Project Number: 09123

MICRO AERIAL VEHICLE

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ABSTRACT

The main objective of project 09123 is to develop a platform for a Micro Aerial Vehicle (MAV) that is expandable and reusable for future MAV designs. With the basis of the previous team's MAV project (P08120), Impact Technologies and the MAV faculty mentor, Dr. Jeffery Kozak (Mechanical Engineering Department faculty at Rochester Institute of Technology), the team was able to design a platform that was within the customer specifications and easy to manufacture. To effectively design and manufacture the plane, sections of the plane was assigned to individuals in the team. The sections consist of the fuselage, airfoil, propulsion system, wings and the tail. After the calculations were completed, the manufacturing process was the next concern. For easy manufacturability, fixtures and molds were used to ensure consistency, simplicity and error proofing in every plane that was manufactured. Once the plane was made, flight time, maneuverability and elevation were assessed. After the first trial, the plane managed to take off into the air, but failed to be able to be easily controlled. From analyzing the videos and plane itself, the location of the center of gravity seemed to be the problem. Therefore, weights were added in the nosecone to shift the center of gravity towards the front of the plane. After eight trials, the plane did have a 10 minute flight time. But maneuverability seems to be the ongoing problem. Thus this can be a challenge for future MAV team members.

NOMENCLATURE

MAV: micro aerial vehicle
Aerodynamic: A smooth air flow on the contact surfaces to allow minimum drag resistance during flight time.

Drag: The opposing force acting on the plane when the plane is moving through the air.
Lift: Upward acting force.
Weight: The downward force acting on the plane as a result of gravity.
Thrust: The force pushing the plane forward as a result of the plane's propulsion system.
Airfoil: The inner shape of the wing.
Cord: The line that separates the upper chamber and lower chamber of the wing and starts at the leading edge and ends at the trailing edge of the wing.
Angle of attack: The angle at which the wings need to be tilted to maximize the lift of the plane.
Cruise Speed: The speed of the plane when operated at the optimized performance settings.
Coefficient Of Lift: A dimensionless coefficient that relates lift with the airfoil.
Aspect Ratio(AR): An indicator for the performance of a wing.
Induced Drag: The opposing force acting on the plane when the plane is moving through the air.
Reynolds Number: A ratio between inertial forces and viscous forces. It is used to determine the quality of the air flow on a surface.
Fuselage: The body of the plane where the wings are attached to and a compartment where the cage is inserted into.
Aerodynamic Surfaces: These parts include wings, horizontal / vertical tail.
Center Of Gravity: The point of the plane where all forces acting on the plane are at equilibrium. This point is crucial in determining the flight dynamics of the plane.
Angle Of Attack (AoA): The angle at which the wings are tilted at to maximize the flight dynamics of the plane.

INTRODUCTION/ BACKGROUND

Micro aerial vehicles (MAV) are a new type of remotely controlled aircrafts. Most MAVs today target a length of about six inches. The application of this device is mostly for observational purposes. Therefore, it can be used to unveil hazardous environments, new terrain or any areas that aren't easily assessible by ground. To be able to complete these tasks, the design of the micro aerial vehicle must be miniature aerodynamic, light and include a long ranged controls system. Due to time constraints and limited funding, the objective and specifications of the plane were modified.

The purpose of the designed aircraft will be used as a transition to be a micro aerial vehicle in the future. Therefore, a larger platform will be designed and built so that future members of the MAV team will be able to modify the platform to fit the specifications of a micro aerial vehicle.

Figure 1: The actual plane.

As for the calculations for the platform, the concepts and calculations from the MAV project 08120 will be used as a benchmark to insure the accuracy of the current project. The calculations were also presented to a faculty advisor for thoroughness.

The completed prototype of project 09123 will be semi-autonomous. Therefore, it will be controlled by a wireless remote control. Using the remote control, the user will be able to fly and control the aircraft without any external interference.

PROCESS (OR METHODOLOGY)

When designing the micro aerial vehicle, the main concern was if the plane will be able to fly. Firstly, the plane will include a propeller, nosecone, equipment cage, pair of wings, ailerons, fuselage and a tail assembly with vertical and horizontal stabilizers. The desired outcome of designing the plane was for the plane to have an aerodynamically sound surface to allow a smooth flight time. Also, the propellers,

ailerons, vertical and horizontal stabilizers have to be able to be controlled by the user to have complete control of the plane during flight time.

