BEAM Takes Flight!

Evan Chin & David Paner | Fall 2020

Adapted from: David Paner's Fall 2018 Lesson, Takeoff, Gyro, and Off Balance

Field(s) of Interest: Aerospace Engineering, Physics

Brief Overview:
In this lesson, mentees will learn about the mechanisms and forces behind flight through fun builds and demos!

Agenda:

- Module 0: Plane Wing Demo (15 mins)
    - Alternate: Toilet Paper Demo (5 mins)
- Module 1: Hand Helicopters (15 mins)
- Module 2: Floor Skimmers (20-25 mins)
- Conclusion (5 min)

Teaching Goals/Key Terms:	**Mentor Development Goals:**
➔ **Bernoulli's Principle** - points of faster moving fluids will exert less pressure than points of slower moving fluids ➔ **Forces of Flight:** ◆ **Lift** - another mechanical force generated by the interaction between an object and a fluid that acts upwards. ◆ **Weight** - downward force acting on an object from gravity. ◆ **Thrust** - a mechanical force that works with a working fluid that propels an object in the opposite direction of the fluid ◆ **Drag** - aerodynamic force akin to friction that opposes an aircraft	

Background for Mentors: Module 0

Teaching Goals

- Bernoulli's Principle
- Forces of Flight:
  - Lift

Airplanes take advantage of many different types of forces, but the one integral component to increasing its altitude is called **lift**. Lift is a force that pushes upwards on the wings of airplanes, allowing the entire structure to rise. The other key forces, **weight**, **thrust**, and **drag** will be discussed in greater detail during the next modules.

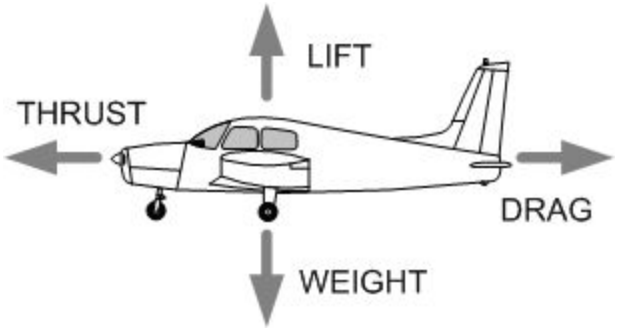

Figure 1: The four main forces of flight—lift, weight, thrust, and drag

The way airplanes generate lift isn't as simple as it first appears. Air moves across both the top and bottom surfaces of the fixed-wings, but it is the *speed* of the moving air that allows the wings to generate lift. This is where **Bernoulli's principle** comes in. This principle states that as a fluid's speed increases, the pressure it exerts *decreases*. The *shape* of the wing allows for a difference in air pressure between the air on the top and the air on the bottom of the wing. For one thing, air moves faster over a *curved* surface because it needs to travel a farther distance. Take **figure 2** below. The air moves must travel a farther distance across the top of the wing, meaning it must speed up, *decreasing* its pressure. This means that there is a lower force of pressure pushing down on the wing than there is pushing up on the wing. The resulting net force is an upwards force, generating the lift that the plane needs in order to gain altitude.

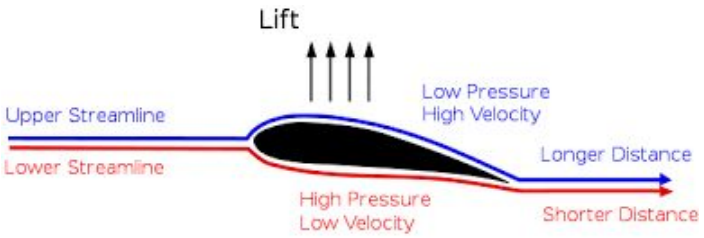

Figure 2: *The shape of a wing helps air travel faster over the top than the bottom— creating lift through Bernoulli's principle.*

Background for Mentors: Module 1

Teaching Goals

- Rotary Wings
- Torque
- Forces of Flight:
  - Lift
  - Weight

Unlike airplanes which utilize fixed-wings to generate lift, a helicopter utilizes **rotary wings** in order to fly, allowing it to perform movements that an airplane cannot—such as hovering and flying backwards. Helicopters move air over their wings by spinning them, and this creates the air pressure differential via Bernoulli's principle that generates **lift**.

