Can We Pretend That Airplanes

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Field(s) of Interest: Physics, Engineering

Brief Overview (1-3 sentences):
In this lesson, mentees will learn what makes airplanes fly, by building several types of paper airplanes that challenge mentees' physical intuitions of what can fly and how.

Agenda:

- Introduction (5 min)
- Module 1: Let's get things darted (10-15 min)
- Module 2: Up, down, funk you up (10-15 min)
- Module 3: A Thousand Miles (20-25 min)
- Conclusion (5 min)

Main Teaching Goals/Key Terms:

- ➔ Force
- ➔ Thrust
- ➔ Drag
- ➔ Torque
- ➔ Lift
- ➔ Gravity/Weight
- ➔ Newton's third law
- ➔ Coanda effect
- ➔ Dihedral angle
- ➔ Force diagrams
- ➔ Center of mass

Background for Mentors

Module 1

- Force
- Thurst
- Drag
- Torque

Force is a vector quantity with a direction and magnitude that causes a change in an object's speed or direction. It is a push or pull that can cause an object to speed up, slow down, or change its trajectory.

Thrust is a force that modifies the translation movement of some object. For example, plucking a guitar string induces vibrational translation. A more common example would be rocket engines which propel a rocket upward.

Drag is a force in the opposite direction of an object's movement relative to a surrounding fluid such as air or water. This is caused by the friction by moving air particles on the surface of the object. The equation for drag at high speeds is

$$D \propto \rho A v^2$$

where ρ is the fluids density, A is its area, and v its velocity. Thus, drag in water, for example, would be higher than in air because water has a much higher density. This equation also explains why fins work better than hands for swimming, or why parachutes need to be so large, as the higher area induces a greater drag force.

Torque is an analogue to force in the case of rotation. Instead of being a push or pull, it is a twist around some point. To model torque, we can think about it as applying a force to the end of a lever that rotates about a point. We can relate torque and force mathematically as in the image below:

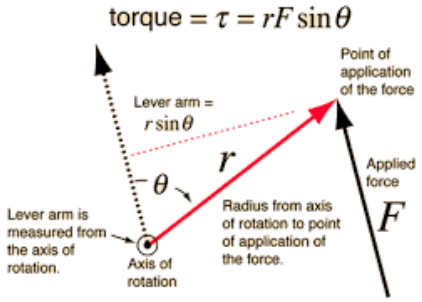

Figure 1: Diagram depicting torque

Although drag can be thought of as being oppositional to thrust, when used correctly, it can be a stabilizing force, with flaps on a plane intentionally using torque induced by drag to steer the plane and keep it at a particular angle.

Module 2

- **Gravity/Weight**
- **Lift**
- **Newton's third law**
- **Coanda effect**

Gravity is a force that pulls objects with mass together. This force is equal and opposite on both objects, but as the earth is much more massive than any object on earth, the earth experiences far less acceleration. **Weight** is the force of gravity on an object. Although heavier objects have a greater weight, when in free fall in a vacuum, all objects experience around 9.81 m / s^2 of acceleration. The reason leaves, paper and feathers fall slower in the air is because they act like parachutes due to drag.

Lift is the perpendicular component of the force induced by a fluid moving relative to an object. Lift is typically modeled with air moving over an airfoil.

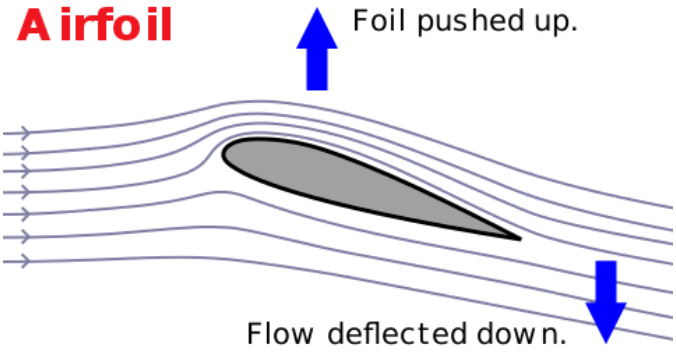

Figure 1: Airfoil modeling lift

Lift is also proportional to the area of the wing, although this may also induce more drag and increase the weight of the plane.

