Introduction

The purpose of this report is to outline the testing procedures that the SAE Aero Micro team will be conducting in order to showcase how the testing procedures meet the design and customer requirements. The customer and design requirements will be outlined, and a detailed testing plan will be presented, including how each requirement will be met through the tests presented.

Project Description

The purpose of the SAE Aero Micro team is to create a remote-control airplane that can carry a payload and meet the design requirements of the SAE Aero Micro competition. Some of the main requirements of the competition are to take off within 8 feet, be driven by an electric motor, and have a maximum wingspan of 48 inches. This project is sponsored by W.L. Gore, and Northern Arizona University Mechanical Engineering Department. The team is advised by Dr. David Willy who is a professor at Northern Arizona University.

Design Requirements

The customer needs and design requirements are directly connected to the teams QFD (Appendix A). The design requirements were created directly from the customer needs, that come from the competition rules and regulations.

Table 1: Engineering Requirements

Ranking	Engineering Requirements (ER)	Units
ER1	Light weight	Pounds
ER2	Increase Reliability	Percentage
ER3	Increase Durability	Percentage
ER4	Power limiter	Watts
ER5	Cargo Bay volume	Inches Cubed
ER6	Low Cost	US Dollars
ER7	Increase impact tolerance	Crashes before repair
ER8	48-inch Wingspan	Inch
ER9	Lift Forces	Pounds
ER10	Drag Forces	Pounds
ER11	Thrust	Pounds
ER12	Ground turning radius	Inches
ER13	Payload unloading time	Seconds
ER14	Low control surface slop	Degrees
ER15	Must have 4 cells or less battery for the electronics	Number of cells
ER16	Adequate servo sizing for aerodynamic forces	Ounces/inch
ER17	Must use 2.4 GHz radio control system	GHz
ER18	Must land within 200ft	Feet
ER19	Takeoff within 8 feet	Feet
ER20	Cannot exceed 55 pounds	Pounds
ER21	Optimize safety factor	Factor of Safety
ER22	Meets SAE Rules and Regulations	Percentage

Table 2: Customer Requirements

Ranking	Customer Requirements
CR1	Meets the requirement of the rules
CR2	Safe design
CR3	Able to take off and land
CR4	Innovative Design
CR5	Manufacturable
CR6	Low cost
CR7	Modular compatibility
CR8	Static load capability
CR9	60 second lift-off time limit
CR10	200 feet landing distance
CR11	Payload extraction in one minute or less
CR12	Use of Lithium Polymer Batteries
CR13	Use of Power limiter (450-Watts)
CR14	Must have one cargo bay
CR15	Ability to make a turn in air
CR16	Ability to make a turn on the ground
CR17	Steering mechanism for landing gear
CR18	Must use an Electric motor
CR19	Fixed Wing
CR20	Functional failsafe for radio control systems
CR21	Must be equipped with a red arming plug
CR22	Must use model airplane safety nut
CR23	Appropriate center of gravity
CR24	Must have a radio control system

Top Level Testing

Experiment/Tests	Relevant DR's
Generated Thrust Test	ER11, ER19, CR3, CR10
Generated Lift Test	ER9, ER19, CR3, CR10
Takeoff/Flight Test	ER9, ER10, ER14, ER19, CR3, CR8, CR9, CR15, CR23
Payload Test	ER5, ER13, ER21, CR11, CR14, CR23
Landing Test	ER3, ER7, ER12, ER18, CR3, CR8, CR10, CR15, CR16, CR17

Detailed Testing

Generated Thrust Test:

Equipment:

- Thrust force testing bench

- 3 cell battery
- Electric motor
- Propeller
- Radio controller

Design Requirements Tested:

- Thrust
- Takeoff within 8 feet
- Able to take off and land
- Land within 200ft

Recorded Variables:

We will be recording the generated thrust made by the electric motor in grams. The team will need to calculate the thrust to weight ratio after this is found. To do this, we divide the thrust generated by the motor to the final weight of our plane. The theoretical thrust can be calculated using the equation below.

$$Thrust = 4.392399 * 10^{-8} * RPM * \frac{Diameter^{3.5}}{\sqrt{Pitch}} * ((4.23333 * 10^{-4} * RPM * Pitch) - Velocity)$$

The result of this equation is approximately 3.5lb of static thrust force depending on the variables that are used.

Process:

The electric motor will be secured to the thrust force testing bench with the propeller installed. The team will secure it in place by screwing the testing bench into a piece of wood on a table. Then we will run the motor at various amounts of throttle and record the generated thrust provided by the digital output in grams.

