Endurance Plane Documentation

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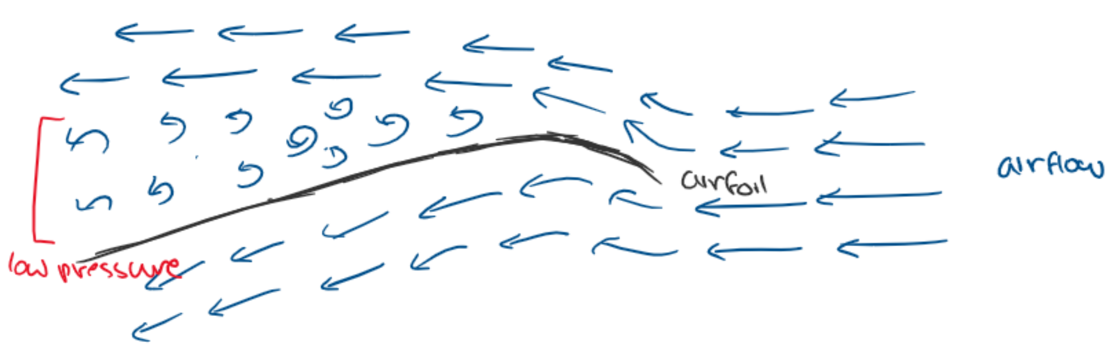
Research Consolidated and Interpreted

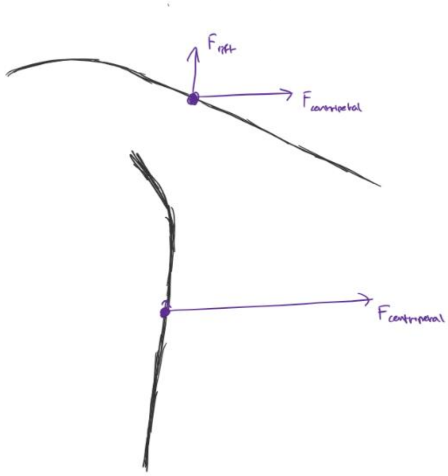
During any plane's flight, concepts in thermal physics explain disturbances in a flight's motion. One reason is the air pressure which varies based on elevation above ground level, so planes must calibrate and adjust fly safely. Furthermore, sudden changes in pressure caused by the sudden changes in pressure result in turbulence. In the indoor airplane model, however, the room's air pressure is relatively uniform, but the plane tends to have shifts in elevation. The shifts in elevation occur due to convection currents within the room. The air conditioning pushes cold air into the room and another vent sucks the excess air to maintain constant pressure within the room. Nevertheless, the introduction of cold air creates convection currents. Cold air is more dense than warm air, so the cold air sinks to the ground while the warm air rises up to the vent. However, since the cold and hot air layers are in contact with each other, the cold air near the ground heats up and rises again where excess heat leaves through the vent. Eventually, the temperature in the room becomes uniform, but due to miserable insulation in my house, convection currents run incessantly in my room. In addition to the turbulence, changes in elevation can occur when introducing another independent variable.

Assuming the temperature remains constant for the duration of the flight and the door is closed, the pressure in the room will increase as the air conditioner pushes more air into the room. If the door is opened, the volume of the house will be annexed to the original "container" (room), so the increase in volume would lessen the pressure within the room. With a lower pressure in the room, the force on the plane would decrease proportionally (Force = Pressure * Surface Area). The plane, however, maintains an elevation where the air pressure on the wing is constant, so the plane's elevation would drop to equalize the air pressure when the door is opened. By dropping its elevation, the air molecules will increase the force exerted on the wing because the surface of the area of the wing remains the same but a lower elevation will put more air molecules on top of the wing. The greater number of collisions with the wing increases the air pressure on the wing as the plane's elevation drops. The elevation change is visible because the plane has a very low mass of approximately 7-8 grams (0.007-0.008 kilograms), resulting in a very low momentum (momentum = mass * velocity). Low momentum means that there will be little resistance to changes in the mass, so the plane will respond to changes in the environment.