Lift is partially a consequence of **Newton's Third Law,** which states that every action has an equal and opposite reaction. Air traveling over the airfoil gets deflected down, inducing an upward force on the wing. The reason the air gets deflected down is due to the **Coanda Effect**, where fluid jets have the tendency to stick to curved surfaces. This is due to the jet causing an area of low pressure close to the surface, causing the jet to be pulled in.

To maximize the distance of a glider, one wishes to balance lift and weight to keep the glider vertical, while minimizing drag to keep speed from propulsion. However, at the beginning, one wishes to get more speed from gravity by throwing the airplane up and having it glide the rest of its trajectory.

Module 3

- **Dihedral angle**
- **Force diagrams**
- **Center of mass**

The **dihedral angle** is the angle between the wings.

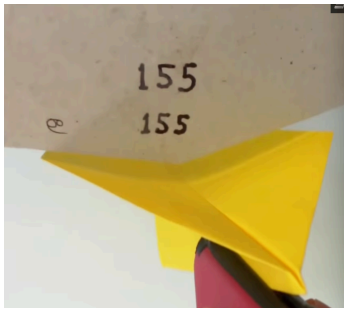

Figure 1: Dihedral angle of the module 3 airplane

It keeps the plane flying straight, since if the plane tilts along the vertical axis, more of one side of the plane is exposed to wind. Wind can then push that side back to being straight. By increasing the exposed area by increasing the dihedral angle, the plane becomes more stable.

Force diagrams are used to visualize all the forces acting on an object.

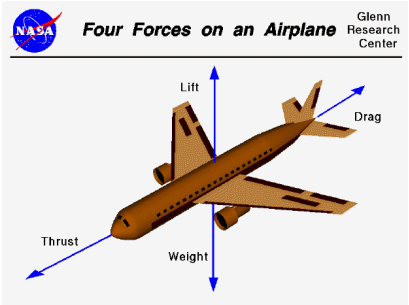

Figure 2: Force diagram of an airplane

The **center of mass** is the average position of an object's mass. It allows one to treat an object as a particle with all of its mass at that single point. If you balance a stick on two fingers, the center of mass is located between them. If you hold and object at the top with two fingers where it can pivot, the center of mass must lie in a line directly below where you are holding it as show below:

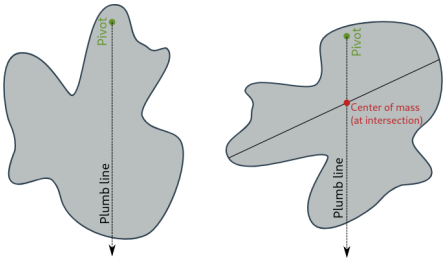

Figure 3: Center of mass of a blob

Introduction

This lesson teaches the basics of force, torque, aerodynamic principles, and how physics influences design. Mentees are shown how these fundamentals of science and engineering connect to objects in their everyday life and how understanding these concepts can drive ingenuity.

Concepts to Introduce ● Lift is a central concept to this lesson, as creating paper airplanes requires them to generate enough lift to slow their descent and gain distance. Try to draw parallels between how a bird flapping its wings drives it up and how an airplane wing redirecting air downwards generates lift. ● As most mentees have played with paper airplanes before, use this to make an analogy to how real planes fly.	**Questions to Pique Interest** ● Ask mentees if they have built paper planes before or been on a plane. How does a plane fly despite being so heavy compared to a paper plane? ● What properties of paper planes (and real planes) allow them to stay in the air?
Scientists, Current and Past Events ● The Wright Brothers were bike mechanics who made the first airplane in 1903. Their bike shop gave them the tools, money, and knowledge they needed to help design the plane. They did not have high school diplomas. ● NASA launched the Apollo 11 in 1969. The designers of this rocket needed a clear understanding of forces such as torque and lift, which ultimately allowed man to step foot on the moon for the first time in history!	**Careers and Applications** ● Aerospace engineers and mechanical engineers, when creating machines and aircraft, need to consider how these different forces can influence the design and behavior of what they're developing.

