



Objectives

- Students will learn the four forces on an airplane
- Students will discover how surface area of a wing is related to lift
- Students will learn that lift is created by a combination of factors such as Newton’s third law of motion and Bernoulli’s Principle
- Students will learn about the STEM career—Commercial Airline Pilot

Vocabulary

- | | |
|--------------------|-----------------------------------|
| • Thrust | • Newton’s Third Law |
| • Lift | • Bernoulli’s Principle |
| • Drag | • Flaps |
| • Weight (gravity) | • Slats |
| • Jet Engine | • Fuselage |
| • Propeller | • Airfoil (wings) |
| • Downwash | • Linear/Non-linear relationships |
| • Air Pressure | • Proportional |
| • Surface Area | • Rate of Change |
| • Trapezoid | • Parallelogram |

About the Lesson

- This lesson explains the science and math behind airplane flight.
- Students will learn about the four forces of flight such as lift, drag, weight, and thrust.
- Students will learn about how the surface area of a wing relates to the amount of lift force a plane has in different conditions.
- Students compare how lift relates with surface area and how lift relates with velocity.
- Students will explore how lift is generated through Newton’s third law of motion and Bernoulli’s principle.
- Teaching time: one to two 45-minute class period(s).

Activity Materials

- Compatible TI Technologies:
 TI-84 Plus CE with the latest operating system.



Tech Tips:

- This lesson includes screen captures taken from the TI-84 Plus CE handheld. Slight variations to these directions may be required if using other technologies besides the handheld.
- Watch for additional Tech Tips throughout the lesson for the specific technology you are using.
- Access free tutorials at <http://education.ti.com/calculators/pd/US/Online-Learning/Tutorials>.

Lesson Files:

Student Activity

- STEM_On_The_Fly_student_84 CE.pdf

TI-84 CE program and images

- STEM-On The Fly.8xp
- Image6.8ca
- Image7.8ca
- Image8.8ca
- Image9.8ca
- Image0.8ca
- Pic0.8ci
- Pic1.8ci



Background

STEM CAREER—This activity presents students with some background about being a commercial airline pilot. Students will learn about how airplanes fly and are introduced to some examples of how pilots fly them. Pilots are required to be versed in the math, science, and engineering behind the phenomenon of flying. A commercial airliner can weigh as much as 157,000 pounds or more! To get that much mass in the air requires a lot of lift and a lot of thrust. The pilot needs to be familiar with these concepts to ensure passengers make it to their destinations safely.

OVERVIEW—Students will be introduced to the four forces that affect the flight of an airplane; lift, drag, weight, and thrust. They will also explore the mechanisms of lift such as Newton's third law of motion and Bernoulli's principle. In addition, students will discover the mathematical relationships between surface area of a wing and lift as well as lift and velocity (thrust). There are multiple variables when it comes to flying. This activity attempts to make sense of them individually and how they affect one another.

Meet Alex Livingston and Adam Schindall

Alex is a high school student and pilot in training. He is a member of the Civil Air Patrol and has flown gliders and single prop planes. Alex is considering a career in aviation as a commercial airline pilot. Recently Alex made a trip to Dallas to tour a major airline carrier. He spoke with a commercial airline pilot named Adam Schindall.

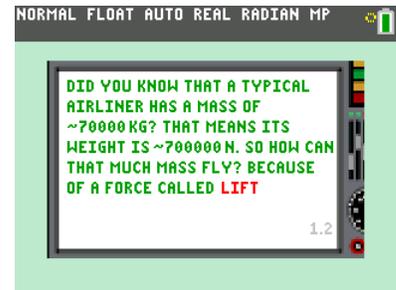


Schindall is known as a **check airman**. A check airman is responsible for working with newer pilots to train them and evaluate their skills in a flight simulator before they become actual commercial airline pilots. Adam has thousands of hours of flight experience. Adam explained that a strong foundation in math and science is essential for any student considering a career in aviation as a pilot.