Background And Theory

When the plane is flying, four forces will be acting on the plane. The forces are drag, lift, the weight of the plane and thrust. When designing a plane, the aim will be to minimize the weight and drag of the plane so that the lift and thrust of the plane can be maximized. With that said, the plane will be able to sustain flight at a maximal height and time.

When dealing with lift, one would need sufficient understanding on airfoils. The shape of the airfoil is important to the plane because it creates the force that is perpendicular to the direction the plane is moving in. Therefore lift is created. In order to select an airfoil, one must characterize the flow in which the foil will be operating. To do this, Reynolds Number is used. The equation for Reynolds Number is in equation (1)

$$\mathrm{Re} = \frac{\rho v l}{\mu} = \frac{v l}{\upsilon} \qquad (1)$$

Once the flow was characterized and an operating velocity was set, Coefficient of lift calculations as needed. Equation (2) was used to determine the minimum coefficient of lift.

$$C_{l_{\min}} = \frac{Lift}{q \cdot S} = \frac{Lift}{0.5 \cdot \rho \cdot v^2 \cdot S} \qquad (2)$$

In equation (2) lift is defined by the lift force attained, or needed (for calculation purposes the estimated maximum weight of the plane was used), from the corresponding velocities. ρ is the air density of the environment where the plane will be flown. v is the velocity that is being analyzed. Lastly S is the surface area of the pair of wings of the plane. To define the possible speeds of the plane, the minimum, maximum and cruise speed of the plane will be needed to be set. Minimum Coefficient of Lift calculations are performed on these velocities as well.

To determine the shape of the foil that would fit the needs of the plane, the chord length and angle of attack will be needed to be determined in Figure 2.
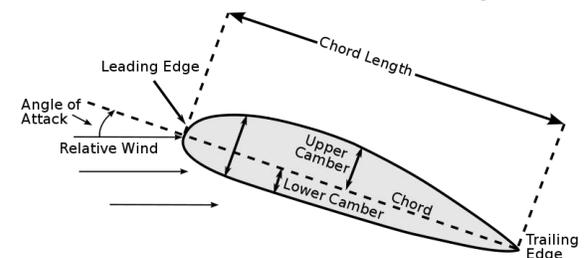

Figure 2: Pictorial representation of the cord length and angle of attack for the plane.

When calculating the appropriate cord length of the wings, vertical and horizontal stabilizers, the surface area (S) and the length (b) of the wings and stabilizers have to be determined. Then, the cord of each of the parts will be calculated using the Standard Mean Cord (SMC) in equation (3).

$$SMC = \frac{S}{b} \qquad (3)$$

When a chord length has been set, Cl vs. Angle of Attack plots must be made. These graphs can be obtained through an Excel program or other airfoil design programs. These graphs are dependent on airfoil shape and dimensions, therefore a variety of airfoils will be examined. From this graph, the best airfoil shape will be selected based on needed Cl at a reasonable angle of attack (generally between -2 and +5 degrees).

Once the airfoil is selected, corrections to the calculations must be made. All previous calculations have been for 2D airfoil sections of infinite span, thus corrections for a 3D finite wing must be made. To start this process, one needs to calculate the Lift Curve Slope. This is most easily done by finding the slope of the linear portion of the Cl v. AoA graph for the selected airfoil. Then, using equation (4) convert the 2D slope into the 3D slope.

$$a = \frac{a_0}{1 + \frac{57.3 a_0}{.9 \pi AR}} \qquad (4)$$

Next, the static angle of attack will be needed to be obtained through equation (5). This is the angle at which the wings will be mounted onto the fuselage.

$$\alpha = \frac{C_L}{a} + \alpha_{L=0} \qquad (5)$$

It is generally known that a wing in the shape of an air foil is inherently unstable. This is due to the moment about the aerodynamic center produced by the pressure difference directly above and below the wing. This moment produces an upward pitching moment. In order to correct this downward pitch a horizontal stabilizer is commonly used. A smaller wing, called the tail, is placed behind the main wing of the aircraft. The tail is attached to the plane at a fixed length and is sized to produce a lift that creates the corrective moment arm to stabilize the aircraft. This aspect of aerodynamics has been studied at length, and has been succinctly documented for ease of use. It was found in [4] that a simple calculation can be used to size the tail.

$$S_{HT} = c_{HT} \overline{C}_W S_W / L_{HT} \qquad (6)$$

Where C_{HT} is tail volume coefficient found in table 6.4 from [6], $\overline{C}_W$ is the mean chord of the wing, S_W is the Plan form area of the wing, and L_{HT} is the distance the tail is from the aerodynamic center.