Fluid dynamics also plays a role in controlling the circular motion and the upward motion of the plane because the velocity of the front and rear wings create an area of lower pressure on the upper portion of the wings (figure below). The shape of both the front and rear wings are that of an ideal airfoil:



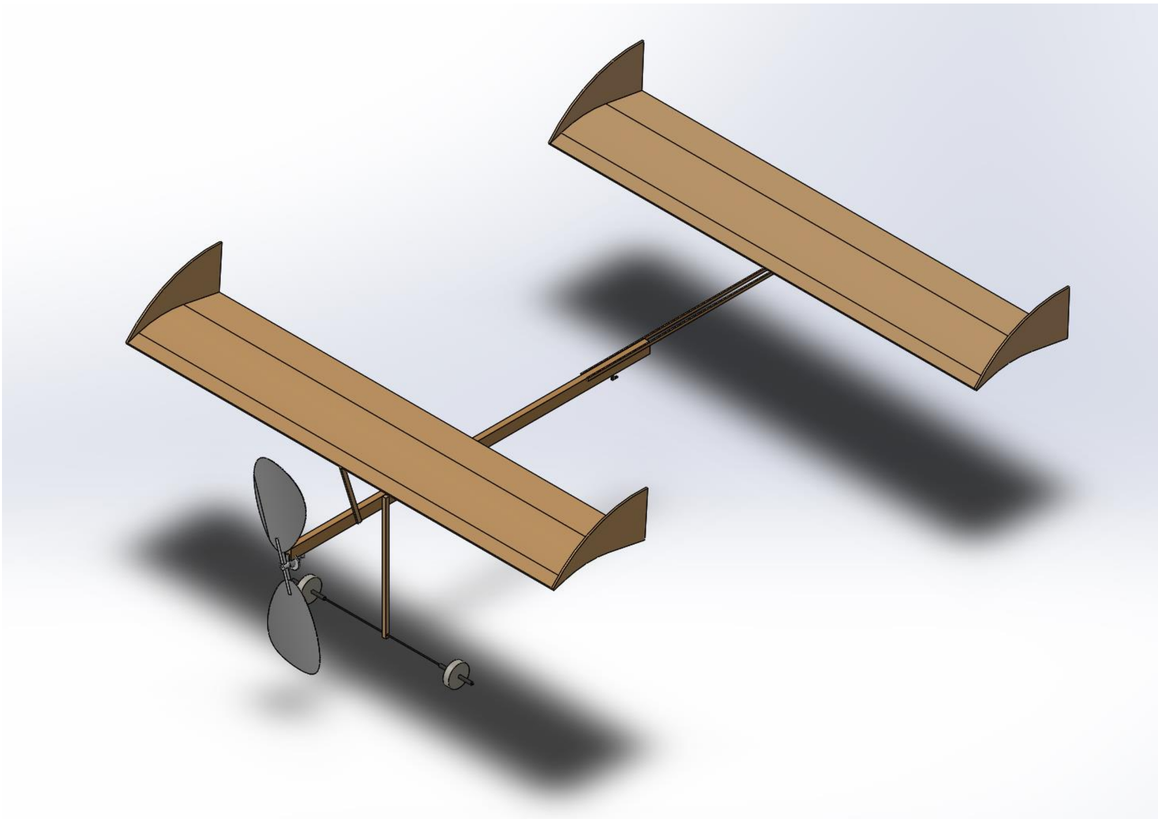
Since the wing is only composed of one layer, the shape resembles that of the top of the car. During any positive acceleration (Bernoulli's Principle), the pressure on the wing enters a state of low static pressure (represented by the curved lines in the diagram above). Low pressure is characterized by larger volume and fewer molecules, creating a vacuum-like region. By the diffusion principle, molecules travel from areas of high pressure to areas of low pressure to maintain constant pressure in the environment. To fill the area of low pressure, the front wing is pushed upward to create lift, resembling the characteristic of a vacuum. As the plane reaches higher elevations, the air pressure will be lower, so the maximum elevation will be determined by the depth of the airfoil, the velocity of the plane, and the ability to make a larger vacuum. To create the rotational motion, the rear wing is tilted so that the low-pressure area is created on the outer part of the airfoil of the intended circle. The low-pressure area which attracts the whole rear assembly creates the centripetal force by pulling the plane's tail outside of the circle. Therefore, the rear wing's centripetal force serves as the frictional force for the entire plane, permitting the plane to maintain the circular motion. Additionally, the closer to vertical the rear wing is tilted, the smaller the circle will be since the centripetal force of the rear wing will be maximized. Since the rear wing serves as a two-dimensional vector, positioning the rear wing vertically would transform more of the lift force into centripetal force (figure above). Therefore, the right balance must be found to maintain the elevation of the plane while also flying in a circle with a small diameter (limitation of the room).