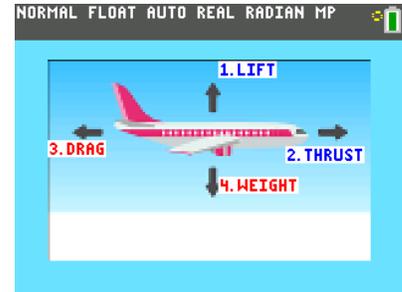


Move to pages 1.2 to 1.4 on the handheld.

1. This page introduces the idea that something as heavy as an airplane can actually lift into the air and fly long distances through a process called, **lift**.



2. Pages 1.3 and 1.4 explore the four forces associated with an airplane; lift, thrust, drag, and weight. Lift and thrust achieve upward and forward motion while drag and weight resist upward and forward motion. On page 1.4, select the terms to explore the four forces of flight.



Question 1.

Which of the following *best* describes the interaction between drag and thrust?

Answer: B. Drag is air resistance which is a counter force to thrust.

Question 2.

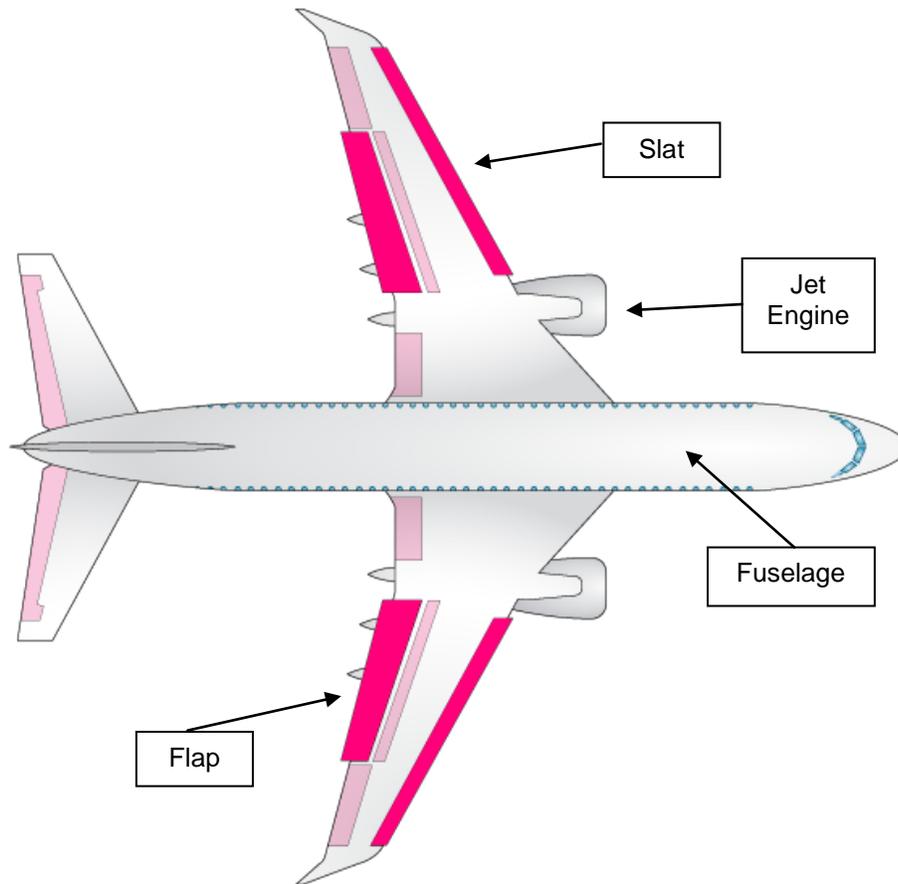
In which of the following situations is drag *most* useful?

Answer: C. Drag helps to slow the plane down during the landing portion of the flight



