3: Practical activity #1

Cardboard glider construction and flights

Estimated Duration: 3 hrs

Abstract

In this lab, we will be constructing gliders out of cardboard. A glider is an aircraft that has a large wingspan intended for maximizing lift over drag. This is a key performance factor of flight endurance. Gliders are generally unpowered, meaning that a glider must rely on momentum and gravity to produce its forward velocity, and in turn, its lift. The gliders made today will be hand-launched and will serve as good models for defining and identifying all of the principle forces that act on an aircraft.

Key Vocabulary and Acronyms

LE - Leading Edge
CG - Center of Gravity
CP - Center of Pressure
CNC - Computer Numerical Control (Usually refers to manufacturing machines such as lathes and mills, depending on the parts)
Horizontal/Vertical Stabilizer - The parts of the tail that do not move relative to the aircraft
Empennage - Tail assembly. Includes both horizontal and vertical stabilizers, rudder, and elevator
Aspect Ratio - Defined as the square of the wingspan divided by the wing area, this unitless parameter is a good indication of a wing's aerodynamic efficiency.
Lift – One of the four principle forces that act on an aircraft, responsible for keeping the aircraft off of the ground.
Drag – Another of the four principle forces, acts in the reverse direction of the plane's motion.
Thrust – The third of the four principle forces, is created by the engines and propels the aircraft forward.
Weight – The final and most common principle force, created by the force of gravity acting on the aircraft.

Equipment Needed

This lab has been designed to use as many common household items as possible to ensure everyone has equal opportunity to build this aircraft. However, these are by far not the only materials you could use to do this project, so while the items listed below may be the most commonly found, feel free to substitute them for whatever other equipment you would be able to use instead. NOTE: This glider lab has been written specifically for a paperboard design, if you are using cardboard or paperboard, please refer to the other glider build manuals.

Items:

- Paperboard
- Scissors/Box Cutter
- Ruler/Tape Measurer
- Pencil
- Wood/White Glue
- Packing Tape