Figure 3: A helicopter's rotor blades allows it to hover and fly forwards, backwards, and laterally.

All this spinning requires a great amount of rotational force—**torque**, which by Newton's third law would cause the helicopter fuselage to spin around in the opposite direction of the blades' movement. This is why helicopters have *tail rotors*, to counteract the torque of the main rotors and keep the helicopter straight.

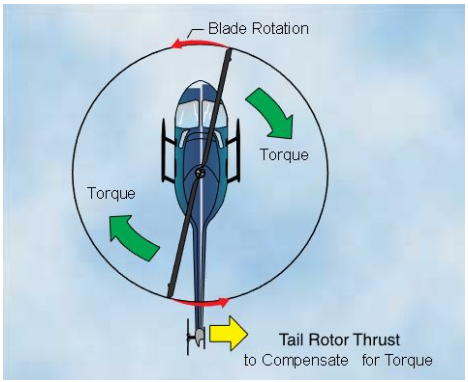

Figure 4: *The tail rotor provides thrust in the opposite direction of the torque generated from the main rotor, preventing the helicopter from turning in the direction of the main rotor*

The hand-helicopters made in this module will eventually come back down due to **weight,** the downward force of flight due to *gravity*. We will see a more vivid example of the final two forces of flight, **thrust** and **drag** in the next module.

Background for Mentors: Module 2

Teaching Goals

- Forces of Flight:
  - Thrust
  - Lift
  - Weight
  - Drag
- The Engineering Design Process

We have already learned how fixed-wing airplanes generate **lift**, but what about the other forces that act upon the plane? **Thrust** is the force that pushes the from the back, propelling it forward and moving air over its wings. Thrust can come from a variety of sources, such as—propellers, jet engines, turbines, and rockets. In this activity, thrust will come from the push that mentees give to their floor skimmers.

There are also two major forces that oppose lift and thrust. These two forces are known as **drag** and **weight**. **Weight** is the easier force to visualize, as we experience it every day. It is the gravitational pull that the Earth enacts upon the airplane, bringing it downward.

The force that opposes thrust is known as **drag**. **Drag** is a type of **friction**, a force that is caused by two objects sliding against each other. While not noticeable in everyday life, air provides high amounts of friction (also called *air resistance*) for airplanes as drag increases with the speed of an object. Another factor for friction is the surface area of contact between the two objects sliding against one another. This is how parachutes work: by having a high surface area, they provide more air resistance for a skydiver than the person's body does alone, and slows down the skydiver's fall (which is caused by weight). Contrarily, airplanes are shaped in a form that reduces air resistance in order to fly faster, also reducing the fuel required to travel large distances.

Figure 5: Aircrafts are able to reach extreme speeds with immense thrust and aerodynamic designs that reduce drag

While our floor skimmers won't actually fly, we will be seeing all four of these forces in action.

Introduction

Concepts to Introduce ● Planning on flying in an airplane soon? Well probably not, but here's the science behind the forces of flight! ● Forces make things move. Forces working in the same direction can add, and forces working in opposite directions can cancel each other out. ● We will focus on 4 forces of flight. They can be thought of as forces acting in the up, down, forward, and backward directions. ● Friction is a type of force that occurs when two objects slide against one another.	**Current or Past Events** ● Drone Light Shows - drones use rotary wings to perform intricate maneuvers and create elaborate spectacles ○ https://www.intel.com/content/www/us/en/technology-innovation/aerial-technology-light-show.html ● Unmanned Aerial Vehicles - advances in digital technology have allowed aircraft to travel remotely or completely autonomously ○ https://news.northropgrumman.com/news/releases/global-hawk-unmanned-reconnaissance-system-sets-aviation-record-with-deployment-to-australia ● Renewed interest in commercial supersonic flight ○ https://www.routesonline.com/news/29/breaking-news/276059/japan-airlines-buys-into-us-start-ups-supersonic-dream/
Questions to Pique Interest ● How are airplanes able to generate lift and get off of the ground despite weighing hundreds of tons (hundreds of thousands of pounds!)? ● What can helicopters do that airplanes can't? How are they able to do this? ● How would you design an airplane that would be able to travel at extreme speeds? ● Raise your hand if you have ever been on an airplane! ● What is a force? How do forces relate to the movement of objects?	**Real-life Scientists, Careers, Applications** ● The Wright Brothers - Aviation pioneers credited with developing the first successful motorized airplane all ● Aerospace Engineering - The field of engineering concerned with the development of aircraft and spacecraft.

