flytolearn curriculum

STEM Education Inspired by Aviation

"Science of Flight and Airplane Design"

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TABLE OF CONTENTS

GAMA Aviation Design Challenge

First Flight

"The Wright brothers were engineers first, pilots second."

Introduction

Before you can take off, you need to learn a little more about how to set up the right flight conditions for a new pilot. Then, you will learn about airplane instruments, techniques for taking off, and how to change views of the airplane while flying. After you have a good grasp on flying, you will run different trials to learn how airspeed and altitude are related. Before flying in X-Plane, please read through this handout and watch the corresponding videos. You can always re-watch the videos if you need a helping hand.

Flight Conditions

It's important to take into consideration the aircraft, airport, and weather conditions for your first flight. Planes, as well as runways, vary in difficulty, and the more you practice, the more options you will have. Once you gain more experience, you will be able to fly at night and in windy conditions. For now use the following Quick-Flight Setup instructions. It is a good fit for a new pilot; this lesson has a great corresponding video that goes into detail on how to set these options.

Under File choose Quick-Flight Setup:

- **Airport**: Enter the airport ID of KSEA to select Seattle Tacoma International airport. By default, you will be placed on Runway 16 (RWY 16).
- **Plane**: Click on Open Aircraft, select General Aviation, and double-click Cessna 172SP, 172SP.acf
- **Weather**: Set Time to be "day" and Weather to be "clear." This defaults to 58°F in temperature and 29.92 inHg for barometric pressure. This will maximize visibility, and eliminate clouds, precipitation, thunderstorms, wind, and turbulence.

Click "FLY with these options!" on the bottom right-hand corner of your screen to exit Quick-Flight Setup. Make sure the box next to "Show this window on every startup of X Plane" is checked.

Instruments
In X-Plane you can see your instruments in the bottom half of the screen. The corresponding video will point out each one of these on the control panel so you can match up each with its function.

- **Airspeed Indicator:** indicates how fast the airplane is moving relative to the surrounding air.
- **Attitude Indicator**: shows the attitude of the airplane relative to the horizon.
- **Altimeter**: shows how high the airplane is above sea level—the large hand represents hundreds and the small hand represents thousands.
- **Coordinated Turn Indicator**: indicates the rate and direction of turn.
- **Heading Indicator**: shows the heading of the airplane compared to geographical north.
- **Vertical Speed Indicator**: reports the rate that the aircraft is climbing or descending.
- **Compass**: reports the heading of the airplane relative to magnetic north.
- **Tachometer**: shows the number of times the engines turns per minute.

Need an inflight instrument reminder? Under the About Menu (left of the File Menu) choose Instructions, and click on the Show Instrument instructions in the cockpit. Now when your mouse hovers over instrument you see a brief reminder of what that instrument does.›

Takeoff
1. Open X-Plane and follow the Quick-Flight Setup instructions above.
2. Press "P" to pause the simulator so you can ready the plane without it moving.
3. Click on the red brake light to release the brakes (or press "B").
4. Push the throttle, the black knob in the bottom-right corner of the screen, all the way in using the mouse. You can also press and hold the F2 key while your screen is unpaused to control the throttle.
5. Click on the center of the windshield to make the cross hairs and control box appear.
6. Move mouse pointer to the right of the cross hairs to get the plane started down the runway (otherwise it will drift left).
7. Press "P" to un-pause.
8. As the plane rolls forward, make small corrective movements with the mouse to keep the plane rolling straight down the runway, moving the pointer closer and closer to the cross hairs.
9. At 75 knots, move the pointer to the bottom of the cross hairs and the plane should take off.

Flight Views

X-Plane offers many different camera angles to see the plane and observe your flight. Press P to pause so you can concentrate on learning the different views without worrying about flying.

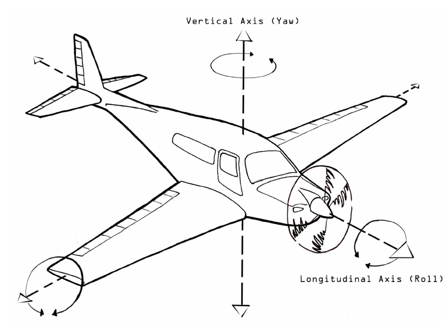
- **e**: Cycles clockwise through views out the plane – the little orange plane and triangle show you which way you are looking out.
- **q**: Cycles counter-clockwise through views out the plane.
- **w**: The standard view straight out the plane.
- **Shift 8**: Press both at the same time to follow behind the plane – Pressing q or e in this view allows you to circle around the plane, counter-clockwise and clockwise, respectively. You can also use the arrow keys to rotate the view around the aircraft. Press + and - to zoom in and out.

Flight Controls

The Wright Brothers were the first to fly because they were brilliant engineers; they were brave (they were test pilots after all), and they persevered. Maybe the most important factor in their success was that they recognized flight's real challenge was control and stability.

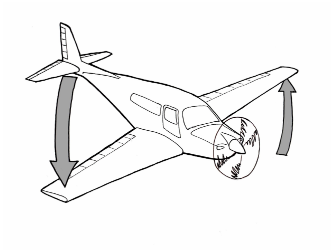
Control

The Wright Brothers described flight in three axes — roll, pitch and yaw.



Roll

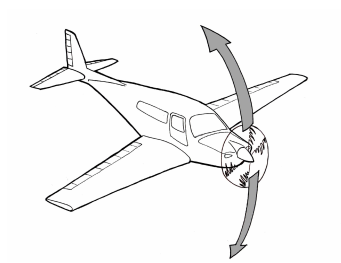
Roll describes the rotation of the wings along the longitudinal axis (nose to tail). The ailerons control roll by increasing lift on one side of the wing and decreasing lift on the other side of the wing. Unfortunately, this also causes the nose of the airplane to turn in the opposite direction of the roll or bank. A nose turning the wrong way is called adverse yaw. We use the rudder to counteract adverse yaw and point the nose in the same direction as the bank.



ROLL

Pitch

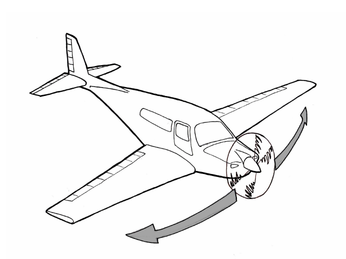
Pitch describes the plane's nose moving up and down. Think of a boat "pitching" in the ocean. The elevator — the part of the horizontal tail section that moves up or down — controls the pitch of the airplane. Pitch also impacts the angle of attack of the wing.



PITCH

Yaw

Yaw describes the plane rotating left or right. The rudder — the part of the vertical tail section that moves left or right — controls yaw. The rudder also prevents adverse yaw. We will learn about adverse yaw in a moment.



YAW

Let's look at a plane on a runway. By moving our mouse around the cursor, we will see the movement of the control surfaces on the airplane. The pilot uses these control surfaces (ailerons, elevator, and rudder) to control the airplanes in the three axes — roll, pitch, and yaw.

Test Piloting

We are going to take a closer look at the movable control surfaces on the airplane.

1. Click on settings and follow these Quick-Flight Setup instructions.
   - ✈ Airport: KSEA
   - ✈ Aircraft: Cessna 172SP
   - ✈ Time: "day"
   - ✈ Weather: "clear"
   - ✈ Click FLY with these options!
2. Press Shift 8 and use the arrow keys so you are looking from directly behind the airplane.
3. Click on the cross and move your cursor down. Observe the parts of the airplane that move. Move your cursor up, left, and then right. Be sure to observe which surfaces move on the wings and the tail. Otherwise, the airplane should be sitting still on the runway.

Investigative Questions

If I move my cursor down (decreasing pitch), what does the elevator do on the tail?

If I move my cursor up (increasing pitch), what does the elevator do on the tail?

If I move my cursor left (rolling left), what does the rudder do on the tail?

If I move my cursor left (rolling left), what happens to the left wing and to the right wing?

If I move my cursor right (rolling right), what happens to the left wing and to the right wing?

Energy Management - Potential vs. Kinetic Energy

As a pilot, you need to be concerned about energy management. Energy exists in the universe in different forms. It cannot be created or destroyed. It simply changes form.