In addition to thermal physics and dynamics (fluid and mechanical), oscillations are the primary cause of sustaining flight in the air for extended periods of time. The rubber-powered propeller's tension increases as the rubber is winded up to approximately 700 rotations. By keeping the length of the rubber constant throughout the winding process while continuing to increase the rotations on the rubber, the tension of the rubber increases because the increasing number of rotations will increase the frequency of the oscillations when winding down. Frequency is directly proportional to velocity (velocity = wavelength * frequency), and velocity is proportional to the square root of the force of tension (velocity^2 = force of tension * linear density of rubber). Therefore, increasing the frequency would result in an increase in tension. However, since the rubber has the ability to break, the number of rotations that can be winded depends on the maximum force the rubber can hold, thus limiting the length of time the plane can sustain flight. This increasing kinetic energy of the rubber as the rubber winds down due to the force of tension is converted into the propeller's rotational energy, thus powering the propeller.

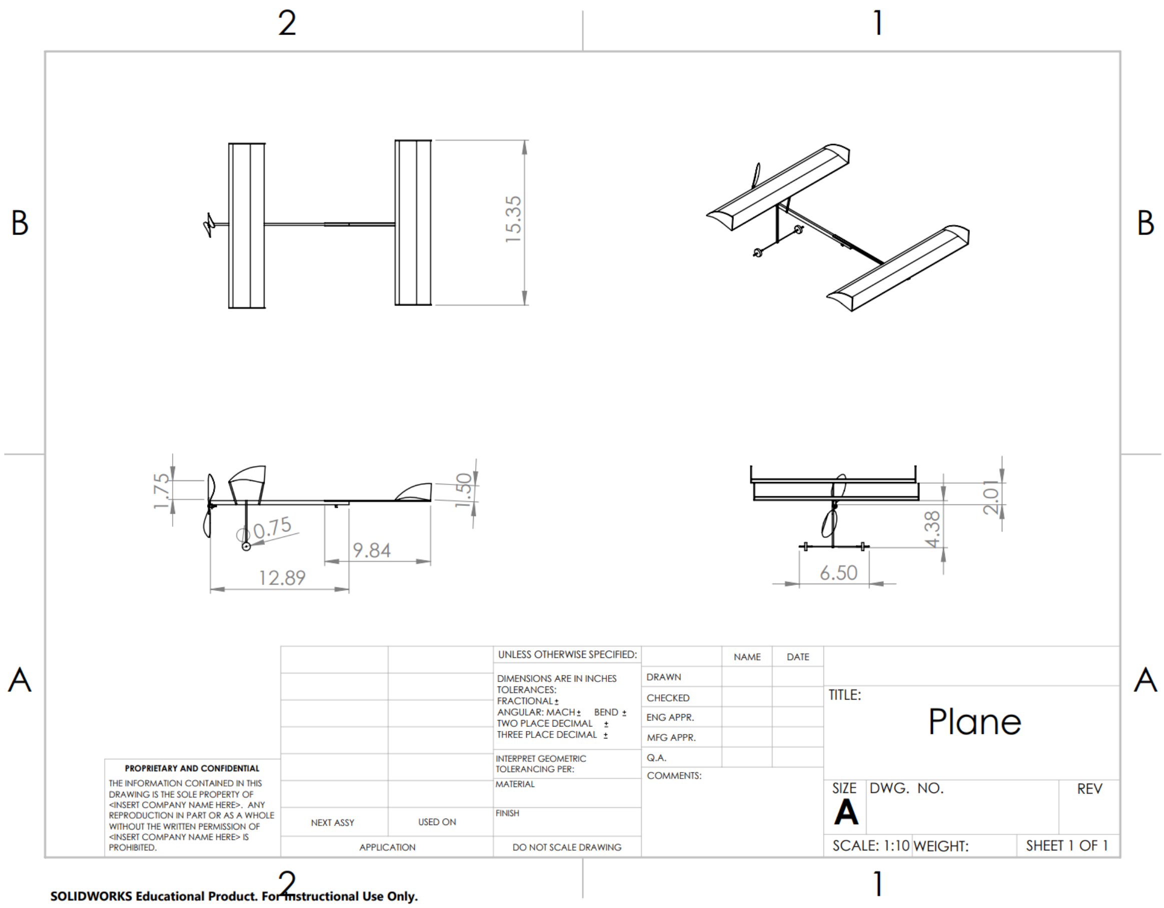
Ultimately, airplanes contribute to a major portion of the real world, and planes continue to advance technologically. Planes must be able to create enough lift to fly at a high altitude to fly in areas with low air-pressure. Low-pressure areas allow the plane to conserve fuel because there will be less air resistance. With a lower concentration of particles in the air above the plane at that altitude, the collisions on the planes' wings will be significantly lower, thus reducing the required amount of fuel per flight. This new method of maintaining rotational motion using a non-rigid body, exemplified in the demonstration, can also promote design changes since a rigid body often results in discomfort for passengers when the plane tilts to change direction. In the end, higher efficiency planes (lower fuel consumption) are essential for passengers’ comfort and to lessen planes’ environmental impact.