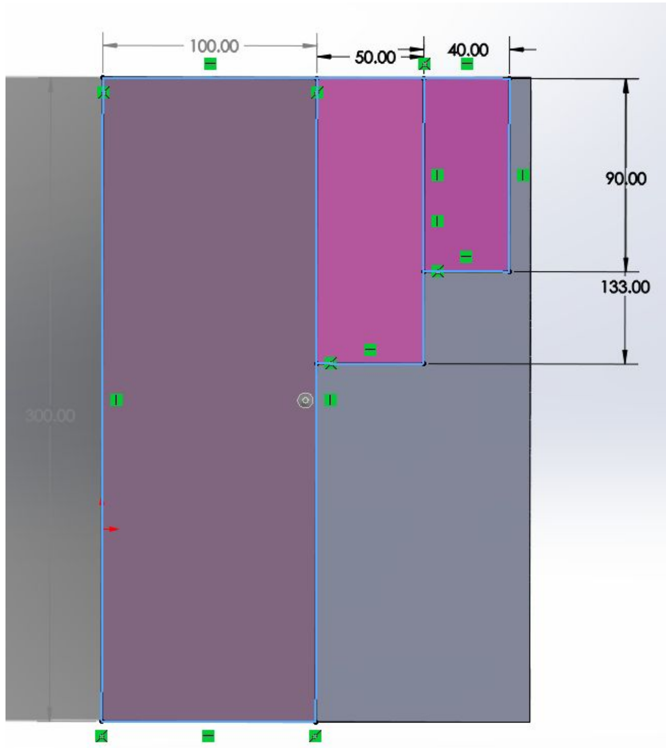
Material Notes

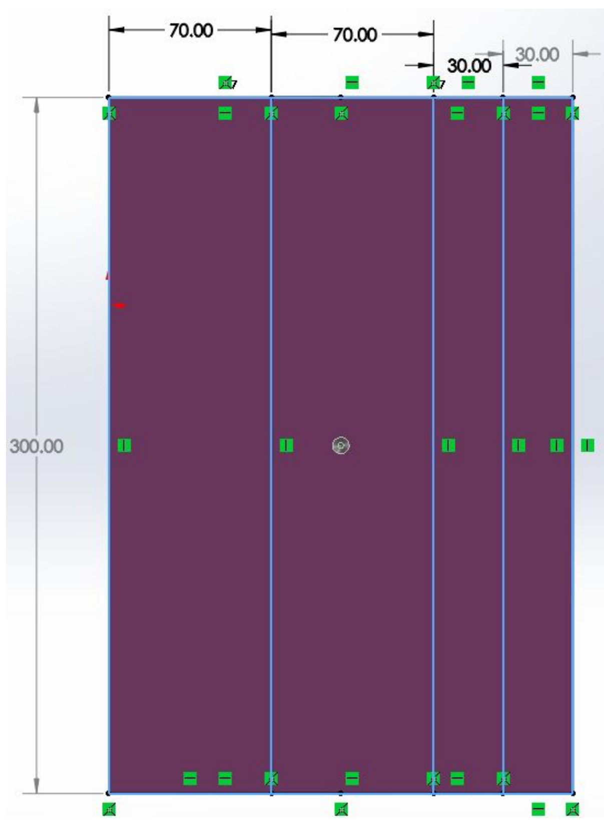
This glider build instructional is written around creating a glider from the paperboard that constitutes a "normal" sized cereal box; 30 x 20 x 5 cm. While this should be the most accessible build, it is also the weakest. So if you have access to enough cardboard or foamboard, I recommend building one of these instead, however, if you do not, that is okay as you will still be able to make a glider that clarifies the forces and principle components of a fixed wing aircraft.

Glider Building Instructions

Step 1: Cut out the following sized pieces of paperboard

Begin by using your ruler to measure out the following sized rectangles onto your pieces of paperboard and cut them out using the dimensioned sketches in Figure 1 for reference on where to source the material from a common 30 x 20 x 5 cm cereal box.





Figures 1 - Paperboard cereal box glider part dimensions

Table 1 - List of rectangular glider pieces and their dimensions

Glider Parts List		
Part:	Quantity:	Dimensions (mm):
Wing (Lower Surface)	2	200 x 70
Wing (Upper Surface)	2	200 x 30
Fuselage	1	300 x 100
Horizontal Stabilizer	1	133 x 50
Vertical Stabilizer	1	90 x 40

Step 2: Cut out the control surface slots

Once you have all the pieces cut out, cut the following marks in your wing, vertical, and horizontal stabilizer so that you can form your control surfaces. This will be just a single straight-line cut on the marked red lines so that you can form the control surface from the stabilizers and wing like you see in Figure 5.

Figure 2 - Control Surface Cut Dimensions (Wing)