Your airplane runs on aviation fuel. This fuel has a great deal of potential energy. Once you start the plane, the engine converts the potential energy of the fuel into the moving or kinetic energy of the propeller turning in the air. As you add more fuel (push in the throttle), the engine turns even more potential energy into kinetic energy (tachometer increases). The plane, pulled by the propeller, will move faster down the runway and then liftoff.

If you continue to apply full throttle (black knob pushed all the way in), the plane will do one of the following: go faster or go higher. If you decide to go faster, the plane is converting the fuel or potential energy into kinetic energy or speed.

If you decide to go higher, the plane is converting the fuel or potential energy into altitude or a different form of potential energy.

It is the same thing as when you pedal your bike down a hill. You are using potential energy of gravity at the top of the hill and converting it into kinetic energy of motion as you ride down.

Unfortunately, not all the potential energy becomes kinetic energy. For example, some of the potential energy becomes heat and does not contribute to speed.

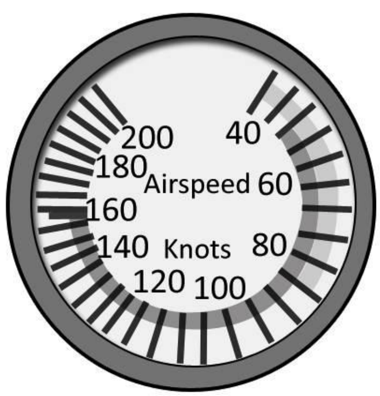
Let’s do a quick demonstration of what we have been discussing.

Under File choose Quick-Flight Setup:

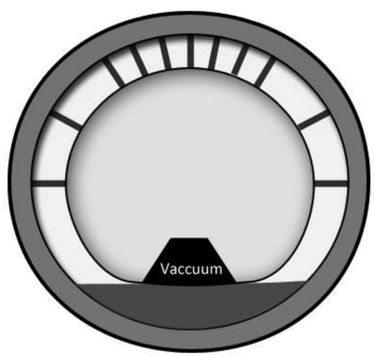
- ✈ **Plane**: Click on Open Aircraft, select General Aviation, and double-click Cessna 172SP, Cessna_172SP.acf
- ✈ **Weather**: Set Time to “day” and Weather to “clear.”
- ✈ **Airport**: Exit Quick-Flight Setup. Click on Location on the top bar and Select Global Airport. Select KSEA, RWY 16, Final Approach 3nm. Be ready to press P to pause!

Level Flight

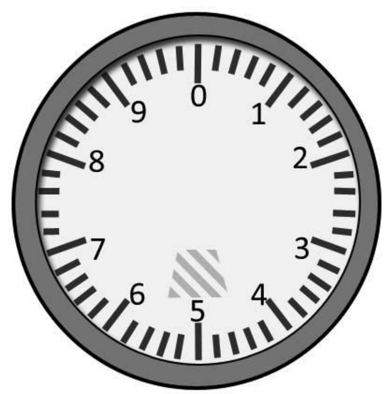
1. Open X-Plane and follow the Quick-Flight Setup instructions above.
2. Press "P" to Pause the simulator so that you can ready the plane without it moving.
3. Click on the center of the windshield to make the cross hairs and control box appear.
4. We should take a look at our top three instruments and jot down what they read.



Air Speed Indicator



Attitude Indicator

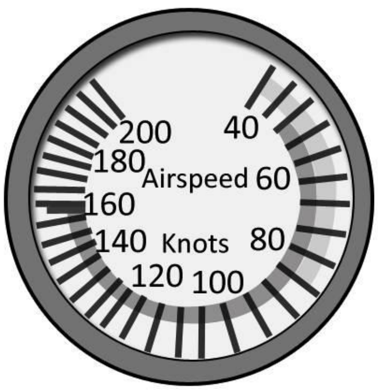


Altimeter

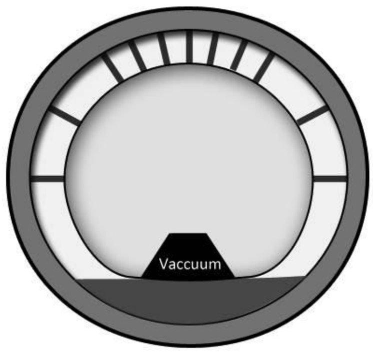
What is the air speed? What does the artificial horizon look like? Where are the big and little hands on the altimeter? Fill in the circles above. Don’t worry about writing down all the numbers — just draw the arrows.

Let’s trade off potential energy for kinetic energy.

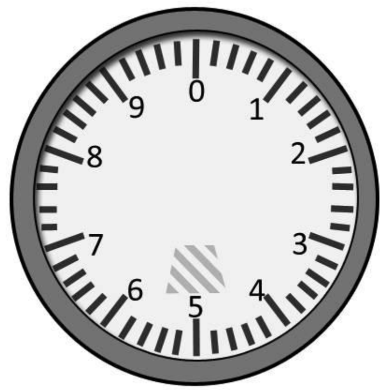
Point the nose of our plane down. After descending for a short time (3 sec), press pause and take another look at our instruments. Note the changes and fill in the instruments below.



Air Speed Indicator

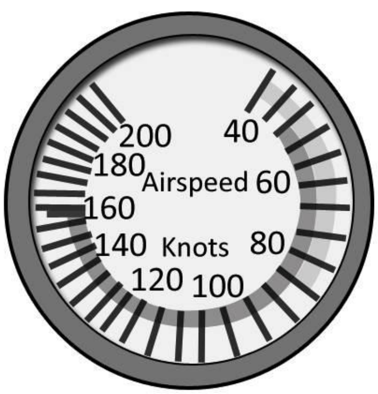


Attitude Indicator

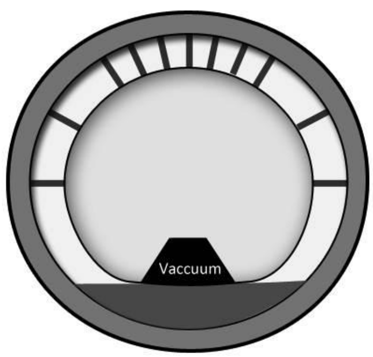


Altimeter

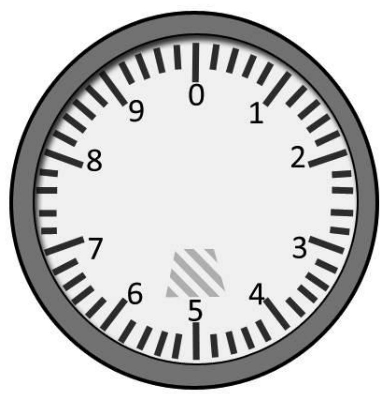
Point the nose up for a short while until you are higher than you were when you started. Then press pause. Again, note the changes and fill in the instruments below.



Air Speed Indicator



Attitude Indicator



Altimeter

Investigative Questions

You as the pilot want to go faster, do you point the nose up or down?

You are flying faster and faster. Is your kinetic energy going up or down?

In terms of energy, why does your plane slow down as you climb?

You don't touch the throttle; can you climb and fly faster?

Why is it dangerous to fly low and slowly?

You are in a dive going faster and faster. At some point the airspeed will stop increasing. Why?

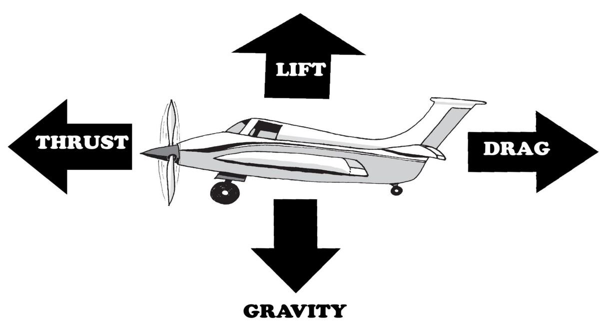
Weight

"The Wright brothers were engineers first, pilots second."

Introduction

Ok, now you have been flying a little while and you realize two things: Flying is fun! And there is a lot to learn to pilot a plane. The good news is the more you learn, the better the pilot you will be. In this lesson you will begin to learn about the four forces that act on an airplane. You will also get your first chance to do more than just fly; you can actually make changes to your airplane. As always, please read through this handout and watch the corresponding videos. You can always re-watch the videos if you need a helping hand.