Answered Questions:

The provided test will answer how much thrust our motor and propeller combination will provide and will tell the team if the plane will be able to take off from finding the thrust to weight ratio.

Generated Lift Test:

Equipment:

- Arduino Uno
- Anemometer
- Load Cell
- Finished Plane
- Load Amplifier
- 2X4 Wood Planks
- Bolts for load cell
- Hardware for Arduino, Load Cell, and Anemometer
- Tiedown Straps

- Vehicle

Design Requirements Tested:

- Lift forces
- Takeoff within 8ft
- Able to take off and land
- Land within 200ft

Recorded Variables:

We will be recording the generated lift of our plane in grams. These results will allow the team to find the lift to weight ratios for different winds speeds. It will tell us at what speed the plane will be able to take off and when it will glide through the air as well as other metrics regarding flying performance. From the team's previous analysis of lift on the plane, we found that the best ratio from coefficient of drag to lift was at a 2 degree angle of attack. This resulted in a ratio of 16.608. The coefficient of lift itself increases as the angle of attack increases, however, the drag increases as well. The team will choose an angle of attack of 12 degrees for takeoff because the drag at low speeds will not impact takeoff as much as gliding speed.

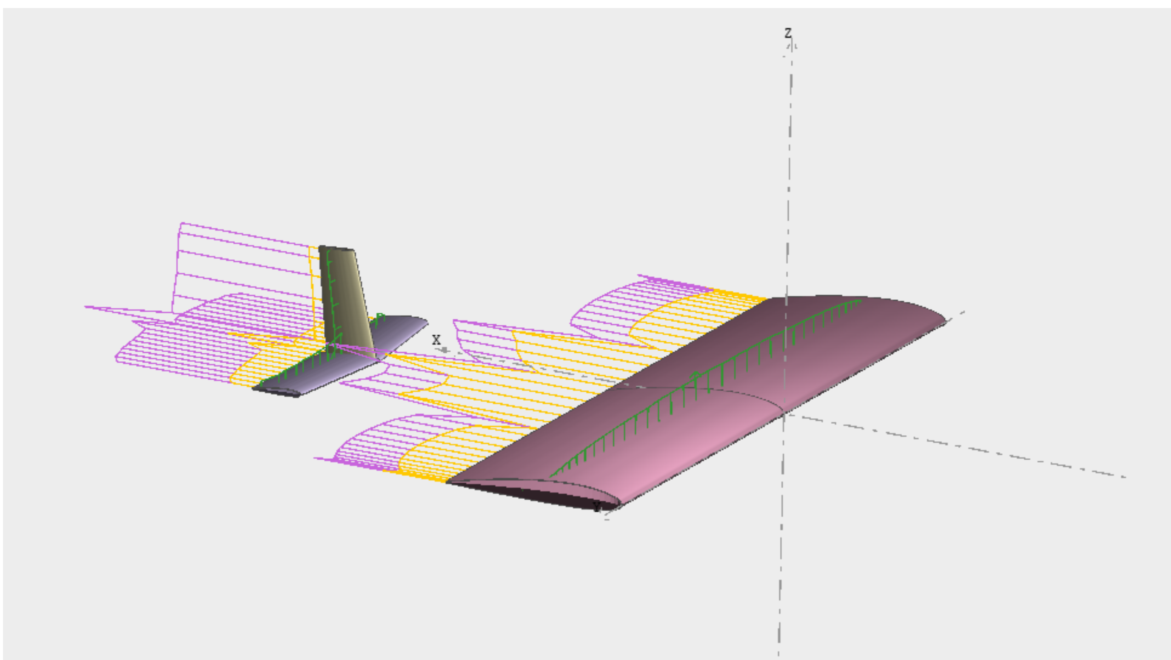

Figure 1: Simulation Results at 3 degrees

V =	27.24 m/s
Alpha =	2.000°
Beta =	0.000°
CL =	0.281
CD =	0.017
Efficiency =	0.931
CL/CD =	16.608
Cm =	3.465
Cl =	-0.001
Cn =	0.012
X_CP =	0.231 m
X_CG =	4.620 m

Figure 2: Simulation Results for 2-degree angle of attack

Process:

The plane will be secured on top of the car with a team member holding it in place. The load cell will be placed under the plane and secured with a wooden plank. The load cell will be attached to the plane via two tie-down straps around the wings and a plank of wood. The driver will proceed to accelerate, and the load cell records the generated lift forces. While this is happening, the anemometer will record the corresponding wind speed for each lift force. The data will be live streamed and recorded to an excel file where the team can analyze it.