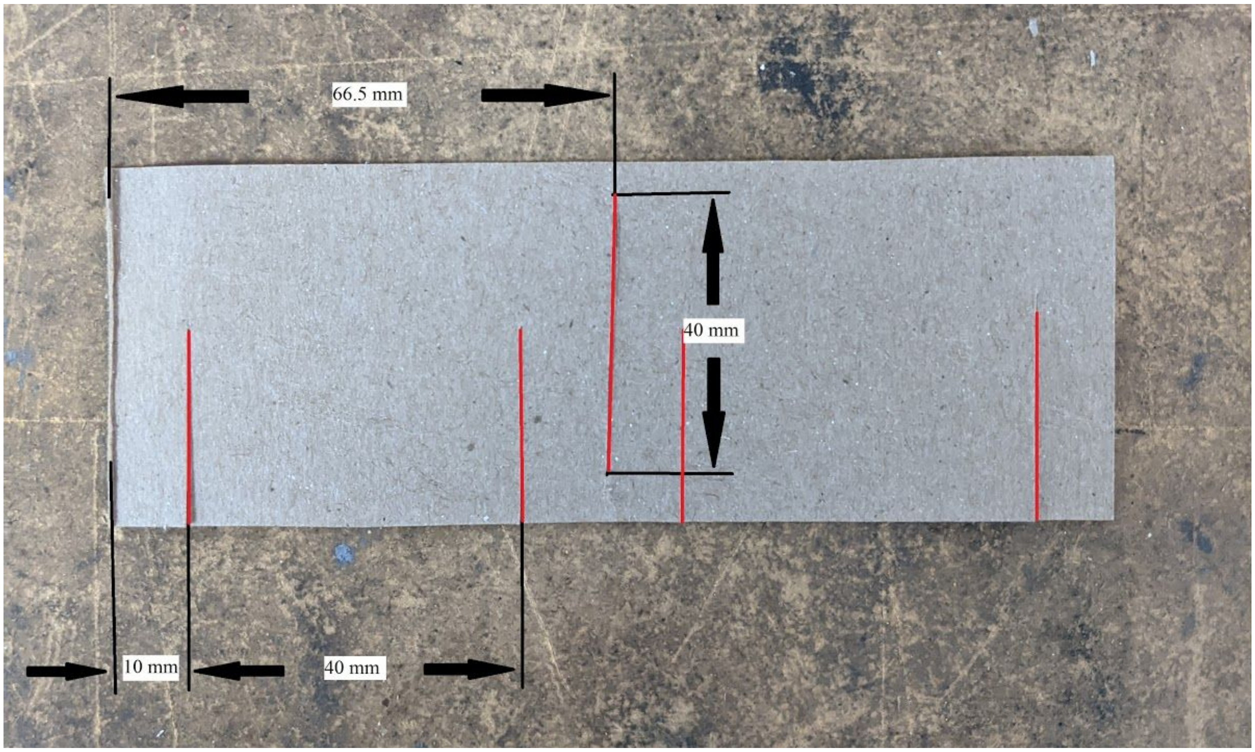


Figure 3 - Control Surface Cut Dimensions (Horizontal Stabilizer)

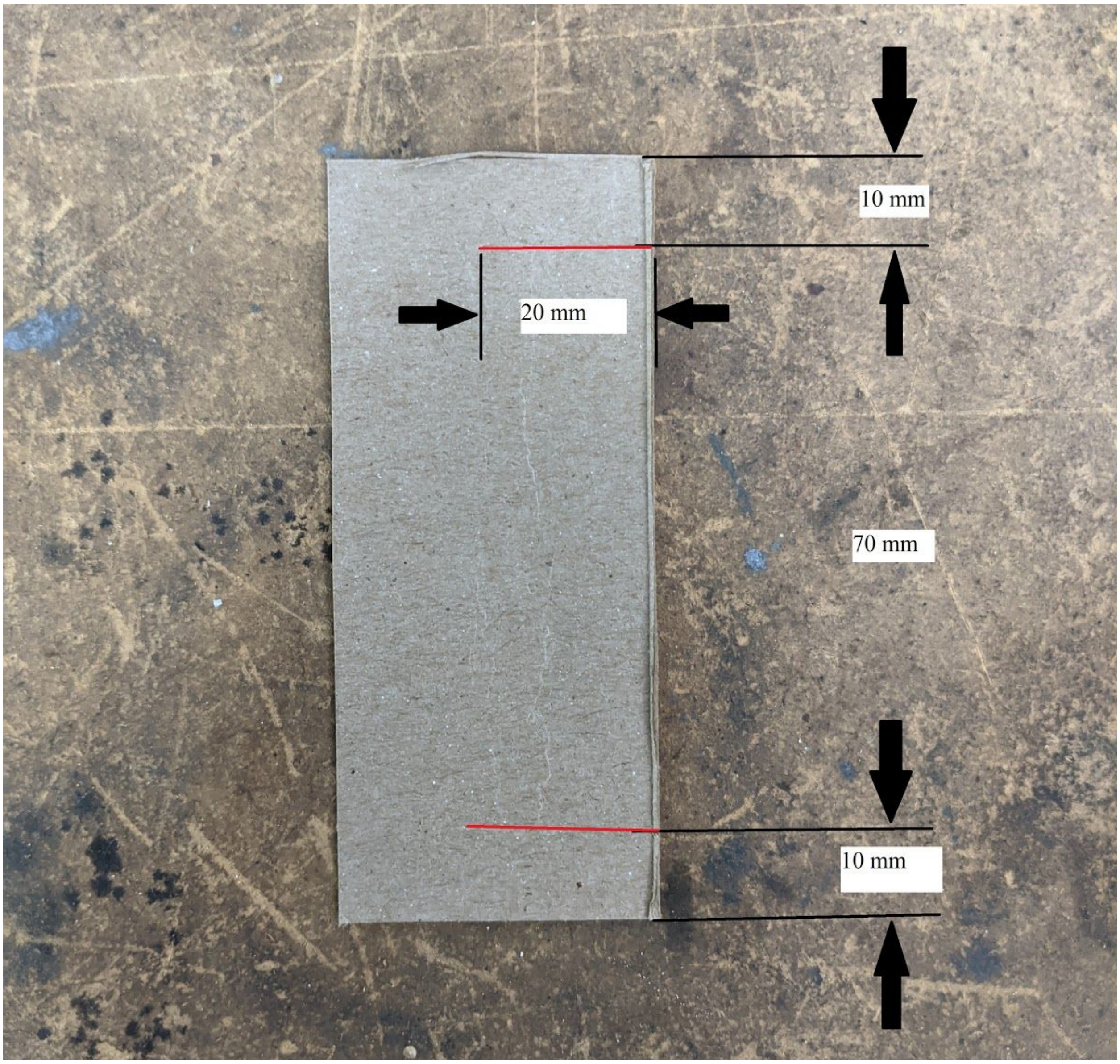


Figure 4 - Control Surface Cut Dimensions (Vertical Stabilizer)

These cuts will allow you to form your control surfaces so that you can control the flight of your glider. The control surfaces will fit into the wing and stabilizers like seen again in Figure 5.