The Four Forces of Flight



Force

Force is a push or a pull. It is composed of magnitude (how large the force is) and the direction of the force. We represent forces by drawing vectors (arrows) that tell us the magnitude and the direction of the force.

Weight

Let's look at weight as a force on an airplane. Weight is the result of mass times gravity. This means that if you were to stand on the moon or another planet you would weigh a different amount because gravity has changed, even though your mass is still the same. The mass of the airplane includes the airplane structures (wings, tail, landing gear, etc.), fuel, and payload. The payload includes cargo (mail and packages), crew, and passengers. The direction of this force in level flight is down or perpendicular to the flight path.

Test Flight: Weight vs. Takeoff Distances

Now let's conduct some test flights to study the impact of weight on takeoff distances. This is important for two reasons: to see the impact of weight on the performance of the airplane and to learn the importance of takeoff distance.

Quick – Flight Setup

- Airport: KSEA
- Aircraft: Cessna 172SP
- Time: "day"
- Weather: "clear"

Collect Test Data

1. Click on Settings.
2. Select Data Input & Output.
3. Click on the last two checkboxes at speeds (line 3).
4. Click on the last two checkboxes at loc, vel, dist traveled (line 21).
5. Click on the last two checkboxes at landing gear vert force (line 66).
6. Click on X to return to the plane.

Set Payload

1. At the top menu, select Aircraft.
2. Click on Weight and Fuel.
3. Make a note of the payload weight. It should be 243 lbs. Please change this value to 296 lbs.
4. Click X to return to the plane.

Takeoff

1. Press "P" to pause.
2. Press "B" to release the brake.
3. Push in the throttle.
4. Click on the center of the windshield.
5. Move the mouse pointer to the bottom of cross hairs.
6. Press "P" to un-pause.
7. As the plane rolls forward, make small corrective movements with the mouse to try keep the plane rolling straight down the runway.
8. The plane lifts off.

Repeat these steps, completing the following table by taking off with different weights.

Test Piloting

If you have not already, please watch the Weight vs. Takeoff Distance video. The plane normally has a load of 296 lbs. Fly it three times. Be sure to keep the pointer on the crosshairs, and the plane will takeoff. Try to fly as consistently as possible. Record the Vtrue airspeed and Takeoff Distance for each flight in the table below. Change the load to 600 lbs and takeoff three more times. Repeat again with the load at 900 lbs.

Load: 296 lbs

Trial	Load	VtrueArspeed	Takeoff Distance
1	296		
2	296		
3	296		

Average Takeoff Distance _________________

Load: 600 lbs

Trial	Load	VtrueArspeed	Takeoff Distance
1	600		
2	600		
3	600		

Average Takeoff Distance _________________

Load: 900 lbs

Trial	Load	VtrueArspeed	Takeoff Distance
1	900		
2	900		
3	900		

Average Takeoff Distance _________________

Once you have completed the Test Flying tables, please complete the bar graph below.

Please note: Vtrue indicates the true airspeed. Vind means indicated airspeed. The plane's instruments give us an indicated airspeed, which is affected by altitude and temperature. Vtrue gives us the actual airspeed independent of altitude and temperature.

Payload vs. Average Takeoff Distance

Average Takeoff Distance (ft)

Payload (lbs)

Investigative Questions

As the payload increases, does takeoff distance increase or decrease?

Does a longer takeoff distance indicate more or less payload?

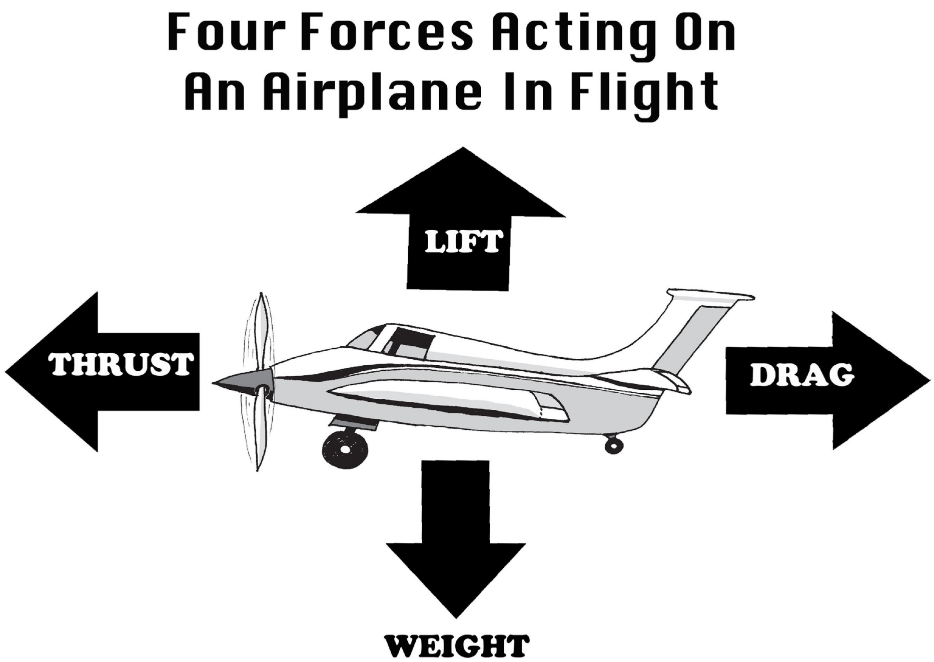
Does the airspeed go up or down as you increase the payload?

Do larger airplanes require larger airstrips?

Weight as a Force

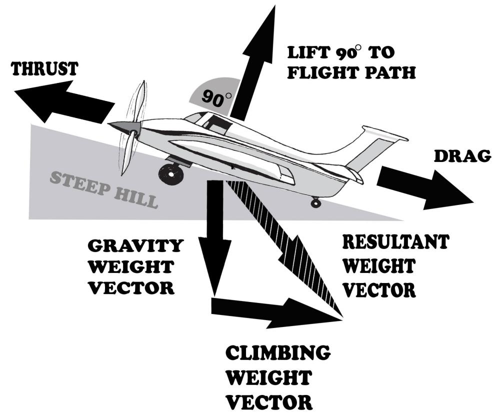
As stated before, weight equals mass times gravity. We can't change gravity, but by reducing mass, we can reduce weight to improve performance. This is true in every aircraft whether it's a jet airliner or a model plane.

We have focused on the impact of magnitude of weight on flight performance. Since weight is a force, it has a directional component. The direction of the weight force will always point to the center of the earth. During level flight, this force is pointed 90 degrees off the flight line.



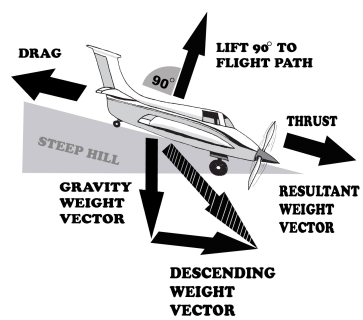
Flying Tip: You can reduce the payload of any flight by getting your talkative friend out of the airplane. It also means a quieter flight.

The Four Forces Of An Airplane In Ascent



When the airplane climbs, part of the weight vector falls back towards the tail. This slows down the plane.

The Four Forces Of An Airplane In Descent



When the airplane descends, part of the weight vector falls forward towards the nose. This speeds up the plane.

Test Flight: Fly me to the moon

You learned that weight equals mass times gravity. We can reduce mass simply by having a smaller payload, but what if we can't reduce the payload? We could reduce gravity! OK, unless we leave the earth, we really can't change gravity in a meaningful way, but we can change it in X-Plane! Let's imagine that we have outposts on the moon and that the moon has an atmosphere. This is important because without an atmosphere, an airplane cannot fly. (Remember, we are imagining the moon with an atmosphere. The moon does NOT have an atmosphere.)

Confirm Payload is still 900 lbs.

1. At the top menu, select Aircraft.
2. Click on Weight and Fuel.
3. Choose the Fuel/Payload Tab.
4. Make a note of the payload weight. It should be at or near 900 lbs.
5. Click X to return to the plane.

Change Gravity

1. Click on Special at top of the menu.
2. Select Set Environmental Properties.
3. Change planet mu (mass) to 00.660, the mass of the moon. The gravity is now 1.6225.
4. Click X to return to the plane.