How wings create lift

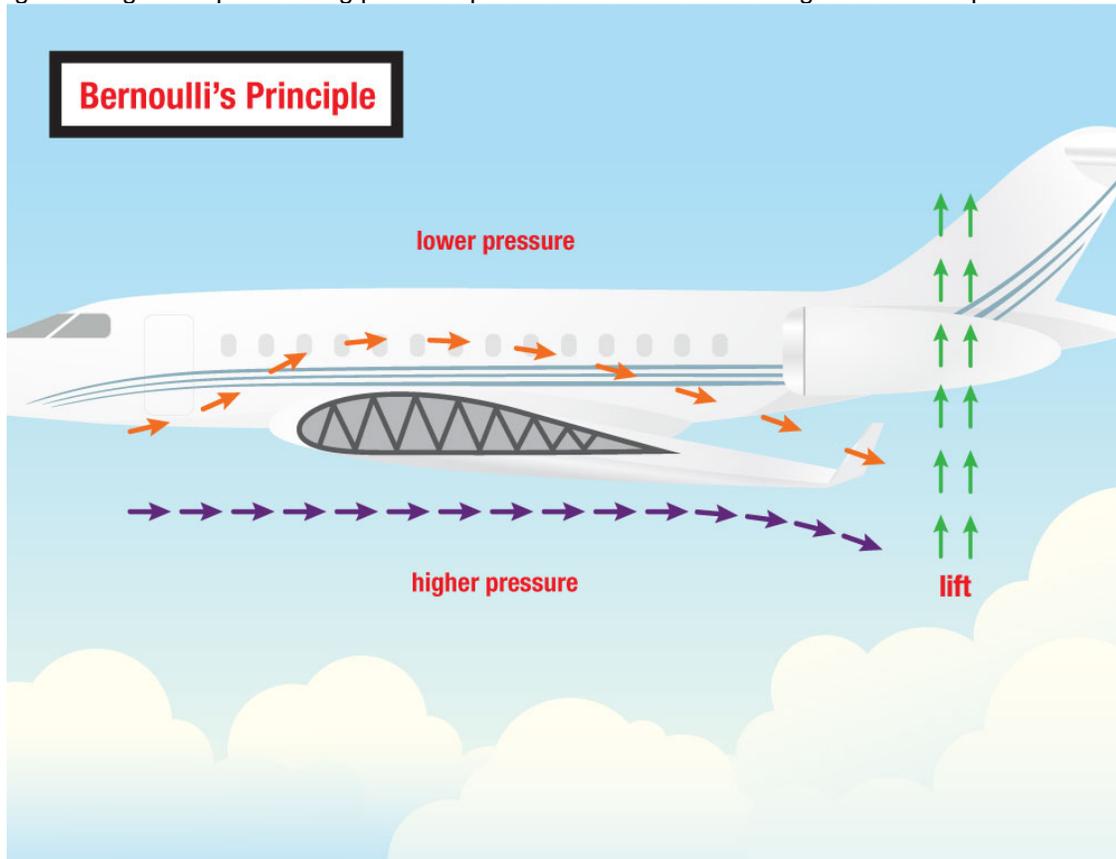
- Planes control lift by increasing or decreasing thrust and/or changing the amount of surface area of the wings. In order to change the surface area of the wings, the pilot can deploy the slats and flaps. Slats are the long thin extensions on the leading edge of the wing. Flaps are the shorter, wider extensions on the trailing edge of the wing.





STEM BEHIND COOL CAREERS

4. One of the mechanisms behind lift is based on **Bernoulli's principle**. Bernoulli discovered that as a fluid's velocity increases, that fluid's pressure on the surrounding area decreases. So, in the case of airplanes, that fluid is air. Because the shape of the top of the wing is more curved as compared to the shape of the bottom of the wing, air above the wing has a tendency to move faster as compared to the air below the wing. As a result of the differences in air speed between the top and bottom of the wing, there is also a resulting difference in air pressure. There is less pressure above the wing than below the wing resulting in the plane being pushed up from the bottom of the wing. We call this phenomenon lift.