Module 0: Paper Wing Demo

Bernoulli's principle states that as a fluid increases its speed, the pressure it exerts decreases. Additionally, as air travels over a curved surface, its speed increases. Using these two ideas in tandem, we will show how lift works by constructing a model of an airplane wing.

Teaching Goals	**Materials**
1. **Bernoulli's Principle -** points of faster moving fluids will exert less pressure than points of slower moving fluids 2. **Lift -** the perpendicular component of a force exerted by a liquid on an object that it is flowing past	• 1 piece of printer paper per site • 1 roll of Scotch tape per site • 1 roll of string per site • 1 straw per site • 1 hole puncher per site • 1 hair dryer per site • 3 pairs of scissors per site

Procedure

1. Take a piece of printer paper and fold it *about* 3" along the longer edge ("hamburger" style), so that you are left with a square shaped piece of paper **(see figure 6)**

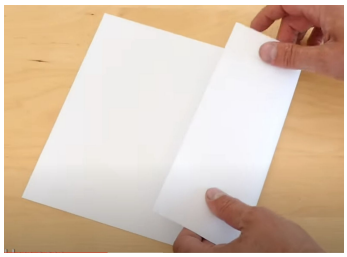

Figure 6: *No need to be exact!*

2. Cut the longer side of the paper so that you are left with about 3.5" on the longer side. You should be left with a piece of paper approximately 7.5" x 8.5", folded slightly unevenly. **(see figure 7)**

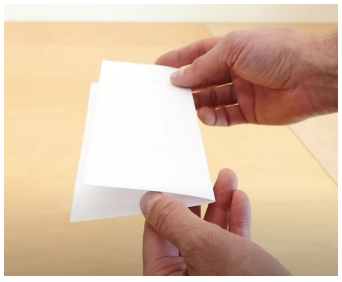

Figure 7: *Make sure one side is slightly longer than the other when folded*

3. Tape the edges together, so you have a "wing" with a curved top (the slightly longer side) and a flat bottom (the slightly shorter side)

4. Have the kids explain the following:
    a. What is the difference between a curved surface and a flat surface, in terms of Bernoulii's Principle?

Answer:
The curved surface speeds up the air moving over it, so the pressure on the curved surface is lower than the pressure on the flat surface

5. Using a hole puncher or a pencil, make a hole in the middle of the long side of the wing, about 1” away from **one** of the long edges.

6. Cut about 2” off of a straw and place it in the hole, taping it so that it stays in place. **(see figure 8)**

7. Take a piece of string of at least 4 feet and put it through the straw. Tape the string to (a) the floor and (b) a higher point (such as the bottom of a table) so that it goes straight up.

8. Now, take your hair dryer and blow it straight into the wing, and watch the wing rise upwards due to Bernoulli’s Principle! This is how airplanes are able to generate lift off of the runway. **(see figure 10)**

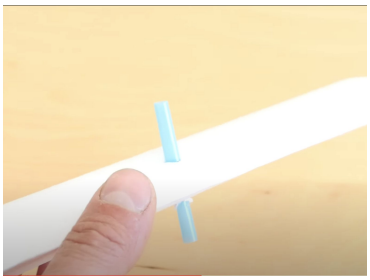

Figure 8: *Place the straw through the hole*

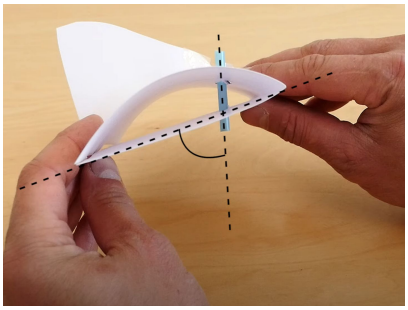

Figure 9: *Side view of straw in wing; notice the wing is slightly angled upwards*

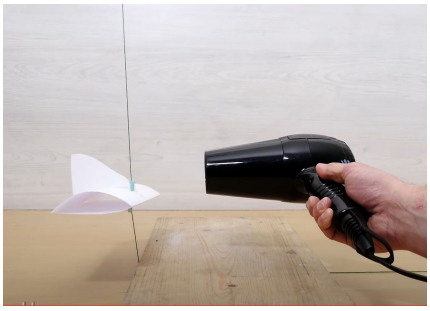

Figure 10: *Aim the hairdryer at the wing and watch it rise up the string like an airplane!*

Classroom Notes

To be added.