Module 1: Let's Get Things Darted

This module starts off by having mentees build the classic dart paper airplane, and then modifying it to explore how modifying it affects its flight to encourage experimentation and creativity.

Teaching Goals	**Materials**
1. **Force:** A push or pull that causes an object to move, slow down, or change direction. 2. **Thrust:** A force that moves an object. 3. **Drag:** A force that acts in the opposite direction of motion when passing through a fluid. 4. **Torque:** A force that causes an object to rotate.	• 1 sheet of paper per mentee • 1 set of scissors per 3-5 mentees • Markers

Different Methods for Teaching (Bradley and Brittney)
If you were able to go to site for lesson 1, then mentees should already be familiar with force.
Connect to Everyday Life:

- **Force:** You can act out pushing and pulling things to demonstrate that you are imparting a force.
- **Thrust:** Something that pushes an object. For example, throwing a ball or a rocketship with its hot gas pushing it upward.
- **Drag:** Examples of drag from real life include parachutes or even swimming, since your hand is pushing off the water. You can do a simple demonstration of dropping a piece of paper vs a marker to show how paper drops slower.
- **Torque:** Opening a door is an example of torque, where you pull on a doorknob to twist the door open. A see-saw is also an example of torque where pushing off the ground rotates the see-saw. If the school has maple trees, you can use the example of the maple tree seeds that spin when they fall down. Connect the flaps on the dart plane to torque.

Classroom Management: This activity can get rowdy! One way to help keep the classroom under control can be to split mentees into small groups each guided by a mentor to help them fold their planes. Collecting the planes until the end of the lesson can help focus the class if they like to fiddle with the materials.

Procedure

1. Make 4-5 groups of mentees
2. Pass out the paper to the mentees
3. Follow either of the following instructions:
    a. Video link
    b. Pictures link
4. Have mentees copy the mentors step-by-step
5. Line up on one side of the classroom and throw it
6. Have mentees collect the airplanes
7. Make two cuts on both wings to make rectangular flaps
8. Line up on one side of the classroom and throw it with the flaps facing up
9. Collect the planes and throw it again with the flaps facing down

Figure 1: *Step by step building instructions*

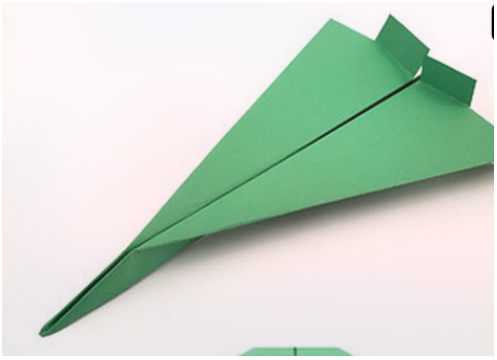

Figure 2: *The rectangular slits*

Module 2: Up, Down, Funk You Up

This module should challenge mentees ideas of what can fly while teaching them important physics concepts in the process. A demonstration will show how a beach ball can generate lift without a wing, and then they will build an airplane without a wing.

Teaching Goals	**Materials**
1. **Gravity:** The force that pulls things towards the ground. 2. **Lift:** The vertical force that is made when a fluid is moving past an object. 3. **Newton's Third Law:** Every action has an equal and opposite reaction. 4. **Coanda Effect:** The tendency for moving air to stick to a curved surface.	• 1 sheet of paper per mentee • 1 beach ball per site • Markers • Tape

Different Methods for Teaching (Bradley and Brittney)

Connect to Everyday Life:

- **Gravity:** Gravity is the reason things fall down. If you drop a paper airplane it will fall.
- **Lift:** Leading the explanation by talking about birds may help introduce lift, as it is easier to physically see birds push down on the air, then relating it back to airplanes. Possibly lead with what lift is before explaining how it works to keep them engaged and motivate the other teaching goals.
- **Newton's Third Law:** Use the example of standing up from a chair or jumping. In both cases, you are pushing your feet down off the ground causing you to go up. This is because the ground then pushes up on you. You can relate this to lift first with a bird, since when a bird flaps its wings, it pushes air down causing an upwards force. Similarly with planes, you can draw an airfoil of a wing to show how when air goes over the wing, it gets pushed downward causing an upwards force.
- **Coanda Effect:** On the same picture of the airfoil you can explain that the reason air sticks to the wing in this way is because of this effect. If they know what friction is, then you can say that the friction of the surface is what causes the air to stick around it. It is like sliding your foot along the carpet causing it to "stick" to the carpet.