The control surfaces that you will be adding to the wing and stabilizers are meant to be reversible in order that both a deflection upward and downward can be created with them. Simply flip the aircraft over and bend the control surfaces in the opposite direction like in Figure 5.

Figure 5 - Wing with aileron formed

Step 3: Folding and taping the fuselage together

Here you will divide your fuselage into thirds, lengthwise, and fold into a triangular prism to create the fuselage of your glider. Bending the two sides up and together like you can see in Figure 6, tape diagonally along the entire length of the fuselage to fully enwrap it and create the fuselage structure.

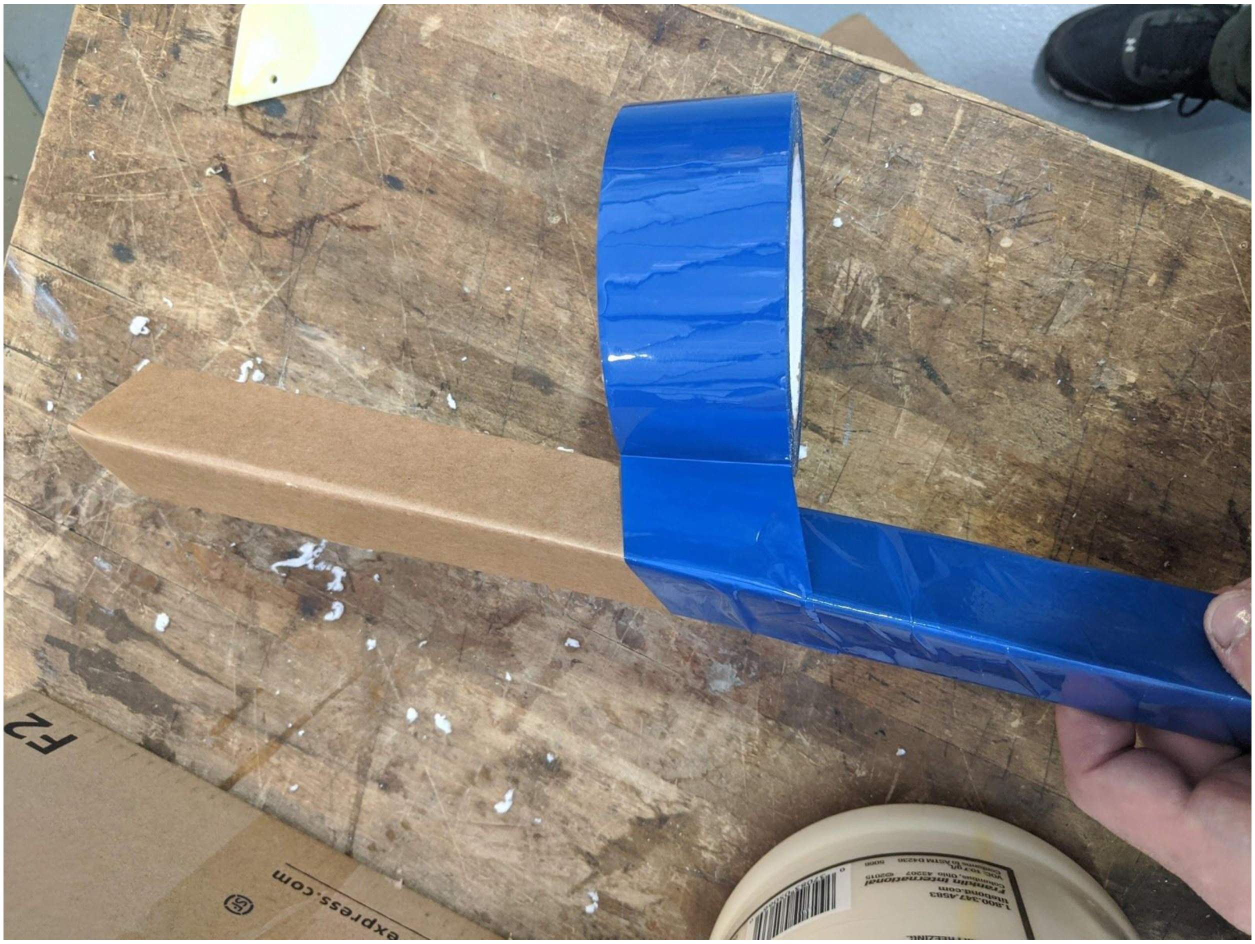


Figure 6 - Folding and Taping Fuselage

Step 4: Putting everything together

You will now begin to glue all of the pieces together to create your gliders. First begin by gluing the upper surface of the wing to the lower surface. Make sure that the upper surface is flush with the leading edge of the lower surface. You can look at Figure 7 for reference of how the wing should look.