There are two accepted methods for vertical stabilizer sizing. One method from Raymer calculates the platform area of the vertical stabilizer through the following equation (7).

$$S_{VT} = \frac{c_{VT} b_w S_w}{L_{VT}} \qquad (7)$$

The other form Stinton in equation (8).

$$\frac{S_{VT}}{S_W} = 0.085 \qquad (8)$$

The larger of these two numbers will be used for stability purposes. Once a platform area is established, the following equations from Stinton were used to calculate span and chord of the Vertical Stabilizer in equation (9) and (10).

$$\frac{AR_{VT}}{AR_W} = 0.30 \qquad (9)$$

$$AR_{VT} = \frac{b_{VT}^2}{S_{VT}} \qquad (10)$$

The rudder calculations were done using the following equation from Stinton in equation (11).

$$\frac{c_\xi}{c_v} = 0.4 \qquad (11)$$

Another force that affects the plane's performance during flight is drag. The amount of drag acting on the plane during flight is dependent on the density of air, velocity between the object and airflow, the viscosity and compressibility of air, the size and shape of the body structure and air flow of the surface of the plane. The equation used to calculate drag is in equation (12).

$$TotalDrag = 2DDrag + InducedDrag \qquad (12)$$

To calculate the induced drag of the equation, equation (13) was used.

$$C_{D,i} = \frac{C_L^2}{\pi e AR} \qquad (13)$$

In equation (13) C_L is defined by the part's minimum lift coefficient. AR is the aspect ratio. To obtain the aspect ratio, equation (14), must be used.

$$AR = \frac{b^2}{S} \qquad (14)$$

The variable b is defined by the wing span of the plane and S is defined by the surface area of the wing.

To calculate the total drag on the plane, the drag for the rudder, horizontal stabilizers, wings and fuselage must be calculated and summed together.

The next force to obtain for the plane is thrust. The ideal thrust at a given prop diameter D and RPM is found using equation (15)

$$T_{ideal} = 2.83 * 10^{-12} * RPM^2 * D^4 * C_p * \frac{Pr\,(in\,Hg)}{29.92} * \frac{528}{(460 + T(oF))}$$

(15)

In equation (15), RPM is defined by speed at which the motor is able to the propeller at. As for the variable D, it defines the length of the propeller. For C_P, it defines the efficiency of the motor.

Making the conservative assumption that the prop is only effective outside the region of the fuselage, the actual thrust is calculated as equation (16).

$$T_{actual} = T_{ideal} * \frac{r_{prop}^2 - r_{fuselage}^2}{r_{prop}^2}$$

(16)

Taking the maximum power output given the battery power and accounting for efficiency of the motor, equation (17),

$$P_{out} = V * I * effeciency$$

(17)

Then P, RPM, and Thrust can be maximized for various combinations using equation (18)

$$P(hp) = RPM * \frac{Pitch}{12} * \frac{T_{actual}}{33000}$$

(18)

The flight time can be calculated by finding RPMs required to overcome the force of drag at a given speed (eq. 17 and 18), backing out voltage based on the kV rating of the motor (eq. 19).

$$RPM = V * kV$$

(19)

Power (V) and voltage values can be used to find current (eq. 20) which can be compared to battery capacity to find flight time.

$$t_{flight} = \frac{C_B}{I}$$

(20)

ANSYS/ Solid Works Concepts And Application

To simulate the dimensions calculated for each part, engineering programs such as ANSYS and Solidworks were used to construct a 3D representation of the final product and also for performance testing.

Firstly, the nosecone was constructed through Solidworks in Figure 3. It will be made out of carbon fiber. On the top of the nosecone, there will be a hole

big enough so that the motor will fit through it and also leaving gaps between them so that heat can dissipate through those gaps.
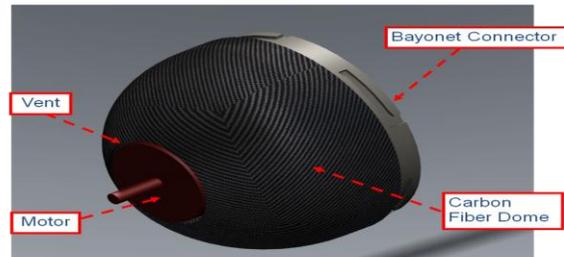

Figure 3: Solidworks model of the plane's nosecone.