Technical Drawings/CAD:



Optimized and Completed CAD of the plane with the appropriate materials. The wing's material changed from a thin sheet of bent balsa to a micron covering film to significantly reduce the mass of the plane while keeping the plane above 7 grams.

Conducted flow simulation to ensure smooth airflow and correct possible fracture points.



Engineering drawing presenting the plane in 3-D, top, right, and front views with fully defined measurements.

Technical Attributes following Construction

Wing

- The pieces of wood making the chord is similar to the proposed shape of the most effective airfoil proposed by NASA- https://www.grc.nasa.gov/www/k-12/airplane/shape.html
- Wing is elevated high off of the fuselage, so the air flows through the wings and is then caught by the tail wing.
- 1/8”x1/16” wood connects the fuselage to the wood on the wing providing a strong but light-weight connection to keep the plane intact.
- The ends of the wing, perpendicular to the wingspan, provide extra stability by preventing vortex shedding
- Micron Film, covering the wing, helps cover/make up the wing without adding significant amounts of mass. Lower mass allows the plane to be more easily supported with minimal thrust (propeller).
- Wing is angled towards one side to create a banked wing, providing greater centripetal force to allow the plane to travel in a circular motion in order to sustain a greater time in limited space.
- Gorilla Glue Gel, glue used to assemble the entire wing, attaches all the wood to each other and the micron covering to the wood.
- Tape on the wing covers any unintentional hole in the mylar film to avoid air leaks.

Fuselage

- Made of 3 struts—1/16”x1/4”x12.75” balsa—connected together with Gorilla Glue to make the strongest but lightest fuselage. Used principles of plywood, which is wood attached and compressed to make the wood stronger. Fuselage is made long enough to fulfill the 32.5 cm (33 cm) requirement and to move the center of mass more towards the center, away from the propeller, to allow for a slower flight.
- Propeller holder is a part sold by Freedom Flight (https://www.freedomflightmodels.com/parts.php), who build very light-weight propellers and holders to complement it; the propeller holder is 3D printed. It is attached to the fuselage using Gorilla Glue Gel.
- The back-end motor-holder is also sold by Freedom Flight, who build this hook by 3D printing it. It is attached to the fuselage using Gorilla Glue Gel.

Landing Gear

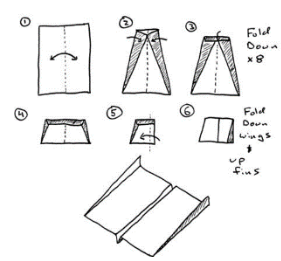
- The axle is a 6.5” carbon-fiber rod with a 1/16” diameter in order to make the landing gear as light as possible.
- The wheels are made of 2 cm diameter circles of Elmer’s foam board which have a thickness of 0.5 cm. This ensures light-weight wheels to make the lightest plane possible.