Answered Questions:

The provided test will answer what our plane will generate for lift at corresponding wind speeds. It will tell us at what speeds the plane will need to achieve to take off.

Takeoff/Flight Test:

Equipment:

- Finished Plane
- Controller

Design Requirements Tested:

- Lift Forces
- Drag Forces
- Low control surface slop
- Takeoff within 8 feet
- Able to take off and land
- Static load capability
- 60 second lift-off time limit
- Ability to make a turn in air
- Appropriate center of gravity

Recorded Variables:

This is a visual test where the team will try to fly the plane so no hard variables will be recorded. The team will, however, visually assess the takeoff of the plane as well as the flight characteristics it has while in the air. The flight test will also be recorded.

Process:

The team will find a safe flat field to takeoff and try to fly the plane. We will pay special attention to specific variables such as the required throttle to take off, distance until takeoff, use of elevator to takeoff, etc.

Answered Questions:

The test will provide the team with a baseline on what to improve on. If the plane tends to fly in a way that is undesirable, the team needs to reiterate the design. If we need to take off within a shorter distance, we may consider using a larger battery or motor. Questions such as this will be generated throughout this test because we will not know the problem until we are presented with it.

Payload Test:

Equipment:

- Finished Plane
- Payload

Design Requirements Tested:

- Cargo Bay volume
- Payload unloading time
- Optimize safety factor
- Payload extraction in one minute or less
- Must have one cargo bay
- Appropriate center of gravity

Recorded Variables:

This is an interactive test where the team will land the plane from takeoff and time us on how fast we can load and unload the payload in our plane. We need to be under 60 seconds which will be our goal.

Process:

The team will find a safe flat field where we will be able to fly the plane and land it successfully. Once the plane has landed the timer will start and the team will attempt to secure the payload and takeoff again within 60 seconds.

Answered Questions:

This test will allow the team to assess whether we can load and unload the payload within the allotted time. It provides us with experience that will help us reiterate our design to potentially decrease our unload time with our payload and perhaps fasten it more securely within the fuselage.

Landing Test:

Equipment:

- Finished Plane
- RC Controller

Design Requirements Tested:

- Increase Durability
- Increase impact tolerance
- Ground turning radius
- Must land within 200ft
- Able to take off and land
- Static load capability
- 200 feet landing distance
- Ability to make a turn in air
- Ability to make a turn on the ground
- Steering mechanism for landing gear

Recorded Variables:

This is a visual test that will allow the team to assess the performance of our plane when attempting to land it. The team will record how safely it lands, can the landing gear withstand the impact, will the landing gear bend, etc. From the team's previous analysis of the landing gear, solid works was utilized to perform a simulation of the impact of a rough landing. The following results were found using an impact force of 3.9 newtons and we can see the deflection is present but not catastrophic.

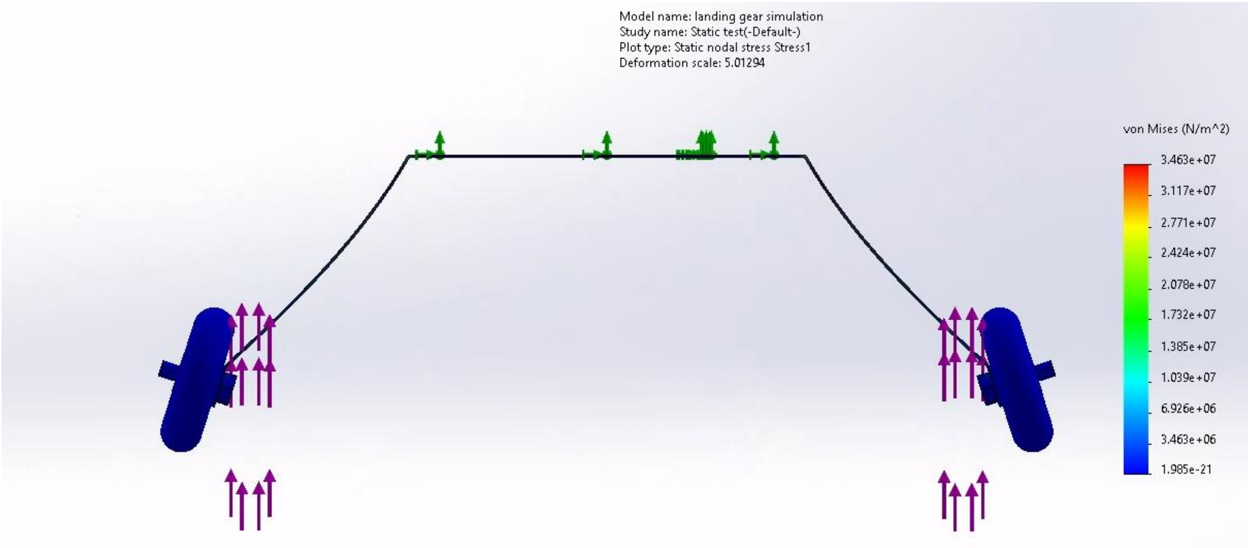

Figure 3: Landing gear simulation

Process:

The team will find a safe flat field where we can fly the plane. Once the plane takes off and completes a successful flight path the team will attempt to land. The process will be repeated several times to acquire accurate data and assumptions. Each flight will be recorded for evidence and will be studied by the team to determine what can be improved upon.

Answered Questions:

From this test the team will answer questions such as can our plane land successfully. It will provide us with results that answer whether the landing gear is adequate for the landing forces. It will answer if our rear landing gear turns on the ground with the static force of the plane while withstanding the force of landing. Other questions may arise during testing and further iterations will be conducted.

QFD

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Light weight																						
Increase Reliability																						
Increase Durability		1		1																		
Low Cost	3			3			1															
Increase impact tolerance	1		9																			
Optimize saftey factor	1	3	3	3			9							1	1							
Meets SAE Rules and Regulations				9	3	1		9				9	9	9	9	9	9	9				

Legend
A SAE Aero Micro 2021
B Hangar 9 Pulse XT
C UMX Turbo Timber

Customer Needs	Customer Weights (1: worst-5: Best)	Light weight	Increase Reliability	Increase Durability	Power limiter	Cargo Bay volume	Low Cost	Increase impact tolerance	48 inch Wing Span	Lift Forces	Drag Forces	Thrust	Ground turning radius	Payload unloading time	Low control surface slop	Must have 4 cells or less battery for the electr	Adequit servo sizing for aerodynamic forces	Must use 2.4 GHz radio control system	Must land within 200ft	Takeoff within 8 feet	Cannot exceed 55 pounds	Optimize saftey factor	Meets SAE Rules and Regulations	1 Poor	2	3 Acceptable	4	5 Excellent
		Technical Requirements (1-3-9)																						**Customer Opinion Survey**				
Meets the requirements of the rules	5	1	1	1	9	9	1	9	9	3	3	3	9	9	9	9	9	9	9	9	9	9	9				BC	A
Safe design	5	1	3	3	9			3							9		9					9	9					ABC
Able to take off and land	5	9	9	9	3					9	9	9			9		9				3	1	3					ABC
Innovative design	2		3	3			1	3		3	3	3			3		1				1	3	3		C	AB		
Manufacturable	3	3	1	1	3	1	9	3		3	3	3			1	3	3	3				9				A	B	C
Low cost	4	3			3		9	9							1	3	3	3							ABC			
Modular compatibility	1		3				1	3					1		3				1	1		1	3		A	BC		
Static load capability	5	9	9	3		9	1							9							9	3	3					ABC
60 Second lift-off time limit	5	3								9	9	9					9			9								ABC
200 feet landing distance	5	3								9	9	9					9		9									ABC
Payload extraction in one minute or less	5					9								9										C				AB
Use of Lithium Polymer Batteries	5		3	3	3		3									9	1	1				1	3				C	AB
Use of Power limiter (450-Watt)	5		3	3	9		1					3					3	3				9	3	ABC				
Must have one cargo bay	5					9								9									3					ABC
Ability to make a turn in air	5									9	9	9			3		9	3					3					ABC
Ability to make a turn on the ground	5												9										9					ABC
Stering mechanism for landing gear	5	3				1	3						9		3		9						9					ABC
Must use an Eletric motor	5				3		3					9				3							9					ABC
Fixed Wing	5		1	1						3	3	3		1	3		1		3	9		9	9					ABC
Functioal failsafe for radio control systems	5																		3				9					ABC
Must be equipped with a red arming plug	5																						9	C				AB
Must use model airplane safety nut	5																						9					ABC
Appropritate center of gravity	5	3				1			1												1		9					ABC
Must have a radio control system	5															1	1	9										ABC
Technical Requirement Units		pounds	Percentage	Percentage	Watts	Inches cubed	US dollars	Crashes before repair	Inch	Pounds	Pounds	pounds	Inches	Seconds	Degrees	Number of cells	ounces/inch	GHz	Feet	Feet	pounds	Factor of Saftey	Percentage					
Technical Requirement Targets		55	100	100		6*6*4	1500		48							4		2.4	200	8	55		100					
Absolute Technical Importance		181	151	124	201	193	153	114	50	225	225	285	136	185	196	131	368	146	121	136	112	230	549					
Relative Technical Importance		11	13	18	7	9	12	20	22	6	5	3	16	10	8	17	2	14	19	15	21	4	1					

Figure 1. Quality Function Deployment

Specification sheet Preparation

According to the ERs and CRs required, we have made the QFD charts. The main purpose of making this chart is to connect ERs and CRs in a more intuitive way and find out the relationship between them. Based on this QFD, we can make a list of all CRs and ERs to check whether we meet these requirements in the test.