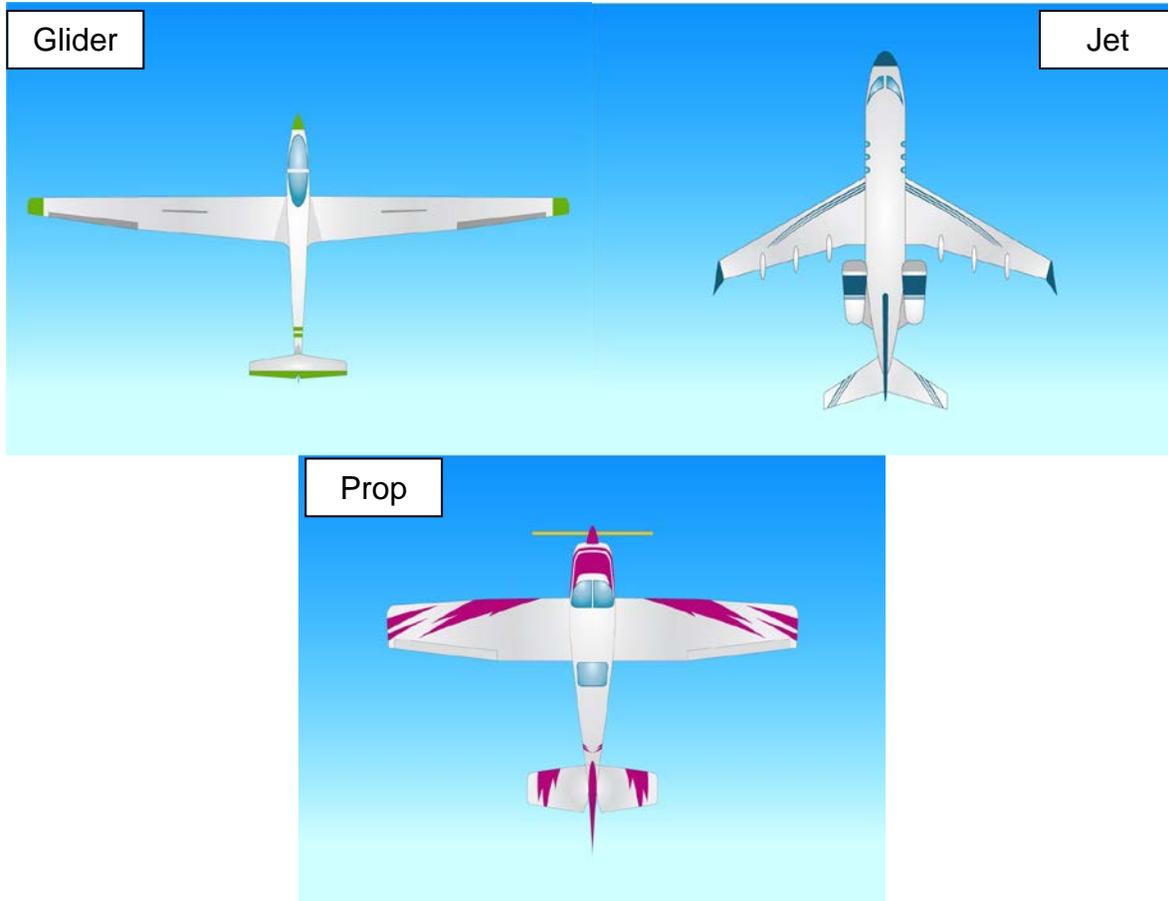
Note –**Newton's third law of motion**, which describes that every action has an equal but opposite reaction, also plays a role in lift since the air hitting the bottom of the wing, when the wing is as at an angle relative to the plane's motion, will push against that wing resulting in lift. The combination of air pressure differences above and below the wing and Newton's third law of motion cause the air at the trailing edge of the wing to move at a slight angle downward. We call this motion of the air at the trailing edge "**downwash**".

**Misconception Alert!* - In some representations of Bernoulli's principle, it is implied that two air molecules that are split between the top and bottom of the wing will end at the same location at the trailing edge with the top air molecule having to move faster because of a longer distance due to the curvature of the top portion of the wing. This "equal transit theory" has been shown to be incorrect. The top air molecule moves much faster than the bottom due to several variables and will find the trailing edge much sooner than the bottom air molecule.*



Not all planes are equal:

5. All planes have wings but not all wings are the same. Smaller planes, such as gliders, require long narrow wings to interact with more air. Smaller powered planes like single-propeller or “prop” planes have shorter wider wings. Planes with a lot of thrust, such as jets, don’t require really long wings. There is an obvious relationship between thrust and wing area.



Question 3.

Gliders have no engines. So how do they achieve enough thrust to generate lift?