To hold the motor into place, a mount will attach the motor to the nosecone as seen in Figure 4.

Figure 4: An assembled nosecone.

Then, the cage was also constructed through Solidworks. The whole cage will be constructed using carbon fiber rods. It will be 8 inches long and 2.25 inches in height and width. These dimensions will ensure that the cage will be able to be placed into the fuselage of the plane leaving some space for the vibration isolators to be installed. The model of the cage can be seen in Figure 5.
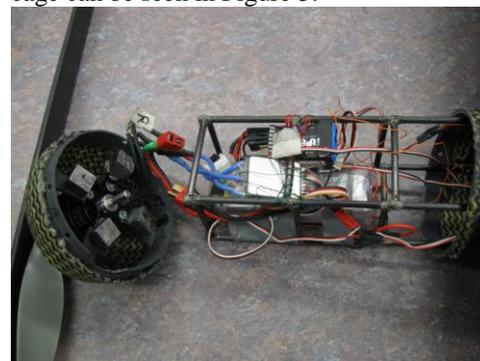

Figure 5: The cage in the fuselage.

In the cage, the contents include a battery and the controls system.

Next, a model of the body of the plane was shown in Figure 6. The material used to make the body was a carbon fiber/Kevlar biaxial sleeve. The reason for using this material is because it can absorb a lot of impact without affecting any internal parts when hardened. Also, by using the sleeves, the original tapered surface will reduce the drag force on the plane during flight.
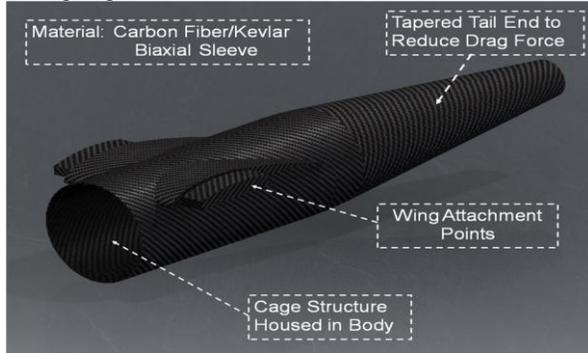

Figure 6: Solidworks 3D representation of the body of the plane.

As seen in Figure 6, there is also a pair of wing attachments at the body. Therefore, this allows the wings to be easily interchangeable.

To connect the body to the nosecone, a bayonet connector will be installed at the inner opening of the body. This allows the user to install the nosecone to the body by aligning the nosecone with the holes and screw in screws to permanently attach both parts together.

For the wings, it will be made out of carbon fiber. The final wing assembly will resemble the model in Figure 7. Since the wings will be hollow, to prevent deformation during flight, ribs will be installed and distributed throughout the whole wing. The other opening of the wing will be used to connect to the wing attachment on the body in Figure 6.

Figure 7:The inner view of the wing.

Tail end of the body in Figure 6 contains the location for another bayonet connector for the tail assembly.

This connection allows the tail assembly to be detachable and easily reattachable.

As for the ailerons for the wings, it was cut out from each of the respective wings. To allow mobility of ailerons, hinges were used to attach the ailerons back to the wings. A servo for each aileron was also installed.

As for the tail assembly in Figure 8, it is made out of a carbon fiber/Kevlar sleeve and the vertical and horizontal stabilizers are made out of carbon fiber.
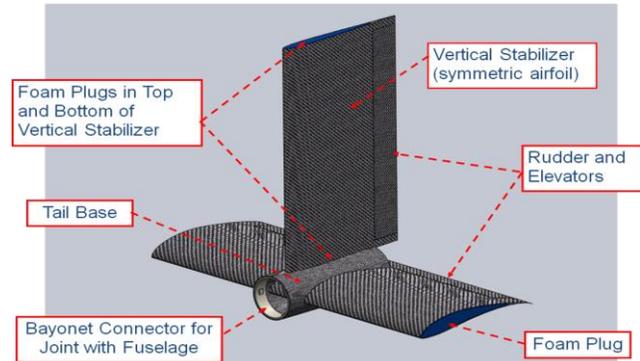

Figure 8: Solidworks model of the tail assembly.