Review Quick-Flight Setup

- ✈ Airport: KSEA
- ✈ Aircraft: Cessna 172_P
- ✈ Time: "day"
- ✈ Weather: "clear"

Takeoff

What is the new takeoff distance?

What is the new takeoff speed?

Did the takeoff distance increase or decrease?

Did the takeoff speed increase or decrease?

You did not change the mass of the airplane; you changed gravity. Thus, the weight was reduced dramatically, and the performance increased substantially.

Be sure to set change planet mu (mass) back to 3.986, the mass of the Earth.The gravity is now 9.7986.
Don't forget the payload weight. Make sure and return the payload weight to at or near 296 lbs.

Climbing Higher

The day the moon has an atmosphere, pigs will fly! Well, maybe… Scientists have come up with a scheme to put an atmosphere on the moon. The sun does not shine directly on the dark side of moon. Scientists believe frozen water may be found at the bottom of deep craters. If you close the top of the crater with a giant sunroof and heat the ice, you will create an atmosphere. Pigs will not fly, but humans might. The moon's low gravity means people with artificial wings would be able to flap their arms and fly like birds!

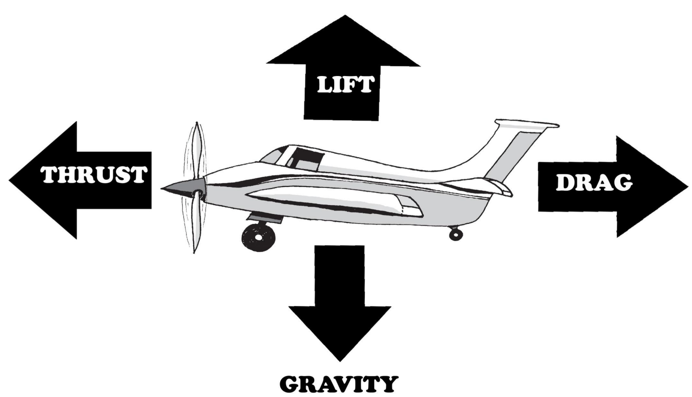
Lift

"The Wright brothers were engineers first, pilots second."

Introduction

In this lesson, you will learn about lift. Lift is a force that helps pilots and engineers overcome weight. If you lose lift in flight, your aircraft will fall out of the sky. You will fly like a rock. I hope that got your attention. No lift, no flying, no way. Please read through this handout, and watch the corresponding videos. You can always re-watch the videos if you need a helping hand.

The Four Forces of Flight



Force

Force is a push or a pull. It is composed of magnitude (how large the force is) and the direction of the force. We represent forces by drawing vectors (arrows), which tell us the magnitude and the direction of the force.

Lift

The direction of this force in level flight is up, or perpendicular to the flight path. Lift results from the differences in air pressure along the wing. The amount of lift is very sensitive to the speed of the air traveling over the wing. When there is not enough air traveling over the wing, lift suffers, and the plane begins to fall out of the sky or stalls. Sounds like fun; let's try it!

Test Flights: Stalls vs. Airspeed

Quick-Flight Setup

- Airport: KSEA
- Aircraft: Cessna 172_P
- Time: “day”
- Weather: “clear”

Location

- Select Global Airport
- Select KSEA
- Select RWY16
- Select Final Approach 3nm
- Be ready to press P to pause the simulation

Collect Test Data

1. Click on Settings.
2. Select Data Input & Output.
3. Choose the Data Set Tab.
4. Click on the last two checkboxes at speeds (line 3).
5. Click on the last two checkboxes at wing lift (line 92).

Show Lift Vectors

1. Select Special.
2. Click on Show Flight Model.
3. White lines should be projecting out of the propeller. These represent lift.

Set Payload

1. At the top menu, select Aircraft.
2. Click on Weight and Fuel.
3. Choose the Fuel/Payload Tab.
4. Make a note of the payload weight. Change it to 296 lbs.
5. Click X to return to the plane.
6. If you are not in a Chase view, press “A”.
7. Press “Shift 8” and circle around the plane.

Test Piloting

If you have not already, please watch the Stalls vs. AirSpeed video. Fly the plane level for 3 seconds. Watch the green lift arrows on the wings and the Vtrue airspeed in the left top corner of the screen.

Put the plane in a 3 second climb, and then pause the simulation, but do not change the throttle.

What does the airspeed do as you climb?

What do the lift arrows do as you climb?

Now continue climbing until the lift arrows nearly disappear or disappear, but do not change the throttle. Pause the simulation.

What is the airspeed now?

Is there much lift occurring on the wing?

Continue the simulation. What happens to the plane?

The wings are no longer producing enough lift to support the weight of the plane; the plane begins to fall. This is known as a stall. The good news is it is easy to recover. You need to gain airspeed again, so what do you do with the nose of the airplane to gain airspeed?

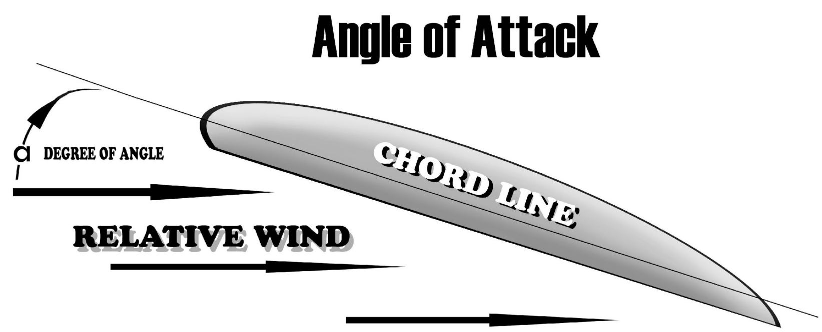
Level the wings, and point the nose down. Once your airspeed approaches 80 knots, pull the nose up slightly. Watch the lift vectors.

Did the lift vectors increase as the airspeed increased?

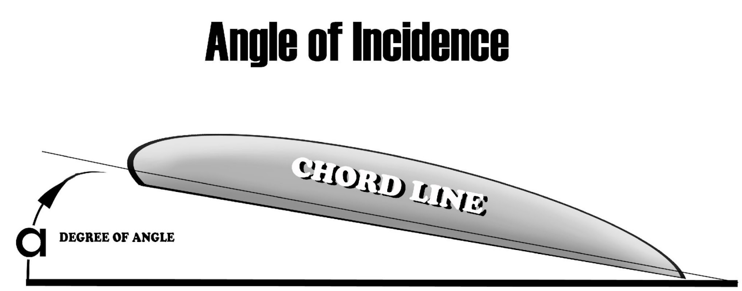
Did the lift vectors increase when the airspeed increased and the nose was pointed up?

Please fly, stall, and recover several times. Watch the lift vectors throughout.

Our test piloting should show us that lift is directly dependent on airspeed. Lift is also dependent on the angle of attack. The angle of attack refers to the angle the airfoil makes with the direction of airflow. This explains the fact that in a dive the airspeed was increasing, but there was very little lift generated until we pulled up the nose. Then with both a better angle of attack and airspeed, the lift vectors rose dramatically.



We have learned that lift is dependent on airspeed and the angle of attack. This angle of attack is small. In fact, to maintain an angle of attack when flying level, engineers build into the wing a small angle of attack. This is called the angle of incidence.

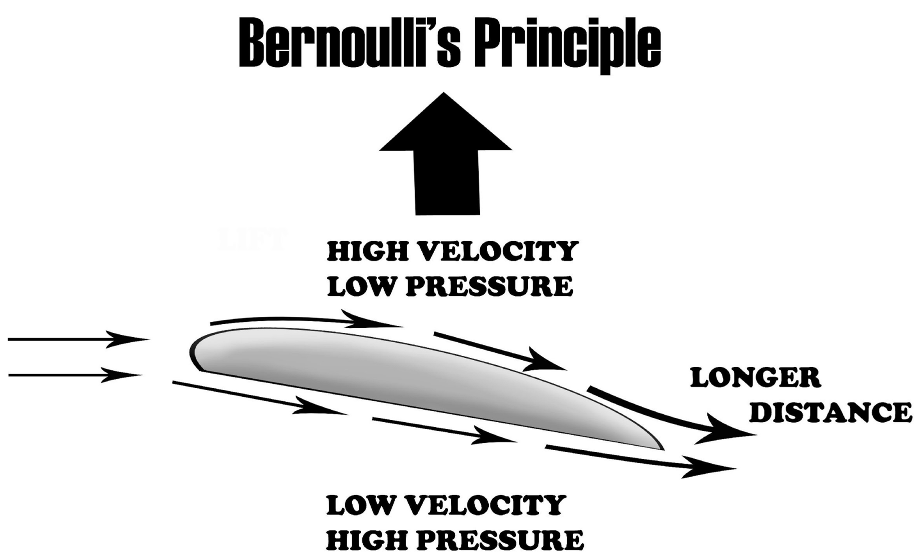


Climbing Higher: What is Lift?