Suggested Answer: Gliders are towed into the air from a powered airplane. Once at altitude, gliders are released and use the air currents to glide. Gliders can generate acceleration with Earth’s gravity and then change the flaps on the plane to then climb. Gliders have long wings to catch updrafts to sustain flight.



Question 4.

Complete the following sentence: As air velocity increases, air pressure _____.

Answer: decreases

Question 5.

Which of the following are primary mechanisms for lift? Multiple answers may be chosen.

Answers:

- A. Bernoulli's Principle
- C. Newton's third law of motion

Move to pages 2.1 to 2.2 on the handheld.

6. These pages have students explore what happens to the force of lift when the slats and flaps are deployed. Students can also explore the differences in lift when the plane takes off from different airports in different weather conditions.



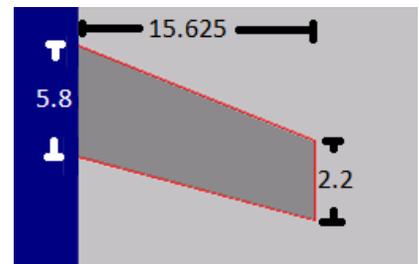
7. On page 2.2 there are three different modes for you to explore. Use the right/left arrows to change between modes. Note: you can only change modes when the flaps and slats are not extended. Press the up/down arrows to extend/retract the flaps and slats. The flaps and slats are parallelograms with the height equal to the extension. The width of the slat is 12.5 meters and the width of each of the flaps is 5 meters.



Question 6.

Use the diagram to the right to compute the area of one wing of the airliner. All the units are in meters and the wing is a trapezoid. Report your answer in square meters.

Answer: 62.5 m²





Question 7.

Set the mode to SAN (San Diego) and determine the total area of both wings for each position of the flaps and slats, and fill out the table with the correct area and corresponding lift.

Base Area one wing (m ²)	Slat Area one wing (m ²)	Flaps Area one wing (m ²)	Total Area one wing (m ²)	Total Area both wings (m ²)	Lift (N)	$\frac{\Delta L}{\Delta A}$
62.5	0	0	62.5	125	771750	----
62.5	1.25	1.25	65	130	802620	$\frac{30870}{5} = 6174$
62.5	2.5	2.5	67.5	135	833490	6174
62.5	3.75	3.75	70	140	864360	6174
62.5	5	5	72.5	145	895230	6174
62.5	6.25	6.25	75	150	926100	6174

Question 8.

How much does the total area of both wings change between row 1 and row 2 of the table? How much does lift change?

Answer: 5 m² ; 30,870 N

Question 9.

How much does the total area of both wings change between row 3 and row 4 of the table? How much does lift change?

Answer: 5 m² ; 30,870 N

Question 10.

Calculate the change in lift with respect to change in area for each row of the table $\frac{\Delta L}{\Delta A} = \frac{L_2 - L_1}{A_2 - A_1}$. What do you notice about the rate of change of lift with respect to area, $\frac{\Delta L}{\Delta A}$, among the rows of the table?

Answer: The rate of change of lift with respect to area remains constant from row to row throughout the table.



Question 11.

What does this mean about the relationship between lift and area?

Answer: This indicates that lift and area are linearly related (assuming all other variables are held constant).

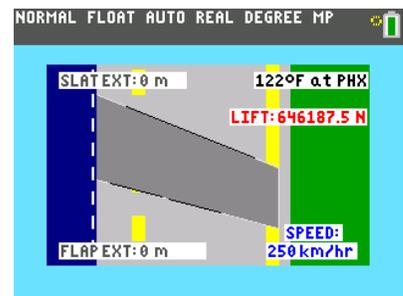
Question 12.

Write an equation that could be used to determine the lift for this aircraft during takeoff in San Diego, given a certain wing area and a velocity of $250 \frac{km}{h}$.

Answer: $L = 6174 * A$

Question 13.

Use the right/left arrows to change the takeoff mode to Phoenix, AZ. During the summer in Phoenix the air can reach extreme temperatures. When temperature rises, air density decreases which changes the relationship between lift and surface area.



Complete the table below for the lift vs. area relationship for an extremely hot day in Phoenix. Use the same area values as the previous table since this is the same plane.