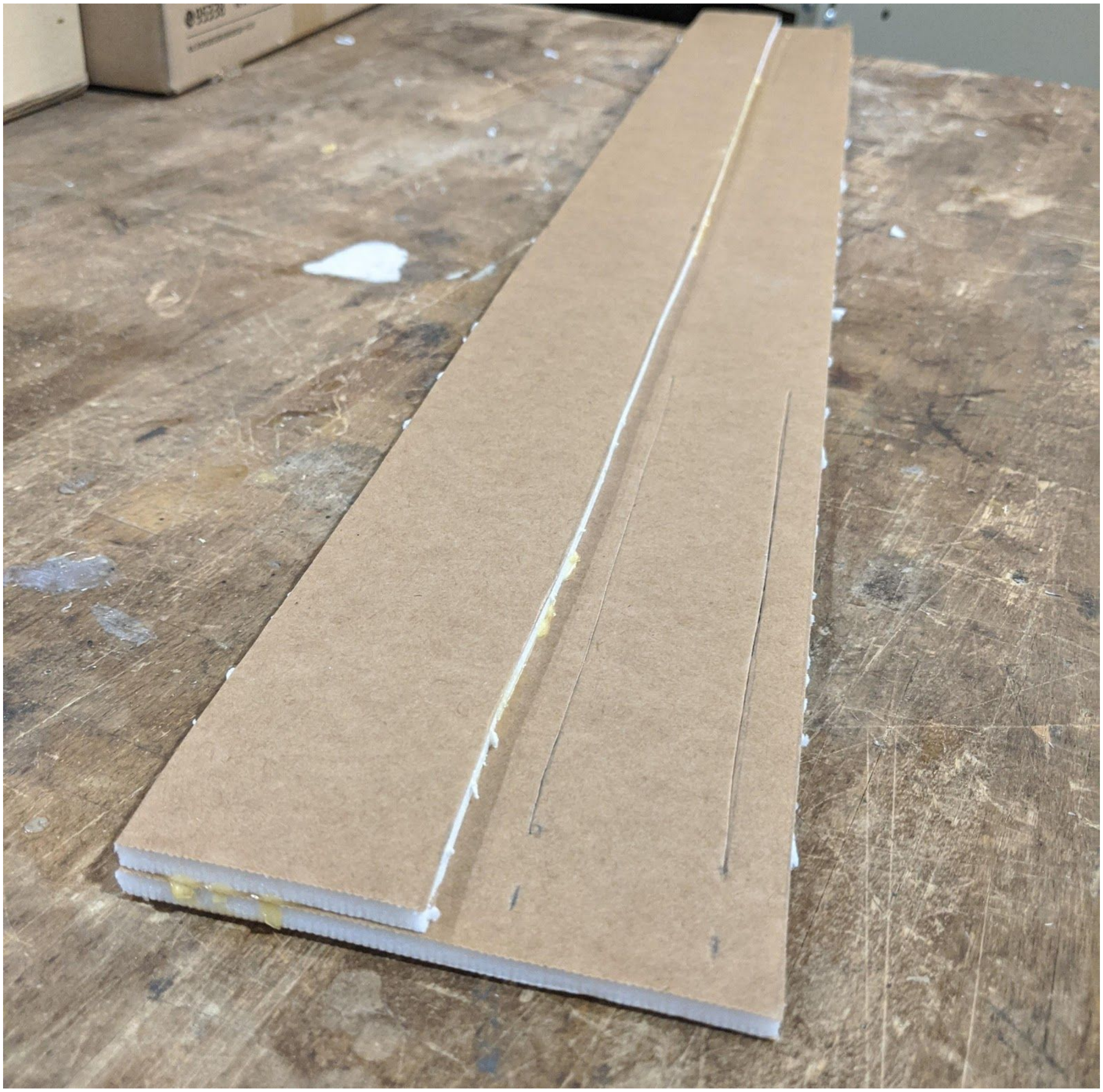


Figure 7 - Wing Shape

The reason the wing looks like this is twofold. It first adds needed structural support to the wing since it has such a large aspect ratio. This will keep the wings from bending upwards too greatly during flight. Next, this actually will create a very simple type of airfoil known as the KFm-2 that has good performance in the low Reynolds Number flight envelopes such as the glider will see. Figure 8 shows a list of the most common KFm airfoils and you can see where the KFm-2 lies on the chart. The reason the KFm-2 variation was used instead of another one was because the average thickness of cardboard will create a wing thickness equal to approximately 10% whereas all other variations would either take more work to create instead of gluing two pieces of cardboard together or they would be too thick if three or more pieces were glued together.