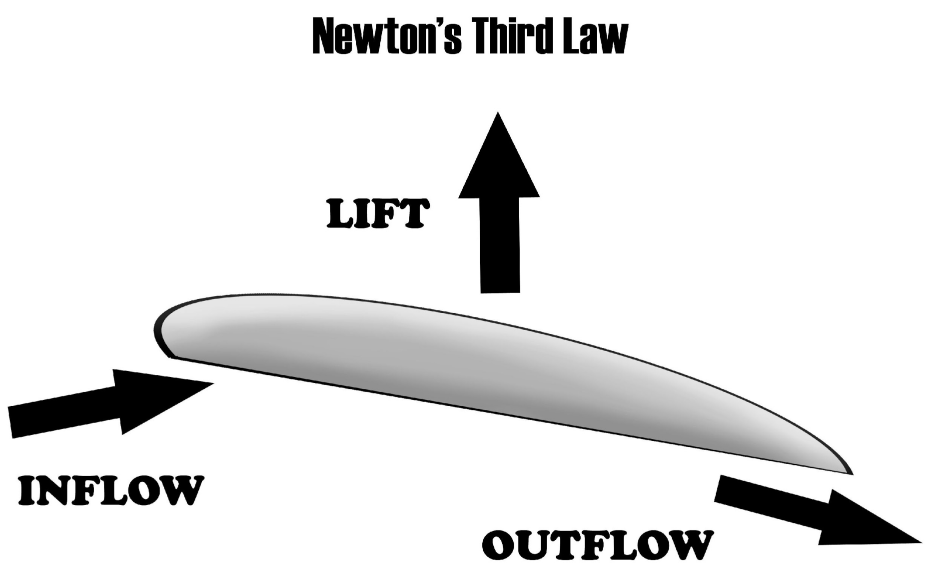
We have learned about the impact of airspeed and the angle of attack on lift, but what is lift? Lift is the result of a difference in air pressure. The pressure on the top of the wing is less than on the bottom of the wing. Most scientists and engineers agree on this point. But what causes the difference? Listed below are several explanations.

The Longer Path or Equal Transit Theory

The air flowing over the top of the airfoil (wing shape) travels faster than the air underneath the bottom of the airfoil. The airfoil is a curved shape. Air molecules traveling across the top travel a longer distance than on the bottom. As the air molecules move over a greater distance, the air molecules spread out and travel faster than the air flowing under the bottom of the airfoil. As air speed increases, the pressure drops. This is also sometimes known as the Bernoulli Principle of Lift.



The Skipping Stone Theory
Due to the angle of attack, the airflow strikes the bottom of the wing and bounces off. The resulting force is lift. This is also sometimes known as Newton's 3^{rd} Law.



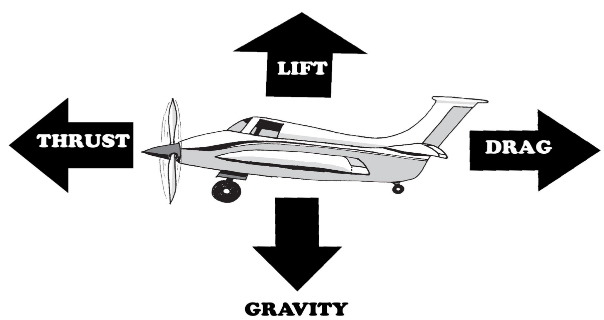
Drag

"The Wright brothers were engineers first, pilots second."

Introduction

In this lesson you will learn about drag. Drag is a force that resists the movement of the airplane through air. Drag slows down planes, and drag results in lower fuel economy. Generally, engineers design planes to reduce drag.

The Four Forces of Flight



Force

Force is a push or a pull. It is composed of magnitude (how large the force is) and the direction of the force. We represent forces by drawing vectors (arrows) which tell us the magnitude and the direction of the force.

Drag

Drag is directed along and opposed to the flight direction. Drag is a force that resists the movement of the airplane through air. Drag is unavoidable. Dang! Let's look at an example.

The good news is that we are going to fly a new plane. This baby is sweet. She's a King Air with two engines. That is right, and two engines mean three times the fun! It also has retractable gear. Once you take off, you can pull up or retract the landing gear.

Test Flights: Air Speed vs. Drag (Deployed Landing Gear)

Open X-Plane and follow the Quick-Flight Setup instructions below:

Quick-Flight Setup
- Airport: KSEA
- Aircraft: King Air C90B
- Time: “day”
- Weather: “clear”

Location
- Select Global Airport
- Select KSEA
- Select RWY16
- Select Final Approach 3nm
- Be ready to press P to pause the simulation
- Press “Shift 8” to bring up the Chase view.

Collect Test Data
1. Click on Settings.
2. Select Data Input & Output.
3. Click on the last two checkboxes at speeds (line 3).
4. Click on the last two checkboxes at landing gear deployment (line 67).
5. Click X to return to the plane.

Test Piloting

If you have not already, please watch the Air Speed vs. Drag (Deployed Landing Gear) video. Fly the plane level for 3 seconds. Be sure that the landing gear is up. Please observe the airspeed.

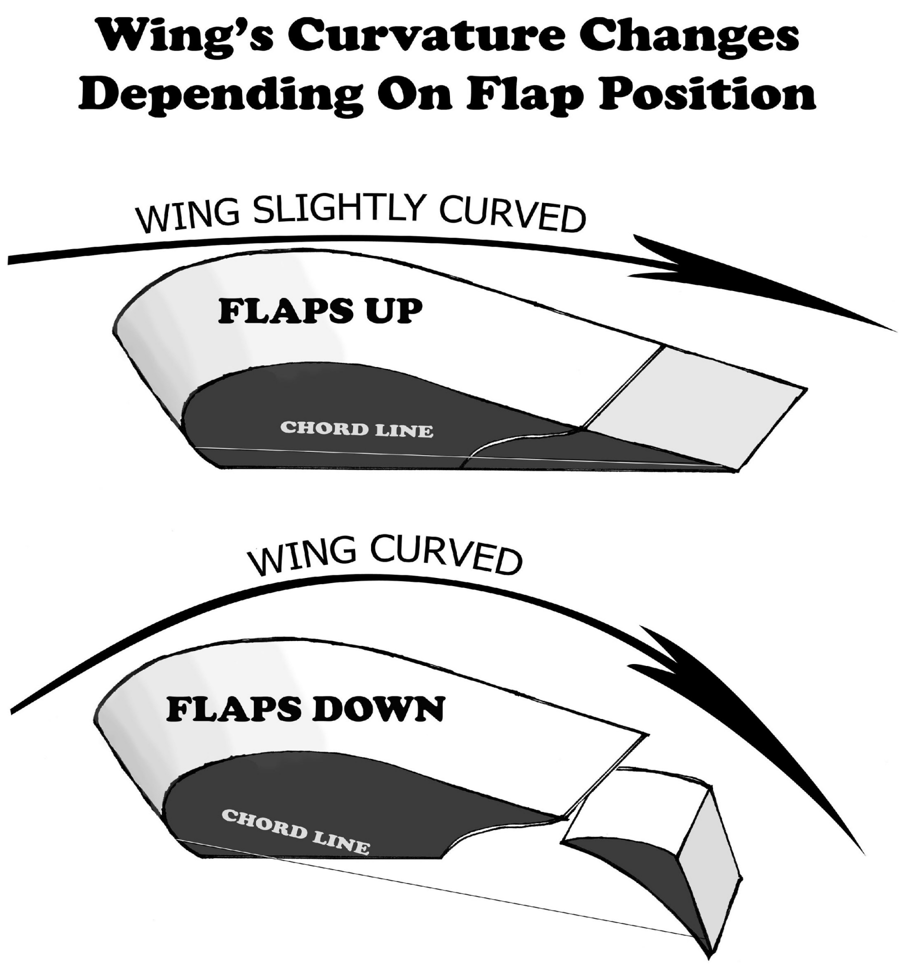
What is the airspeed now?