To install the vertical and horizontal stabilizers, all of the parts were placed in their respective slots in the tail base. This can be seen in Figure 8. As for the rudders, it will be cut from the stabilizers and attached to the servos on the stabilizers. This will allow maximum mobility and control of the plane during flight.

When the whole plane is constructed, the plane will resemble the Solidworks model shown in Figure 1.

Manufacturing

Nosecone
To make a wax mold of a nosecone, wax was poured into a bowl with the diameter of the body. Once the wax hardened, the wax mold was removed and placed into the carbon fiber/Kevlar biaxial sleeve. The sleeve was then stretched until it was shaped into wax mold of the nosecone. Both ends of the sleeve were tied into a knot to ensure that the sleeve is in the shape of the nosecone wax mold. The excess material was removed. Next, hardener was distributed evenly throughout the nosecone and was left to solidify. After 24 hours, the current state of the nosecone was machined into the designed nosecone in Figure 4.

Cage
To create the structure of the cage, 68 inches of carbon fiber rod will be needed. Then, sixteen 2 ¼ inch and four 8 inch rods will be needed to be cut from the carbon fiber rod. To be able to connect the two and a quarter inch rods to the eight inch rods, the tips of the 2 ¼ rods will be machined to have concavity that will fit the outer surface of the longer rod. Then, to attach

the 2 ¼ inch rods to the 8-inch rods, two holes for each of the tips of the smaller rods are needed to be drilled in the 8 inch rods as seen in Figure 7.

After the first hole was drilled, the second will be needed to be drilled 90° and four millimeters away from the initial hole. All 32 holes are needed to be completed similarly and aligned with each other. Thirty-two *3/4* of an inch hollow copper rod were cut. Each of the metal rods was placed into the holes in the 8-inch carbon fiber rod and the 2 ¼- inch carbon fiber rods were connected to the metal rods. The result of this assembly will look like Figure 7. To permanently attach the cage assembly, epoxy was placed on the hinges of each connection and left to dry for 24 hours.

Aerodynamic Surfaces
To manufacture a wing, the shape of the wings must first be accurately obtained. To accomplish that, a wing mold was designed and later machined out of acrylic. An inner mold is made for each molded carbon aerodynamic surface by melting and pouring candle wax into the acrylic mold. After the wax is left for at least 8 hours and refrigerated for an additional 2 hours, the wax is removed from the mold. Ribs are made by cutting four square sheets of carbon fiber, where there are 2 layers each of [0,90] sheets (the carbon fibers intersect each other at 90° angles) and [±45] sheets (the carbon fibers intersect each other at 90° at a 45 ° offset to the [0,90]). After the sheets have been cut, they're placed on top of each other and three ribs will be cut from the lay-up after the epoxy has hardened. Holes will be cut into 2 of the 3 ribs to act as a draining system for the wax. The ribs are then placed in the inner wax mold at pre-determined lengths. Before combining the wax and the ribs with the outer wing layers, the acrylic mold is cleaned thoroughly and mold release is applied to all the inner surfaces of the mold. The outer wing lay-up is made by cutting 2 sheets that will cover the size of the wing, where one is a [0,90] configuration and the other is a [±45] configuration. Lay-up one side of the two layer outer surface, place the inner wax mold with the ribs, then lay-up the other side. Close the acrylic mold by screwing the bolts in the sequence shown in Figure 9.
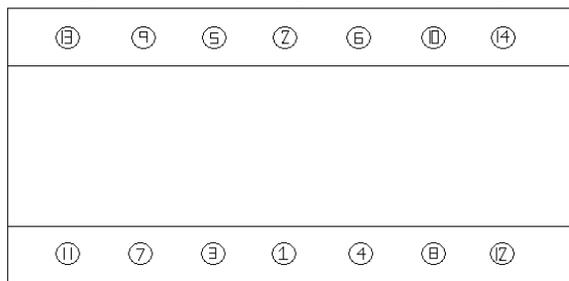

Figure 9: Sequence to screw bolts into acrylic mold

The mold is further tightened by clamping the middle surface to ensure that no air bubbles will be present during the hardening process. The whole assembly is left undisturbed for 24 hours to fully harden. The wax is then melted out, and the extra carbon composite material that is not needed for the wing is cut and sanded down.