Customer Requirement	CR met? (√ or ×)	Client Acceptable (√ or ×)
CR1 Meets the requirements of the rules	×	
CR2 Safe design	√	
CR3 Able to take off and land	√	
CR4 Innovative design	√	
CR5 Manufacturable	√	
CR6 Low cost	√	
CR7 Modular compatibility	√	
CR8 Static load capability	√	
CR9 60 Second lift-off time limit	√	
CR10 200 feet landing distance	√	
CR11 Payload extraction in one minute or less	√	
CR12 Use of Lithium Polymer Batteries	√	
CR13 Use of Power limiter (450-Watt)	√	
CR14 Must have one cargo bay	√	
CR15 Ability to make a turn in air	√	
CR16 Ability to make a turn on the ground	×	
CR17 Sterring mechanism for landing gear	×	
CR18 Must use an Eletric motor	√	
CR19 Fixed Wing	√	
CR20 Functional failsafe for radio control systems	√	
CR21 Must be equipped with a red arming plug	×	
CR22 Must use model airplane safety nut	×	
CR23 Appropriate center of gravity	√	
CR24 Must have a radio control system	√	

Table 2. The result tables for testing

As shown above, this table lists all Customer Requirements. All our testing plans are carried out around this table. In the table, we divide all CRs into two parts. The blue part does not need to get results through specific tests, but through observation and evaluation. We will conduct a comprehensive evaluation of the project after it is completed to obtain the results of the blue part.

The red parts must obtain their results through test. Among them, the results of CR3 and CR 10 will be jointly obtained by Generated Thrust Test, Generated Lift Test and Landing Test. The result of CR9, CR15 will be given by Takeoff/Flight Test. The result of CR11, CR14 will be given by Payload Test. The result of CR23 2ill be given by joint of Takeoff/Flight Test and Payload Test. And the result of CR15, CR16 and CR17 will be given by Landing Test.

In addition, we also prepared the engineering requirements table. This table lists all our engineering requirements for comparison in the experiment.

Engineering Requirement	Target	Tolerance	Met?	Client Acceptable?
Light weight	55(Pounds)	+∞	Y	
Increase Reliability	100 (Percent)	±0	Y	
Increase Durability	100 (Percent)	±0	Y	
Power limiter			Y	
Cargo Bay volume	6*6*4(Cubed inches)	0	Y	
Low Cost	1500(Dollars)	-500	Y	
Increase impact tolerance			Y	
48 inch Wing Span	48 (inches)	±1inch	Y	
Lift Forces				
Drag Forces				
Thrust				
Ground turning radius			N	
Payload unloading time				
Low control surface slop				
Must have 4 cells or less battery for the electronics	4 (Number of cells)	±0	Y	
Adequate servo sizing for aerodynamic forces			Y	
Must use 2.4 GHz radio control system	2.4 (GHz)	0	Y	
Must land within 200ft	200 (ft)		Y	
Takeoff within 8 feet	8 (feet)	-1 feet	N	
Cannot exceed 55 pounds	55 (pounds)	+∞	Y	
Optimize safety factor				
Meets SAE Rules and Regulations	100 (percent)	±0		

Table 3. Engineering Requirements table

By comparing this table, we can further improve the results of the experiment. In the table, there are some requirements that do not have specific unit to use, and these requirements need our comprehensive evaluation. Generated test will affect the results of ER11 and ER19. The Generated Lift Test will affect the results of ER9 and ER19. Takeoff/Light Test will affect the results of ER9, ER10, ER14, and ER19. The Payload Test will affect the results of ER5, ER13, and ER21. And the Landing Test will affect the results of ER3, ER7, ER12, and ER18.

The results of the above two tables will be presented to everyone at the end of the semester.

Conclusion

In this assignment, we specifically discussed what engineering requirements and customer requirements we have, and what test plans we have made based on these requirements. On these basics, we developed specific test steps. These steps will guide us to test and prevent errors or omissions in the test. In addition, we also prepared a demand form to record the experimental results.