Now press “G” to lower the gear. Fly the plane level for 3 seconds. Be sure that the landing gear is down.
What is the airspeed now?

What is your hypothesis to explain what happened?

Flaps

Sometimes we want to slow down an airplane, like any airplane that is taking you back to school. Actually, you will find it easier to land if you slow down the plane. Careful, though! If you slow down the plane too much, you'll stall and fall out of the sky. How do we add drag? Stick your hand out the window of the airplane? Drag your feet across the clouds? How about making the wing bigger? Actually, engineers have developed a way to make the wing bigger by using flaps. Flaps extend the wings trailing edges back and change the airfoil, or shape of the wings. This increases drag. It also increases lift. As you land, the flaps slow down the plane while increasing the lift on the wing, so lift is maintained at slower air speeds to avoid stalling.



Test Flights: Air Speed vs. Drag (Flaps)

Open X-Plane and follow the instructions below:

Quick-Flight Setup

- Airport: KSEA
- Aircraft: King Air B200
- Time: “day”
- Weather: “clear”

Location

- Select Global Airport
- Select KSEA
- Select RWY16
- Select Final Approach 3nm
- Be ready to press P to pause the simulation
- Press “Shift 8” to bring up the Chase view.

Collect Test Data

1. Click on Settings.
2. Select Data Input & Output.
3. Choose the Data Set Tab.
4. Click on the last two checkboxes at speeds (line 3).
5. Click on the last two checkboxes of trim/flap/slat/s-brakes (line 13).
6. Click on the last two checkboxes of wing lift (line 92).
7. Click on the last two checkboxes of wing drag (line 93).
8. Click X to return to the plane.
9. Press “W” to return to cockpit view.

Try to fly as consistently as possible for 3 seconds. Record the airspeed, lift and drag for each flight in the table below.

Flaps Up

Trials	Flaps	Vtrue Airspeed	Lift wing1	Drag wing1
1	Up			
2	Up			
3	Up			

Average Vtrue Airspeed ________
Average Lift wing1 ________
Average Drag wing1 ________

Flaps Down

Trials	Flaps	Vtrue Airspeed	Lift wing1	Drag wing1
1	Down			
2	Down			
3	Down			

Average Vtrue Airspeed ________
Average Lift wing1 ________
Average Drag wing1 ________

Please answer the following questions:

When you deploy or lower flaps, what does drag do?

When you deploy or lower flaps, what does airspeed do?

When you deploy or lower flaps, what does lift do?

Why would it be dangerous to land a plane with flaps if the flaps only increased drag, but did not increase lift?

Kinds of Drag

Much like homework, drag comes in different forms.

Parasitic Drag

Parasitic drag is created from dragging a body (fuselage, wing, flap, landing gear) through the air. You can see this by making a fist and putting it out the window of a car doing 60. This drag varies with the square of the speed of the plane. A simplified equation would be Speed = $Drag^2$, so changing airspeed means an even greater change in drag. Engineers try to shape or change the body of the plane to reduce this kind of drag. For example, engineers developed retractable landing gear to reduce this kind of drag in fast airplanes. Automobile engineers try to reduce drag in cars to increase performance and fuel economy.

Induced Drag

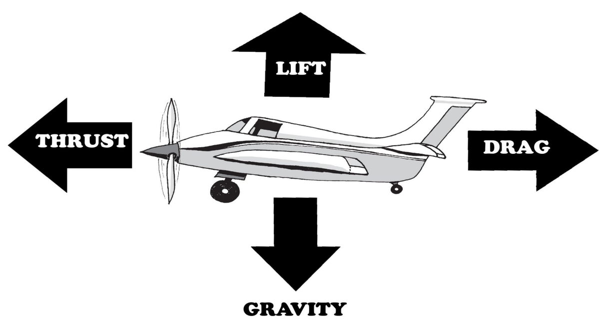
Induced drag is the result of lift. Yes, induced drag is caused by the creation of lift. Engineers spend a great deal of time looking at different airfoils or shapes of a wing that will give them the greatest amount of lift with the least amount of drag for a wing under certain conditions. Any part of the plane that generates lift generates this form of drag. This includes the wing, tail surfaces, and the body.

Thrust

Introduction

In this lesson you will learn about Thrust. Thrust is a force that helps pilots overcome drag. Thrust also determines the altitude of the airplane. You climb or descend by adding or subtracting thrust. In this lesson, you will learn how the plane makes thrust and understand how thrust will help you land an airplane. Yes, that's right you get to practice landings. Takeoffs are optional, but landings are mandatory, so we need to understand and practice landing procedures. As always, please read through this handout and watch the corresponding videos. You can always re-watch the videos if you need a helping hand.

The Four Forces of Flight



Force

Force is a push or a pull. It is composed of magnitude or how large the force is and the direction of the force. We represent forces by drawing vectors (arrows), which tell us the magnitude and the direction of the force.

Thrust

The direction of this force is forward in the flight path. Thrust in an airplane comes from the propeller pulling or pushing the airplane through the air. The propeller acts like a rotating wing. The blades on the propeller create lift, which creates the propulsive force. Usually a gas engine provides the power to turn the propeller in an airplane.

Test Flights: Landings

Quick-Flight Setup

- Airport: KSEA
- Aircraft: Cessna 172SP
- Time: “day”
- Weather: “clear”
- Click FLY with these options!

Location

- Select Global Airport
- Select KSEA
- Select RWY16
- Select Final Approach 3nm
- Be ready to press P to pause the simulation

Test Piloting

If you have not already, please watch the Landing video.

Landing – Basic

1. Put the plane into level flight.
2. Reduce the throttle until the engine runs at 1600 RPM.
3. Keep the wings level.
4. Maintain the airspeed around 85 knots.
5. Be sure to watch your altimeter and your vertical speed indicator.
6. Watch the PAPI – Precision Approach Path Indicator:
    a. All red – you are too low on your approach.
    b. Half red and half white – you are on the right approach.
    c. All white – you are too high on your approach.
7. Once you touch down, throttle down and apply brakes.
8. Repeat until you can land the plane on the runway every time.

Landing – Full Flaps

1. Put the plane into level flight.
2. Reduce the throttle until the engine runs at 1500 RPM.
3. Keep the wings level.
4. Reduce the airspeed to less than 85 knots.
5. Deploy full flaps.
6. Watch the PAPI – Precision Approach Path Indicator:
7. Add or remove throttle to stay on the proper approach according to the PAPI
8. Repeat until you can land the plane on the runway every time.

Investigative Questions

Do we use the throttle or change the pitch of the airplane to control altitude?

If you come in too low, instead of adding throttle, why not pull the nose up?

What are the advantages of landing at a slower speed?

Can you land at a slower speed with full flaps?

Can you land on a shorter runway with full flaps?

Why not fly all the time with full flaps?

Taking It Higher

Landing an airplane on land can be both fun and challenging. Imagine landing at sea on an aircraft carrier? Here is your chance!

1. Follow the Quick-Flight Setup instructions below:
   a. Airport: KSAN (San Diego International)
   b. Aircraft: Cessna 172SP
   c. Time: "day"
   d. Weather: "clear"
   e. Click FLY with these options!
2. Location - Select Global Airport
   a. Make sure KSAN is selected
   b. RWY09
   c. Final approach 3nm
   d. Be ready to press P to pause
3. Click on Aircraft
   a. Select Aircraft & Situations
   b. Select Aircraft Carrier Approach
4. Go for it. Fly navy!

Want a bigger challenge? Try making a night carrier landing.

Still too tame? Try landing in rough seas.

a. Select Environment
b. Click on Weather
c. Select Water Tab
d. Change wave height to 10 ft.
e. Press "X" to exit

Flight Stability

"The Wright Brothers were engineers first, pilots second."