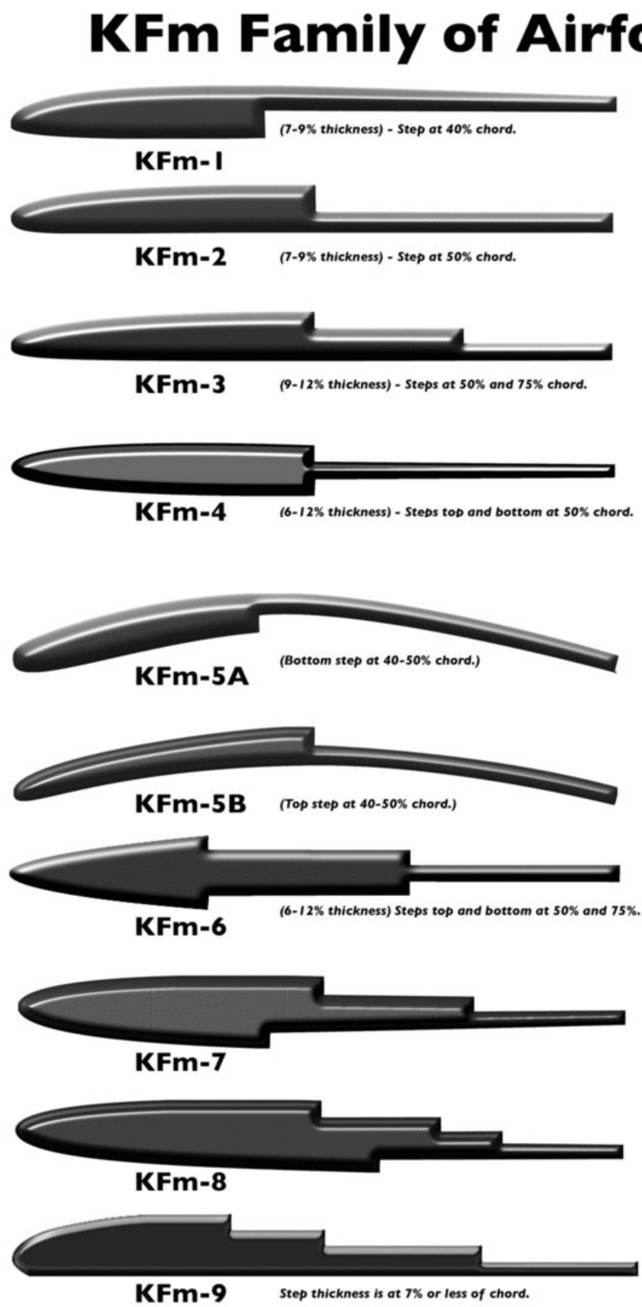


Figure 8 - Chart of KF Airfoils

After the wing has been created, see Figure 9 to locate the areas that the wing and stabilizers should attach to the fuselage. You will again just use your glue to attach the wings and stabilizers, making sure to keep them as centered as possible.

Figure 9 - Fuselage Wing and Stabilizer Placement

Begin by gluing the wing to the fuselage in the same place as the picture above. It might help to flip the fuselage and wing over so that the wing is laying flat on the table with the fuselage being securely pressed on top while the glue dries.

Next, you should carefully slot the vertical stabilizer into the horizontal and glue to create the empennage. See Figure 10 for reference. Ensure that the control surfaces on both the horizontal and vertical stabilizer are facing the same direction and that the empennage is facing forward. Wait until the empennage is fully dried before attempting to glue to the fuselage.