(Alternate) Module 0: Toilet Paper Demo

Essentially the same concepts as the previous module, but in a more time and material-friendly demo.

Teaching Goals	**Materials**
1. **Bernoulli's Principle -** points of faster moving fluids will exert less pressure than points of slower moving fluids 2. **Lift -** the perpendicular component of a force exerted by a liquid on an object that it is flowing past	● 1 roll of toilet paper

Procedure

1. Pass around the rolls around the class and have the students blow straight and over the roll with 2-4 squares hanging off the end

2. The loose end will rise up, just like an airplane wing does when air is moving through it

Figure 11: *Blowing over the top of a piece of paper causes it to rise*

3. Have mentees explain the following:
    a. What is the difference between a curved surface and a flat surface, in terms of Bernoulii's Principle?

    b. Why does the end of the toilet paper rise when we blow on the roll?

Answers:

a. the curved surface speeds up the air moving over it, so the pressure on the curved surface is lower than the pressure on the flat surface

b. As we blow over the top of the roll, the pressure above the roll decreases while the pressure below stays the same. This difference in pressure leads to lift, which causes the toilet paper end to rise.

Module 1: Hand Helicopters

Now that students are familiar with lift, Bernoulli's principle, and torque, we can now apply these concepts and construct some helicopters!

Teaching Goals	**Materials**
1. **Rotary wings -** wings that revolve around a mast, allows for more complex movements than a fixed-wing aircraft is capable of. 2. **Torque -** rotational force, the measure of how much a force acting on an object causes that object to rotate 3. **Weight -** The force of gravity, acts in a downwards direction toward the center of the Earth.	• 1 jumbo craft stick per student • 1 new, unsharpened pencil per student • 1 sharpened pencil per student • 1 hot glue gun per site • 8 rulers per site

Procedure

1. Start by passing out the craft sticks to the students.

2. Using a ruler, measure the center point on the craft stick, both across the long and the short sides. Mark this point with the sharpened pencil.

3. **Gently** twist the craft stick as shown below, or help them if they are having trouble. Try to avoid cracking the stick, but it is alright if small cracks do form. **See Figure 12**

4. Using the hot glue gun, glue the pencil to the point that you marked earlier. Wait for the glue to dry before touching the helicopter again. Once you're done, the product should look like **Figure 13**.

5. Have students spin it fast between their hands and let go!

6. Ask the following questions while they experiment with the helicopters:
    a. What causes the helicopters to fall?

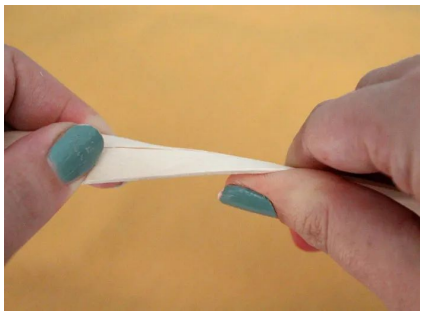

Figure 12: *Gently twist the craft stick to permanently bend it.*

Figure 13: *Make sure the pencil is tightly secured onto the popsicle stick. In this figure, the pencil has actually been pushed through a hole in the craft stick, but in this lesson we will be using a hot glue gun.*

Answers:

a. Weight! Earth's gravity pulls

b. What force is generated by spinning the helicopter?
c. How does the popsicle stick generate lift?

down on the helicopter, counteracting its lift.

b. Torque! Torque is a rotational force, and it is what rotates the helicopter. It is also why the flight is somewhat erratic, as we have no way of countering the torque generated to stabilize the helicopter's flight.

c. Due to its curvature, as it rotates, the air over the top of the wing travels faster than the air below, generating lift through Bernoulli's principle.

Classroom Notes

Make sure sure helicopters are spun the correct direction! Spinning them in the opposite direction may lead to bruised fingers. An easy way to tell if you are spinning correctly is to quickly spin them one way and let go briefly, then closing your hands to see which direction they travel. Have students launch the helicopters from one side of the room to prevent injuries!

Module 2: Floor Skimmer

Now that we've covered how helicopters generate lift, we'll be taking a look at a design more similar to a fixed-wing aircraft. In this module we will be applying the engineering design process and creating floor skimmers!