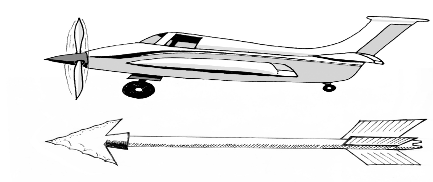
Introduction

We have learned about the four forces that act on an airplane and as we learned earlier, the Wright Brother recognized the importance of stability in flight .

Stability

Stability describes the tendency of the airplane to return to its original condition after a disturbance. For example, if a gust of wind pitches the airplane up, a stable airplane will react by pitching down. If the plane is unstable, the plane will continue to pitch up instead of returning to its original condition.

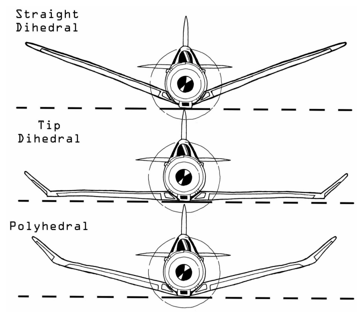
Let me try to explain this in another way. Why does an arrow have feathers on its tail? The head of the arrow is heavy and sharp and does the damage. What do the feathers do? Shoot an arrow without feathers, and very quickly the arrow is traveling sideways out of control because any disturbance (wind, rain, etc.) causes the arrow to change direction.
Add feathers and the arrow flies straight. This is because the feathers dampen the effects of any disturbance helping the arrow fly straight. The feathers give the arrow stability by keeping the tail in the back. The tail of the airplane acts like the feathers on an arrow. The tail (horizontal and vertical stabilizers) gives the plane stability.



What if the pilot had worked all day before embarking on a late night flight? On a stormy night? When tired? The point of stability is to reduce the pilot's workload and make it easier to fly the aircraft. The pilot wants to be able to look down at a map or let go of the controls for a second to adjust the microphone without the plane trying to roll inverted. This may be due to a gust of wind or bump of turbulence. Engineers design stability into aircraft. They recognize that no amount of pilot control can overcome an inherently unstable airplane. We will look at two important examples of ways we can increase the stability of an airplane.

Roll and Yaw Stability

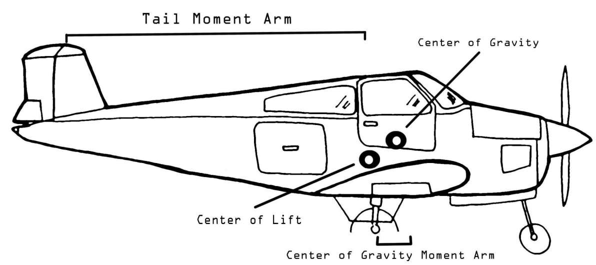
Many airplanes incorporate a dihedral angle in the wings. Look below, and you will see several wings. Notice the wings are higher at the tips than where they join the fuselage.

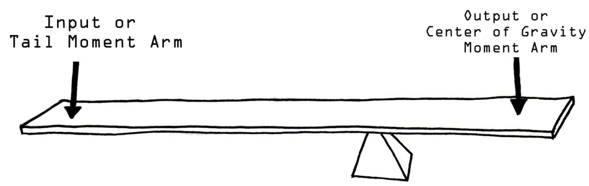


Dihedral helps to keep a plane's wings level. For example, a gust of wind causes a plane to roll, dropping the left wing down and raising the right wing up. Dihedral causes the lower wing to rise and the higher wing to sink, restoring stability to the flight path.

Pitch Stability

Imagine the airplane as a teeter-totter. The nose of the airplane is at one end of the teeter-totter, and the tail is at the other end. The fulcrum or balancing point of our airplane/teeter-totter is the wing. The distance between the tail and the wing can be thought of as a lever arm that acts like a teeter-totter. We can control the pitch of the airplane by varying the amount of force applied to the tail. In physics, the application of force to rotate an object about a fulcrum is called torque.





You have already learned and experienced changing the pitch of the airplane using the elevator, the part of the horizontal tail section that moves up or down. We can also increase pitch by adding a force (like weight) to the end of the tail. This newly added force multiplied by the distance from the end of the tail to the wing would cause the nose to pitch up!

We need the plane to be stable, so we locate the C.O.G in front of the wing and put the tail behind the wing. The C.O.G pushes down pitching the nose down and the tail pushes down which holds the nose up making the plane stable. Let’s look at these forces in action.

Test Piloting

1. Follow these Quick-Flight Setup instructions.
   - ✈ Airport: KSEA
   - ✈ Aircraft: Cessna 172SP
   - ✈ Time: "day"
   - ✈ Weather: "clear"
   - ✈ Click FLY with these options!
2. Location - Select Global Airport
   - ✈ Airport: KSEA
   - ✈ RWY 16
   - ✈ Final approach 3nm
   - ✈ Be ready to hit P to pause
3. Special - "Show flight model" to bring up the lift vectors.
4. Establish level flight. Gently climb up, and dive down several times.

Investigative Questions

In which directions are the lift vectors pointing on the wing as the plane dives?

In which directions are the lift vectors pointing on the tail as the plane dives?

Is the lift created by the tail the same in all flying situations—level, dive, and climb?

Would I achieve the same result if I added weight to the tail? If so, why don't we add weight to the tail?

The Importance of Balance and Safe Flying

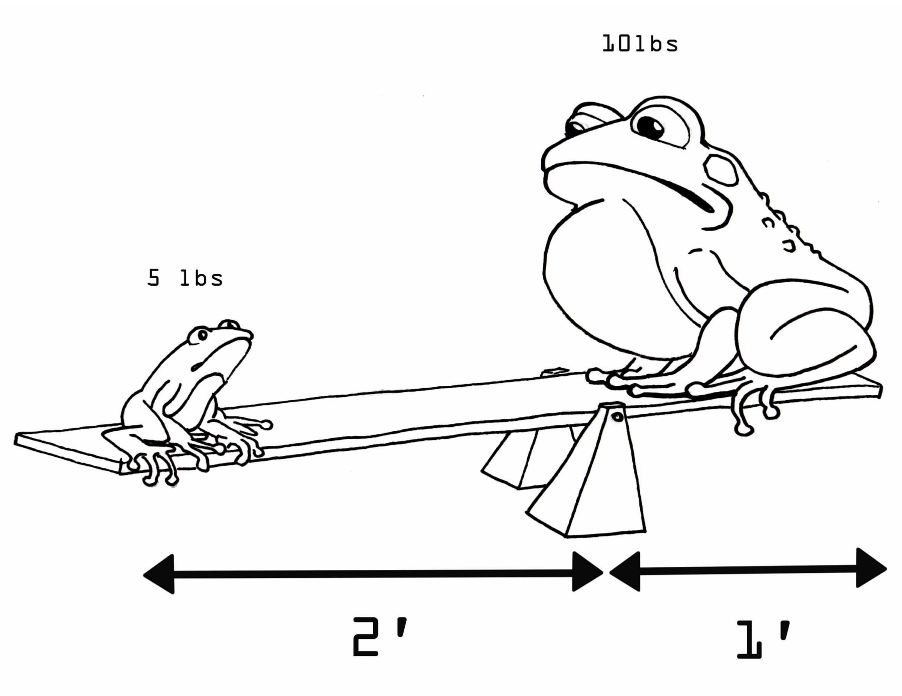
The load and balance of an airplane are very important to safe flying. According to the British newspaper *The Telegraph*, a small airplane crashed in Africa when a crocodile got loose on board the plane. It seems that an animal smuggler had stored a crocodile in his luggage. The croc got loose, causing the passengers to panic and run to the front of the airplane. In spite of the pilot's pulling desperately on the controls, the plane pitched downward and crashed.

Luckily, this is a very rare incident. On every flight, pilots make sure the plane is loaded and balanced properly with all items properly secured.

Climbing Higher

Airplanes, Teeter-totters, and Torque

As we said earlier, torque is the application of force to rotate an object about a fulcrum. To better understand how torque impacts airplanes, let's take a closer look at a teeter-totter.