Total Area both wings (m ²)	Lift (N)	$\frac{\Delta L}{\Delta A}$
125	646187.5	----
130	672035	$\frac{25847.5}{5} = 5169.5$
135	697882.5	5169.5
140	723730	5169.5
145	749577.5	5169.5
150	775425	5169.5



Question 14.

How is the relationship between area of the wings and lift different than in San Diego?

Answer: Lift does not increase as rapidly when you increase surface area. The rate of change (slope) of lift with respect to area is smaller.

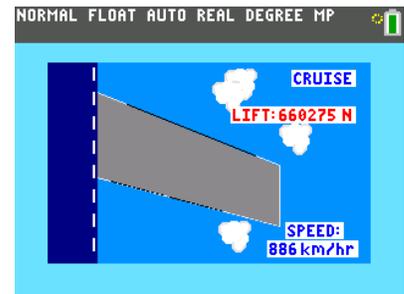
Question 15.

In the given conditions, does it require more area to generate the same lift in Phoenix or San Diego assuming the same takeoff velocity?

Answer: In Phoenix it will require more area, under the given conditions, to generate the same lift.

Question 16.

Use the right/left arrows to change to cruising mode. At cruising speeds, a pilot would not extend the flaps or slats, however, often the velocity can change, and this effects the lift generated. Use the up and down arrow to change the velocity and note the relationship between velocity and lift.



Velocity ($\frac{km}{h}$)	Lift (N)	$\frac{\Delta L}{\Delta V}$
886	660275	----
896	676544	$\frac{16269}{10} = 1626.9$
906	693011	1646.7
916	709676	1666.5
926	726539	1686.3
936	743600	1706.1

Question 17.

How much does the velocity change between row 1 and row 2 of the table? How much does lift change?

Answer: 10 km/h; 16269 N



Question 18.

How much does the velocity change between row 3 and row 4 of the table? How much does lift change?

Answer: 10 km/h; 16467 N

Question 19.

What do you notice about the rate of change of lift with respect to velocity, $\frac{\Delta L}{\Delta V}$, from row to row in the table?

Answer: The rate of change is not constant from row to row. The rate of change of lift, is increasing as velocity is increased.

Question 20.

What does this mean about the relationship between lift and velocity?

Answer: This indicates that lift and velocity are not linearly related. Some students may note that this indicates the relationship is concave up over this domain of velocities.

Question 21.

How is the relationship between lift and velocity different than the relationship between lift and area?

Answer: Lift and surface area are linearly related while Lift is non-linearly related to velocity.

Question 22.

Use the lift equation to show why the relationship between lift and area you found in question 12 makes sense, assuming all the other variables remain constant. The lift equation is $L = C_L \frac{\rho * V^2}{2} A$ where C_L is the coefficient for lift of the wing, ρ , is the air density in $\frac{kg}{m^3}$, V , is velocity in $\frac{m}{s}$, and A is the surface area of the wing in m^2 .

Answer: Since C_L , ρ , and V^2 remain constant; $L = C_L \frac{\rho * V^2}{2} A \rightarrow L = kA$ where k is some constant of proportionality. This matches the model from question 12. Note: some students may not be familiar with the Greek letter 'rho' ρ .



Question 23.

Using the lift equation and the assumption that all the other variables remain constant, explain why your answer makes sense for the relationship between lift and velocity.

Answer: Since C_L , ρ , and A remain constant; $L = C_L \frac{\rho * A}{2} V^2 \rightarrow L = kV^2$ where k is some constant of proportionality. This would indicate that L is proportional with the square of velocity and is therefore non-linear.

Move to page 3.1 to 4.4.

8. These pages give students the opportunity to fly a plane using velocity and the surface of the wing variables. The relationship between lift and thrust becomes even more obvious. Students will also notice that the force of lift required to get the plane off the ground just exceeds the weight of the plane.



Assessment

- Students will answer questions throughout the lesson to ensure they understand the concepts being discussed.

Going Further

Have students explore other parts of the airplane such as the ailerons, spoilers, rudder, and elevator which help with movements such as yaw, pitch, and roll. In addition, have students identify 2 additional careers in aviation outside of being a pilot.