- The rubber around the wheels are blue Rainbow Loom rubber bands that have been twisted multiple times around the rod so that it grips the rod tight enough to stay on the axle and hold the wheels in place.
- The wood connecting the carbon fiber axle to the fuselage is a 1/8"x1/8"x4 1/4" piece of medium-density balsa wood connected perpendicularly to the fuselage to provide enough strength for when it lands (balsa is stronger under direct compression).

Tail Wing

- The horizontal stabilizer, identical to the wing, serves as an elevator, elevating the back-end of the plane high enough to glide smoothly and rise into the air gradually.
  - The horizontal stabilizer is made large in order to catch an appropriate amount of air to elevate the back enough.
    - Catching greater amounts of air would ultimately assist with the lift of the plane and would provide greater stability.
  - The struts that make up the chord form the same airfoil as the wing.
- The vertical stabilizer is embedded onto the wing using the vertical parts of the wing on the two ends to prevent vortex shedding in the rear end.
  - The back-end of the plane serves as the direction controller, so the vertical stabilizers allow the wing to remain resistant to fluctuations in the air.
  - The vertical stabilizer is embedded as the vertical parts of the wing based on the design of the best paper airplane gliders in the world (https://www.wired.com/2012/04/world-record-paper-airplane/).

How to Fold a World-Record Paper Airplane



- All the portions of the wing of the tail wing assembly are constructed in the same way as the wing.
- The tail wing is attached to the fuselage using two 1/8" x 1/16" x 8" pieces of balsa wood, providing enough strength and flexibility for supporting the tail wing's mass.
  - This connection is strengthened using 2 pieces of ¼"x1/16"x1" balsa serving as lap joints to increase surface area for strength.
- 1/8" x 1/16" x 5" piece of wood rigidifies the tail to control the width of the circle.

Propeller (bought from https://www.freedomflightmodels.com/props.php)

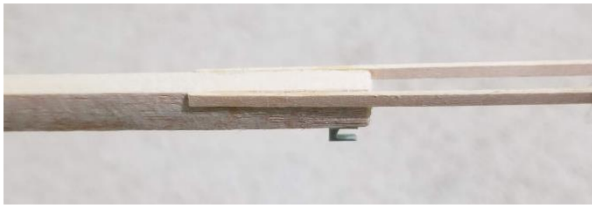
- The propeller has a fixed pitch to conform with the rules in Section E2 of the Flight Endurance rules, adjusted to a pitch that is deemed optimum by Freedom Flight.
- The red, plastic ball bearing minimizes the friction between the plastic parts of the propeller. It reduces friction by minimizing the area in contact between the parts.
- The aluminum wire holding all the parts of the propeller assembly together allows the assembly to be low in mass as aluminum is one of the lightest metals.
- The piece that is inserted into the propeller holder (attached to the fuselage) allows replacement or changes in the propeller in case the propeller breaks and needs to be replaced. The propeller can be taken out and put in at ease.

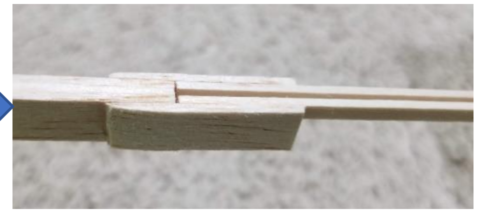
- The hook on the end of the wire holds the rubber motor which would spin the aluminum wire and the propeller.

The motor used to attach to the propeller and the fuselage has a thickness of .072” and is of light density so that the mass of the rubber will remain under 1.50 grams and have a proper thickness (allows for more tension).