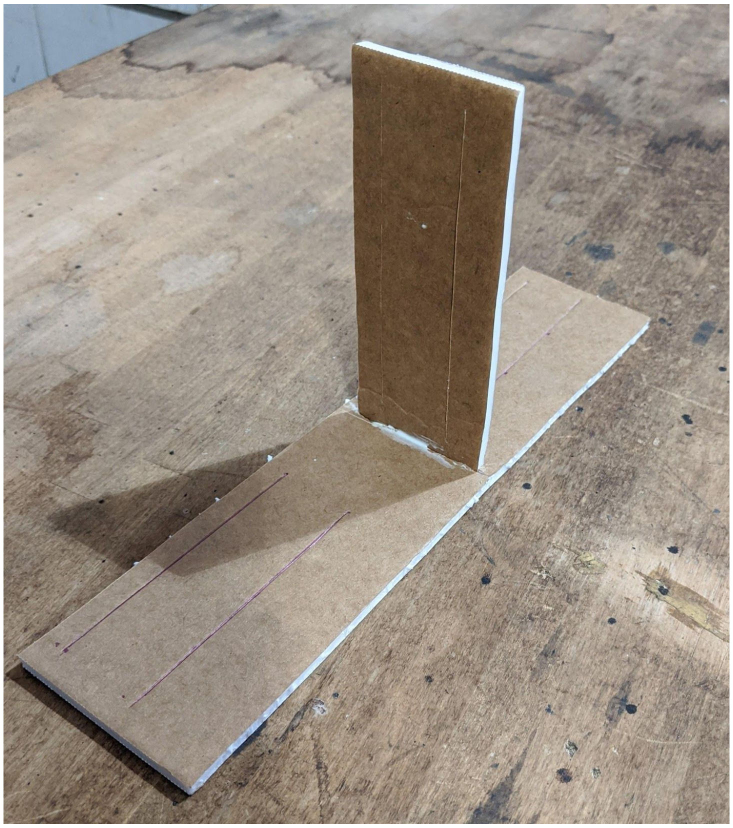


Figure 10 - Vertical stabilizer slotted into the horizontal stabilizer to make the empennage

Finally, glue the empennage to the fuselage in the same spot as shown in Figure 9. Again make sure that the control surfaces of the empennage are oriented in the same direction as those on the wings, i.e. farthest away from the nose. Ensure that the vertical and horizontal stabilizers remain perpendicular while drying and that the whole empennage is not twisted relative to the fuselage.

Step 5: Trimming and CG adjustment.
Once the glider has finished drying, you will find that the Center of Gravity (CG) of the aircraft is too far behind the Center of Pressure (CP) of the wing. When you toss your gliders, they tend to lean back and stall very quickly. To correct this, add more mass to the front of the aircraft until its CG is located at approximately 40% of the chord length from the leading edge (LE) of the wing. This should make the aircraft fly much more stable than you observed earlier.

In order to check whether or not an aircraft's CG is at 40% chord, hold up the aircraft by both wingtips with your two index fingers and slide them down the width of the wing tip until the front and back of the aircraft are both level. Once this position is slightly in front of the midway point of the wing, your aircraft should be stable in flight. It will take some adjustment to make the gliders fly optimally.

Glider Control Surface Introduction

After successfully learning how to trim your aircraft, it's now time to identify each of them and understand what exactly those control surfaces do. The control surfaces on the wings are known as ailerons, the ones on the horizontal stabilizers are called elevators, and the one on the vertical stabilizer is a rudder. They all work on the same principle as one another, but because of their orientation, location, and movements, they make the aircraft move differently than the others.

Looking below at Figure 11, observe the difference between a deflected control surface and one that's not. When a right-side up airfoil is deflected downwards, the camber of the airfoil is effectively increased which also makes the airfoil effectively "see" a higher angle of attack therefore increasing lift. When the control surface is deflected upwards, the opposite effect occurs and the airfoil will lose lift.

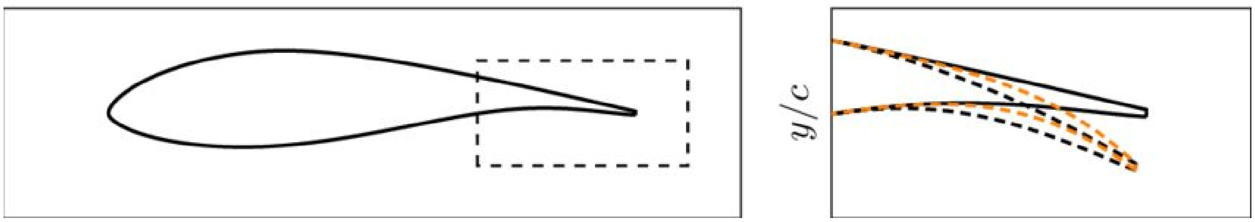


Figure 11 - Image highlighting control surface deflection

The ailerons on the wings will always move opposite of one another, i.e. meaning that if the right one is deflected upwards, the left one will deflect down and vice versa. The ailerons are responsible for controlling the rolling action of an aircraft as one wing begins to produce more lift and the other produces less.