The vertical and horizontal tails are made using the same technique, except the design does not call for ribs, therefore once the inner wax mold is made, the two layers should be laid-up around that exact mold without any additions.

To attach the horizontal and vertical stabilizers together to make-up the tail assembly, a tail base was used in Figure 10. To permanently attach the vertical and horizontal stabilizers together, two sheets of foam were glued onto each side of the outer surface where the vertical and horizontal stabilizers met. As for the rudder, the process was repeated from making the ailerons for the wings.
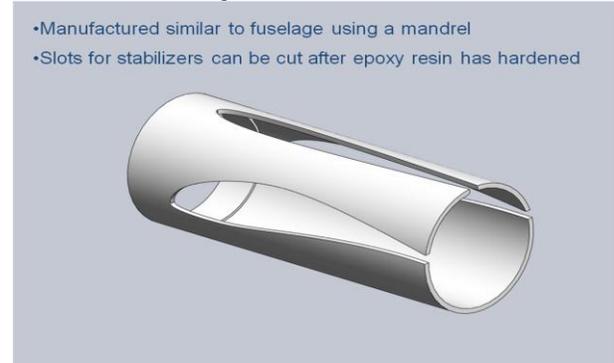

Figure 10: Solidworks model of the tail base

Body
Using PVC that was purchased by the team, it was cut and tapered into shape by a lathe as seen in Figure 13. Then, holes were tapered as shown in Figure 13 and a mandrel was installed in the holes taped. The final product can be seen in Figure 11.

Figure 11: The body mold fixture with the wing attachment.

With the body mold fixture, it was placed into a carbon fiber/ Kevlar biaxial sleeve. On the side with

the larger diameter, the sleeve was tied so that the mold will stay in place at that position. On the other side, the sleeve was pulled until the sleeve compresses into the shape of the mold. Once that was completed, the side was also tied to ensure that the shape of the sleeve will not change. Then, to make the material harden, hardener was distributed equally along all the surfaces of the body mold. Next, the wing attachment was created by using the excess wing from the wing frame and placing it to the appropriate area. Large amounts of epoxy were applied on the wing attachment to ensure that it permanently attaches itself to the body mold fixture of the plane. After all the previous steps were completed, the body was left to dry for 24 hours. When the whole body was hardened, the tied areas were cut and the fixture was removed by pulling the Mandrel. Lastly, two bayonet connector rings were machined and placed on each of the openings of the body to connect the nosecone and the tail assembly as discussed previously.

RESULTS AND DISCUSSION

Before attempting to fly the plane, an analysis of ANSYS was completed to ensure that the body of the plane where all our expensive equipment was located would not be damaged. From Figure 14, the results show that the most stress would be on the wing attachment of the plane or the green area. Since the maximum stress was only 759.8 psi, the wing might not break.
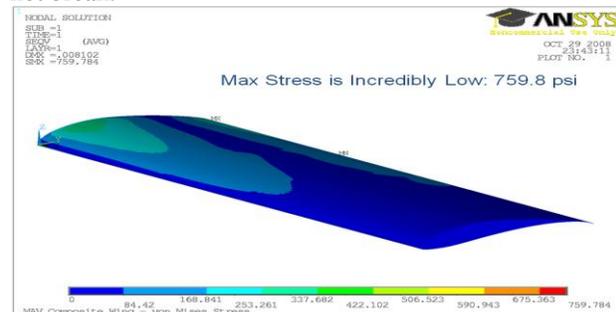

Figure 14: ANSYS analysis on the area with the maximum stress on the wing.

Next, the plane was weighed to see if it did meet the specifications of 1.5 kg. The actual weight of the plane turned out to be 1.105kg. So, the plane weighed .395kg less than the expected weight. Therefore, the specification was met.

After completing these analyses, the plane was ready to be tested. When the plane was first flown outdoors, the plane managed to take off. The only problem was the maneuverability of the plane. After eight trials, the best trial had a flight time duration of 10 minutes. After each trial, the plane did crash to the ground. As expected, the wings broke off each time the plane crashed. Unexpectedly, the hinges of the vertical and horizontal stabilizers were damaged too.

As a result of the trials, it was concluded that the plane is unstable and the dimensions of the plane need to be recalibrated.

RECOMMENDATIONS

From the results, it is necessary to review the stability calculations and location of the center of gravity. Also, the manufacturing tolerance of each part of the aerodynamic surfaces will be needed. In addition to that, a CNC machine mold of the wing joint will be augment the fuselage mold.