Teaching Goals

1. **Forces of Flight:**
    a. **Thrust** - a forward force generated when an object accelerates or expels mass in the other direction (Newton's third law).
    b. **Lift** - The force that acts perpendicular to an object's motion through air and is created by a difference in air pressures.
    c. **Weight** - The force of gravity, acts in a downwards direction toward the center of the Earth.
    d. **Drag** - a form of friction that airplanes experience when moving through air, also known as air resistance
        i. **Friction** - a force that acts in the opposite direction of motion when two objects slide against one another
2. **The Engineering Design Process**, the process of planning, designing, and improving that engineers utilize in creating their products

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MD Goals

written by MD, not applicable for every module

List and explain how to reinforce MD goals during the module.

Materials

- 1 manilla folder per student
- 1 pencil per student
- 1 skimmer printout per student
- 2 paper clips per student
- 8 glue sticks per site
- 3 pairs of scissors per site
- 1 roll of Scotch tape per site
- 8 rulers per site

Procedure

1. Use the scissors to cut out the skimmer shapes from the printout.

2. Trace the cutout outlines onto the manilla folder. Press lightly with your pencil to avoid bending the cutouts, or you may end up with slightly different shapes. **See Figure 14**
    a. You can use a ruler to keep the lines as straight as possible.
    b. For lines on the interior of the outline,

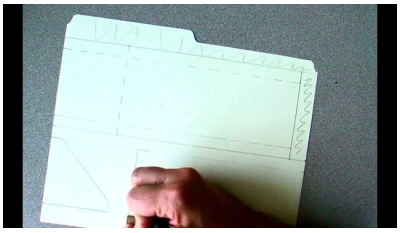

Figure 14: *Tracing out the parts for our skimmer onto the manilla folder*

mark important crossing points on the edge of the outline and connect the points by tracing along the edge of the ruler.

3. Cut out the shapes from the manilla folder. *Only cut solid lines. Don't cut the dotted lines, those are for folds!*

4. Assemble your skimmer, folding parts wherever there are dotted lines. Glue the fins to the sides of the main body and the air scooper to the bottom. **See Figure 15**
    a. You may find it helpful to use the ruler to fold on the solid straight lines and ensure they are straight.
    b. The ruler can also be useful for pressing glued pieces together in hard to reach places, such as in the air scoop under the main body.

5. Once you have assembled these parts, slide the paper clips onto the front. The purpose of the paper clips is to give the skimmer some extra momentum as well as weigh down the front of the skimmer, otherwise the air scooper may cause the skimmer to flip over.
    a. The air scooper is meant to raise the front of the skimmer just a tad in order to reduce surface area with the ground. This reduces friction, which in turn increases speed. However, without the paper clips, the skimmer could raise too much and flip over.

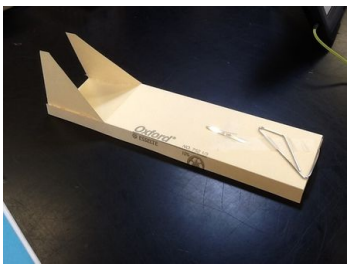

Figure 15: *An example of what the finished product should look like*

Classroom Notes

To be added

Conclusion

In this lesson, we covered the four major types of forces of flight. However, there are many more questions to be asked and explored about the nature of forces. Airplanes are not the only things that experience these types of forces. How do birds take advantage of these forces? What types of forces affect boats floating on the water? Where else do we see friction and drag? (Hint, friction can be experienced within all forms of matter— solids, liquids, and gases included) Anywhere there is movement, there are forces in action. Keep in mind that forces are still in action whenever an object *isn't* moving, this is called **stability** or **balanced forces**.

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Summary Materials Table

Material	**Amount per Site**	**Expected $$**	**Vendor (or online link)**
Printer Paper	1 per site		
Scotch Tape	1 roll per site		
String	1 roll per site		
Straw	1 per site		
Hole Puncher	1 per site		

Hair Dryer	1 per site		
Jumbo Craft Stick	1 per student		
Pencil	2 per student		
Scissors	3 per site		
Sharpie	1 per site		
Hot Glue Gun	1 per site		
Manilla Folder	1 per student		
Skimmer Printout	1 per student		
Paper Clips	2 per student		
Glue Stick	8 per site		
Rulers	8 per site		