If you wanted to roll an aircraft to the right, how would the ailerons be oriented on each wing?

The rudder on the vertical stabilizer works by producing more lift either one way or the other, so when looking down an aircraft from the back, if the rudder is deflected to the left, the nose of the aircraft will also point left and vice versa.

The elevators on the horizontal stabilizers will always work in tandem with both either deflecting upwards or downwards. The thing about the horizontal stabilizers and elevators is that they are actually designed to produce lift downwards! Referencing Figure 12, you'll be able to tell why the tail actually needs to produce downforce in order for the aircraft to fly straight and level. So when the control surface is deflected upwards, the horizontals will produce more downforce sending the nose of the aircraft up and vice versa. The exact reasoning for why both aerodynamic forces are located behind the CG will be explained in the lecture after today's lab, but keep this in mind and see if you can figure it out beforehand!

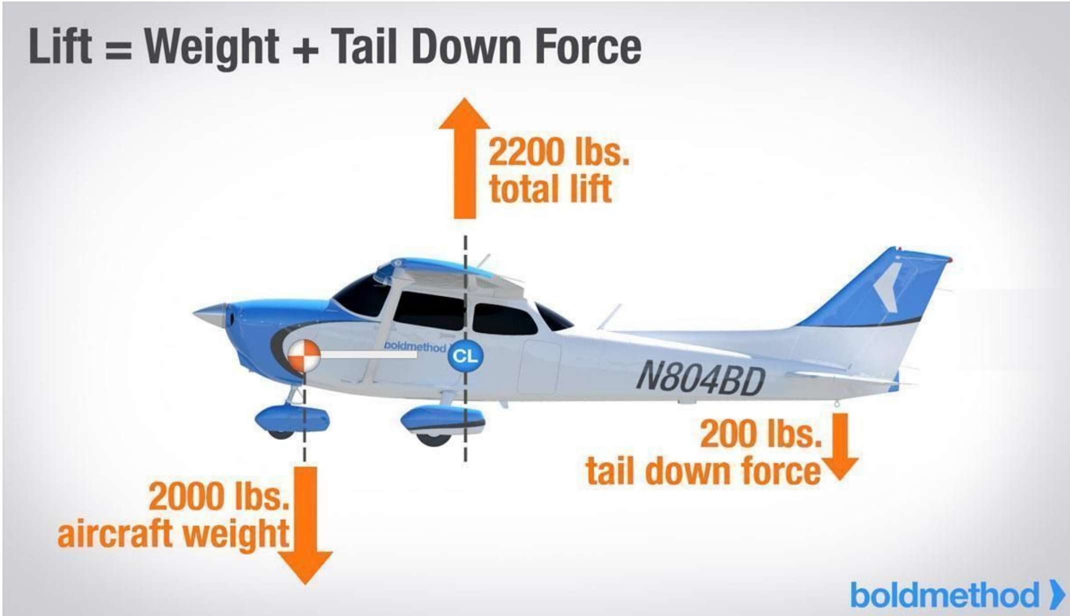


Figure 12 – Force balance diagram to highlight tail downforce

Table 2 can be used as a quick reference guide for how to move the control surfaces to achieve the desired aircraft movements!

Table 2 - Aircraft maneuvers and the corresponding control surface deflections

Control Surface Cheat Sheet	
Aircraft Maneuver	Control Surface Deflections
Roll Right	Right aileron up, left aileron down
Roll Left	Right aileron down, left aileron up
Yaw Right	Rudder right
Yaw Left	Rudder left
Pitch Up	Elevator Up
Pitch Down	Elevator Down

Glider Control Activity

Now, with your glider build completed, it's time to predict and observe the aircraft's movements by adjusting the control surfaces in the same fashion shown above.

Try to make your aircraft perform the following maneuvers by adjusting the control surfaces.

1. **Roll right**
2. **Roll left**
3. **Pitch up**
4. **Pitch down**
5. **Yaw right**
6. **Yaw left**
7. **Roll right AND pitch up**
8. **Yaw right AND roll right**
9. **Yaw left AND pitch down**
10. **Roll left AND pitch down**

How did these go? Were you able to successfully complete all of the maneuvers? While the aircraft was clearly stuck in the maneuvers that your control surfaces dictated, hopefully you can see now how being able to control these control surfaces during flight would allow an aircraft to move any way it wants!