Next, the power of the servos needed to control the plane will need to be recalculated. The location of the servos will also need to be redesigned to improve the aerodynamics and maneuverability of the plane.

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ACKNOWLEDGMENTS

Requirements and Advice

Construct an outline
A proper outline is the framework upon which a good paper is readily written. In the process of making the outline, ideas are classified and thoughts are ordered into a logical sequence that is readily transformed into complete sentences. In outline form, the sequence of the various items and the progression of thought can easily be adjusted and readjusted until the desired order is obtained.

Length
Your paper should not exceed 8 printed pages, all inclusive!

Style. The chief purpose of the paper is to convey information to others, many of whom may be less familiar with the general subject than the author. Care should be taken, therefore, to use simple terms and expressions and to make statements as concise as possible. If highly technical terms or phraseology are necessary, they should be adequately explained and defined. The use of the first person and reference to individuals should be made in a manner that avoids personal bias. Company names should be mentioned only in the acknowledgments.
Papers should be concise. Long quotations should be avoided by referring to sources. Illustrations and tables are desirable but they should be kept to a reasonable minimum. Detailed drawings, lengthy test data and calculations, and photographs that may be interesting, but which are not integral to the understanding of the subject, should be omitted. Equations should be kept to a reasonable minimum.

Originality
Only original contributions are accepted for publication. Under certain circumstances, reviews, collations, or analyses of information previously published may be acceptable.

Accuracy
All technical, scientific, and mathematical information contained in the paper should be carefully checked. SI units of measurement should be used. When U.S. customary units are given preference, the SI equivalent should be provided in parentheses or in a supplementary table. Similarly, when preference is given to SI units, the U.S. customary units should be provided in parentheses or in a supplementary table.

Headings
Headings and subheadings should appear throughout the paper to divide the subject matter into logical parts. Headings assist the reader in following your thought process and in forming a mental picture of the points of chief importance.

Tabulations/Enumerations
It is often advantageous to put related items in tabular or enumerative form, one after the other, rather than simply running them into the text. This arrangement, in addition to emphasizing the items, creates a graphic impression that aids the reader in accessing the information. It is customary to identify the individual items as (1), (2), (3), etc., or as (a), (b), (c), etc. Although inclusion of such elements makes the text livelier, care should be taken not to use this scheme too frequently, as it can make the reading choppy.

Mathematics

Equations should be numbered consecutively beginning with (1) and including any appendices. The number should be enclosed in parentheses and placed on the right-hand-side of the equation. It is this number that should be referenced within the text. An example is shown below in Eq. (1).

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha} \frac{\partial T}{\partial t} \qquad (1)$$

Formulas and equations should be created to clearly distinguish capital letters from lowercase letters. Care should be taken to avoid confusion between the lowercase "l"(el) and the numeral one, or between zero and the lowercase "o." All subscripts, superscripts, Greek letters, and other symbols should be clearly indicated.

In all mathematical expressions and analyses, any symbols (and the units in which they are measured) not previously defined in nomenclature should be explained. If the paper is highly mathematical in nature, it may be advisable to develop equations and formulas in appendices rather than in the body of the paper.

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All figures (graphs, line drawings, photographs, etc.) should be numbered consecutively and have a caption consisting of the figure number and a brief title or description. This number should be used when referring to the figure in text. Figures should be referenced within the text as "Fig. 1." When a reference begins a sentence the abbreviation "Fig." should be spelled out (e.g., "Figure 1"). You may use single column figures or, if needed, the figure may span both columns.

Figures should be embedded electronically into your paper. Be sure to include the actual figure and not a link to another file. We will produce your paper from the electronic format that you provide. All photographs should be submitted as good quality jpeg or tiff files embedded in the Word file.

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All tables should be numbered consecutively and have a caption consisting of the table number and a brief title. This number should be used when referring to the table in text.

Tables may be inserted as part of the text, or included on a separate page immediately following or as close as possible to its first reference, with the exception tables included in an appendix.

Format

Papers must be submitted in Microsoft Word format. Your paper will be printed and prepared directly from your electronic media. Do not assume that any additional layout work will be performed, although we do reserve the right to make layout changes and editorial changes as needed to meet the publication turn-around time.

Check all page headings to be sure that dates and paper numbers are current. Also:
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