Connect to the Activity:

- The tube airplane has no wings but it is still able to fly! It works kind of like football or a beach ball, with air spinning along the outside until it pushes downward on the air causing the plane to be pushed up. If you draw lines on the outside of the plane, you can see that it spins.

Adapt to the Classroom:

- Change your explanations and teaching goals to match your mentees' level. Lift can be hard to explain, so simplifying the explanation to just "the wing pushing down on the air causes it to be pushed up" is great for younger sites.

Procedure

1. Have a demonstration with a beach ball thrown without spin. Then throw it with spin and it'll fly without a wing.
2. Remake 4-5 groups of mentees
3. Pass out the paper to the mentees
4. Build the tube airplane with these instructions
    a. Video link
    b. Pictures link
5. Write your name on the airplane where it is visible
6. Line up on one side of the classroom and throw it!
7. Tip: Throw with a slight twisting motion and a bit more force than a normal airplane

Figure 1: *Step by step building instructions*

Classroom Notes

If the tube doesn't stay together, try folding the thin side into itself a slight amount to hold it together. Otherwise, use a little bit of masking tape. Too much tape could weigh it down!

Module 3: A Thousand Miles

This module should synthesize what was learned to motivate the (previous) world record plane.

Teaching Goals	**Materials**
1. **Dihedral angle:** The angle between two geometric planes, or in this case the wings of the plane. 2. **Force diagrams:** A diagram depicting all the forces of an object to visualize the forces at play. 3. **Center of mass:** The average point of the distribution of mass.	• 1 sheet of paper per mentee • Markers

Different Methods for Teaching (Bradley and Brittney)

Break it Down:

- **Dihedral Angle:** This word can seem intimidating to mentees, but you can break it down. “Di-” means two here, and the suffix “-hedral” means faces (i.e. tetra-hedron is a shape with 4 faces), so a Dihedral angle is the angle between two faces. You can then relate this back to the beginning of the activity by saying how the V-shape of the wings helps it fly straight by correcting its heading
- **Force Diagrams:** Adapt the explanation to your site! For a younger site you can simplify the concept by saying its a diagram that scientists or engineers use to look at forces while for an older site you can draw out the forces that this plane experiences
- **Center of mass:** The tricky part about this term is bringing it into how it helps the plane fly further. The forward-facing center of mass changes how the plane tilts in response to forces allowing it to stabilize itself.

Classroom Management:

- Go ahead and have the competition outside so that the airplanes can go farther! Feel free to allow mentees to use or decorate a previous airplane instead.

Procedure	
1. For the demonstration, color the two sides of the airplane a different color 2. At the front of the classroom, have the plane face them, and ask them which of the two colors they see 3. Tilt the plane so that one side mostly faces the mentees and ask the students which color they see. Connect this to stability and the dihedral	

angle.

4. Remake 4-5 groups of mentees
5. Make the plane following these instructions
    a. Video link
    b. Pictures link
6. Write your name on the plane
7. Line up on one side of the classroom and throw it
8. Collect the planes
9. Decorate and modify plane of choice
10. Go outside and see whose airplane flies the farthest!

Figure 1: Summary of *step by step building instructions*

Conclusion

In this lesson, we learned the physics behind what makes airplanes fly, enabling us to make a (previous) world record plane! This lesson stresses the importance of experimentation and understanding to empower iterative design.

References

- Aerodynamics Explained by a World Record Paper Airplane Designer, John Collins, Wired.
  Aerodynamics Explained by a World Record Paper Airplane Designer | Level Up | WI...

Summary Materials Table

Material	**Amount per Site**	**Expected $$**	**Vendor (or online link)**
Paper	3 per student	32	Amazon
Scissors	5 per site	(Already have)	
Beach ball	1 per site	8	Amazon
Markers	10 per site	(Already have)	
Tape	1 roll per site	(Already have)	