Modifications after Finding Deficiencies

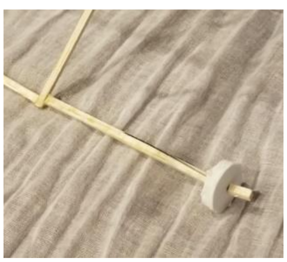
Tail Wing to Fuselage Attachment





- The original tail wing to fuselage attachment caused the entire tail wing assembly to be very flimsy which seemed to have affected the flight.
  - Overtime, the wood became even flimsier because the wood had bent a lot during the many flight tests already conducted.
  - The wood seemed as it was about to break, so a new assembly and connection to the fuselage was made.
- The new tail wing to fuselage assembly provides more support as the two pieces of wood are positioned closer together, which increases strength.
  - The lap joint also strengthens the joint between the fuselage and tail wing assembly.
  - The lap joint is also sanded into a more curved shape, allowing for the air to be better streamlined.

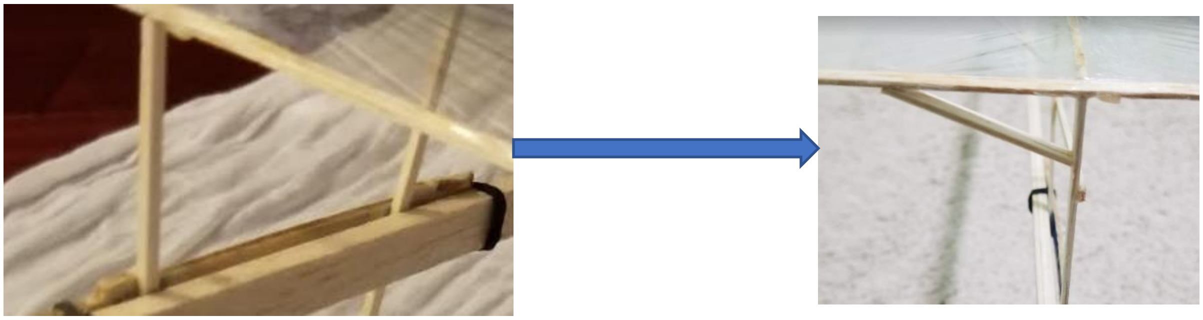
Landing Gear



- The original landing gear had a mass of 4.3 grams, which added a lot of weight to the location in which it was placed.
  - The original contained a 1/8”x1/8” piece of balsa with a thin carbon fiber rod running through each section as the axle. The wood seemed unnecessary and added a lot of weight.
  - The joint of the original landing gear (connecting the two sections of wheels) constantly broke, and the carbon fiber was not a single rod running through the entire landing gear (not supporting the structure from breaking at the joint).
- The new landing gear uses the same wheel, but the axle is a thicker carbon fiber rod running through the entire landing gear.
  - The stiffer carbon fiber rod allows the structure to be stiffer and strengthens the axle although it does not have a wood casing. It also greatly reduces the mass of the landing to 2.7 grams.

- The rubber bands are also very light, keeping the wheel in place and reducing the mass of the plane.

Wing Structure (Supports)



- The original wing had no structural support to support the wing from tipping one way or the other and from breaking off. The glue is the only thing keeping both intact.
    - The sticks also frequently separated from each other, damaging the wing and ruining the air foil of the wing.
- The new wing has structural support supporting the wing by connecting it to the post coming from the fuselage.
    - This disallows the wing from accidentally tipping due to a poor glue-job. This also disallows the wing from breaking off by providing more surface area that is in contact with the post.
    - The stick connecting the two posts prevents the two posts from moving apart from each other and coming close together. This will not allow this to ruin the shape of the wing.

- The original wing was very weak and flexible.
    - The flimsy wing allowed for more vortex shedding, causing more bend in the wood. The frequent bending was caused by the resonance with natural frequencies of vibration, ultimately causing the structural member to disconnect.
- The new wing is more rigid and requires a higher natural frequency to resonate.
    - Since the resonance was limited, this provided to be more effective in preventing vortex shedding.

- The plane travels much more smoothly with the lessened vibrations caused by the flow separation.
- The new wing had not broken as much as it did with the previous wing type.

Current Prototype

Plane needs more testing and experimentation with different types of rubber. The plane shown in the video was the video of its first flight, demonstrating the success of research and application of the research.

After optimizing the rubber (after 3 tries), the plane's flight time reached 2 minutes and highest elevation reached the top of the ceiling.

The plane ***will be further tested*** *once obtaining an open location following COVID-19.*

Rubber motor excluded in the image.