2	16
Drive	Overheating	Aircraft falling out of the sky	6	Rapid testing with no substitution	2	3	36
ESC	Magnetized Interference	Aircraft falling out of the sky	2	ESC is too close to the battery	1	10	20
Subsystem 2: Fuselage							
Main Cabin	Overheating	Debris falling from the sky	6	Drive system heats up corresponding area	2	3	36
Main Cabin	Improper Weight Distibution	Debris falling from the sky	3	Center of Gravity it too far forward	4	2	24
Main Cabin	Fracture	Debris falling from the sky	4	Tolerance Buildup	3	3	36
Main Cabin to Wings	Adhesive failure	Debris falling from the sky	2	Lack of adhesive	3	5	30
Main Cabin to base rod	Adhesive failure	Debris falling from the sky	2	Lack of adhesive	3	5	30
Main Cabin to Payload	Fastener deflection	Debris falling from the sky	3	Payload is too heavy	2	4	24
Main Cabin landing gear	Fastener failure	Debris falling from the sky	3	Tolerance Buildup	4	4	48
Main Cabin to landing gear	Fracture	Debris falling from the sky	3	Tolerance Buildup	5	3	45
Main Cabin to shaft	Fastener failure	Debris falling from the sky	3	Tolerance Buildup	3	4	36
Main Cabin to propeller	Interference	Debris falling from the sky	2	Propeller cannot withstand certain conditions	2	8	32

Subsystem 3: Wings								
Wings	Crack	Aircraft falling out of the sky	3	Tolerance Buildup	3	3	27
Wings	Frame Buckling	Aircraft falling out of the sky	4	Landing	2	2	16
Wings	Adhesive failure	Aircraft falling out of the sky	2	Lack of adhesive	2	4	16
Wings	Hinge Disconnection	Aircraft falling out of the sky	3	Assembly/Building Errors	3	2	18
Rear Tail	Fracture	Aircraft falling out of the sky	3	Tolerance Buildup	3	5	45
Rear Tail	Spins uncontrollably	Aircraft falling out of the sky	3	Tail Heavy	3	4	36
Ailerons	Wiring Connection Failure	Aircraft falling out of the sky	4	Assembly/Building Errors	4	6	96
Rudder	Wiring Connection Failure	Aircraft falling out of the sky	4	Assembly/Building Errors	4	6	96
Rear Tail	External Forces (Wind)	Aircraft falling out of the sky	2	Area of the tail in addition to the cross wind	2	4	16
Wings	Fastener Disconnection	Aircraft falling out of the sky	2	Assembly Error	3	5	30
Subsystem 4: Landing Gear								
Wheels	Condenses	Shrapnel flying when landing	3	Wheels cannot withstand weight	1	3	9
Frame	Buckling	Shrapnel flying when landing	5	Aluminum wiring/connectors fail	6	4	120
Frame	Detaches from Fuselage	Shrapnel flying when landing	3	Worn Adhesive or fastener failure	4	3	36
Wheels	Crack	Shrapnel flying when landing	2	Landing on uneven terrain	1	4	8
Frame	Compresses	Shrapnel flying when landing	2	Landing force	2	4	16
Wheels	Unable to Rotate	Shrapnel flying when landing	2	TIght non-lubed Wheels	2	1	4
Tail Dragger	Collapses before front wheels land	Shrapnel flying when landing	3	Aluminum alloy connector can't withstand force	3	4	36
Propeller	Buckling of Landing Gear	Shrapnel flying when landing	5	Landing gear buckles enough for the prop to break	5	4	100
Controllability	Landing Gear is offset - Crash	Shrapnel flying when landing	4	Landing Gear/Wheels are not level	2	2	16
Tail Dragger and front landing gear	Failure to withstand landing force	Shrapnel flying when landing	3	Flexion to do placement of aluminum connectors	3	5	45