These two frogs are sharing a teeter-totter. I guess the frog pond was getting a bit dull. The frog on the left side weighs 5 lbs and is 2 ft from the fulcrum (triangle). This frog produces 10 ft-lbs of torque or moment. 5 lbs x 2 ft = 10 ft-lbs. Let's calculate the torque or moment of the frog on the right.

The weight of the frog on the right = 10lbs
The distance of the frog on the right = 1ft
Torque or moment =

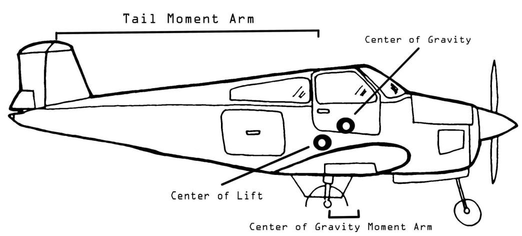
Isn't that cute? Both frogs are producing the same amount of torque. What does this mean? Will the teeter totter rotate clockwise or counterclockwise? Please explain your answer.

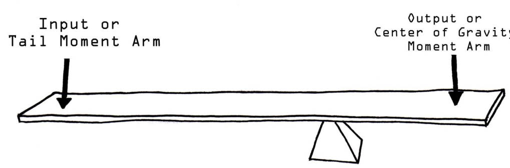
What about a frog that weighs 2 lbs? How far would this frog need to be from the fulcrum to produce 10ft-lbs of torque or moment?

What about a hefty 20 lb frog? How far would this frog need to be from the fulcrum to produce 10 ft-lbs of torque or moment?

Another frog is sitting 2.5 ft away from the fulcrum. How much does this frog weigh if she is producing 10 ft-lbs of torque or moment?

If you solved those problems, you have a pretty good understanding of both teeter-totters and torque. Now, let's return to airplanes.





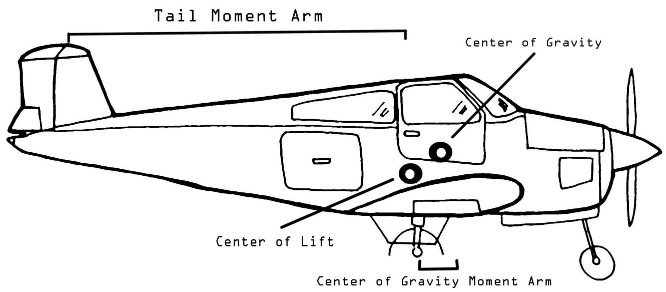
In reality, there are several moment arms at work here in the airplane, but for our purposes, we are going to simplify the situation and assume that two lever or moment arms are impacting the pitch stability.

The distance from the wing to the Center Of Gravity (C.O.G) is the C.O.G Moment Arm. C.O.G Moment Arm multiplied by the Airplane Weight will give us the C.O.G. Torque or C.O.G. Moment.

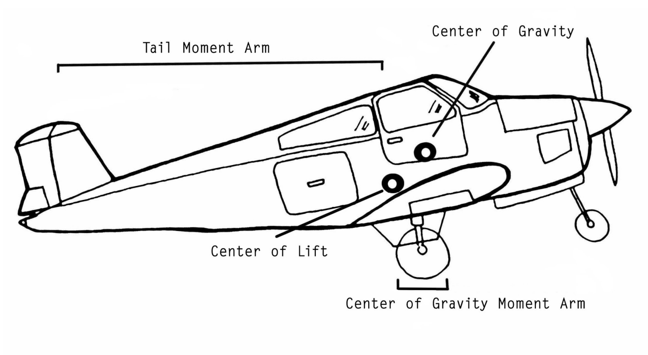
C.O.G Moment = C.O.G Moment Arm X Airplane Weight
The C.O.G. Moment always tries to rotate the aircraft's nose down. The tail must counteract the C.O.G. Moment to hold the nose up.

The distance from the wing to the tail is the Tail Moment Arm. The Tail Moment Arm multiplied by the force generated by negative lift will give us the Tail Torque or Tail Moment.

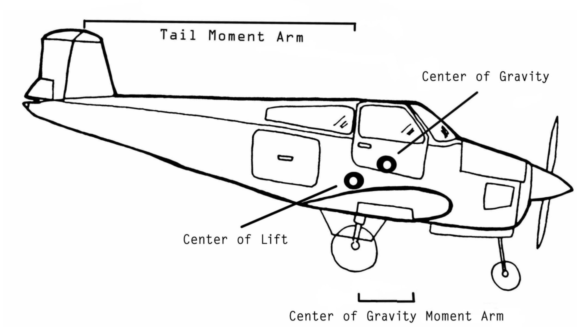
Tail Moment = Tail Moment Arm X Lift Generated By Tail



The C.O.G. Moment equals the Tail Moment when the nose is NOT pitching up or down, but will it will be in equilibrium.



If the plane is pitching up, which is greater — the C.O.G Moment or the Tail Moment?



If the plane is pitching down, which is greater—the C.O.G Moment or the Tail Moment?

Test Piloting

Next, we are going to collect some data during the following test flights.

1. Click on Settings.
2. Select Data Input & Output.
3. Click on the last two checkboxes of each of the following:
   - Payload weights and CG (line 63)
   - Defs:elevators (line 74)
4. Click X to return to the plane.

Quick Flight Setup

1. Open X-Plane and follow these Quick-Flight Setup instructions.
   - Airport: KSEA
   - Aircraft: Cessna 172SP
   - Time: “day”
   - Weather: “clear”
2. Click on FLY with these options!

Select Aircraft

1. Click on Weight and Fuel.
2. Set Center Of Gravity at -16.7 inches.
3. Set Payload at 2799 lbs.
4. Click X to return to the plane.

Select Location - Select Global Airport

1. Airport: KSEA
2. RWY 16
3. Final approach 3nm
4. Be ready to hit P to pause

Flight

Establish and maintain level flight for 3 seconds. Use the Vertical Speed Indicator to help you determine level flight. Record the Elevator Deflection appearing in the cockpit window (You do not need to review the graph). Repeat three times.
Please complete the following table.

Center Of Gravity (-16.7) and Elevator Deflection

Trial	Center of Gravity	Elevator Deflection
1	-16.7	
2	-16.7	
3	-16.7	
AVERAGE		

Set the Center Of Gravity to 22.1 inches and repeat the flight three times as before and complete the following table.

Center Of Gravity (22.1) and Elevator Deflection

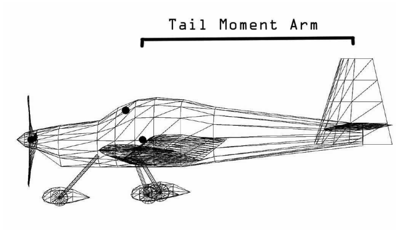
Trial	Center of Gravity	Elevator Deflection
1	22.1	
2	22.1	
3	22.1	
AVERAGE		

Investigative Questions

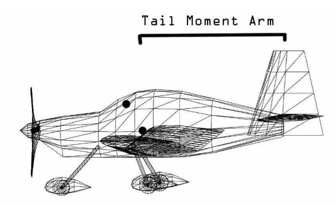
Which Center Of Gravity (COG) resulted in the greatest elevator deflection?

If I added even more payload weight, would that be the equivalent of increasing the COG Moment? Please explain your answer.

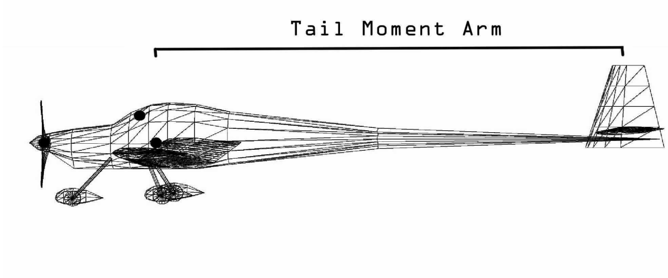
Tail Moment Arm Questions
Please answer the following questions using these drawings.



Airplane A



Airplane B



Airplane C

The amount of lift generated by the tail is the same for all three airplanes. True or False? Why?

Which of the three airplanes has the longest Tail Moment Arm?

Which of the three airplanes has the largest Tail Moment?

Which of the three airplanes has the lowest Tail Moment? Why?

Science Of Flight – Advance Topics

Pressure and Airspeed

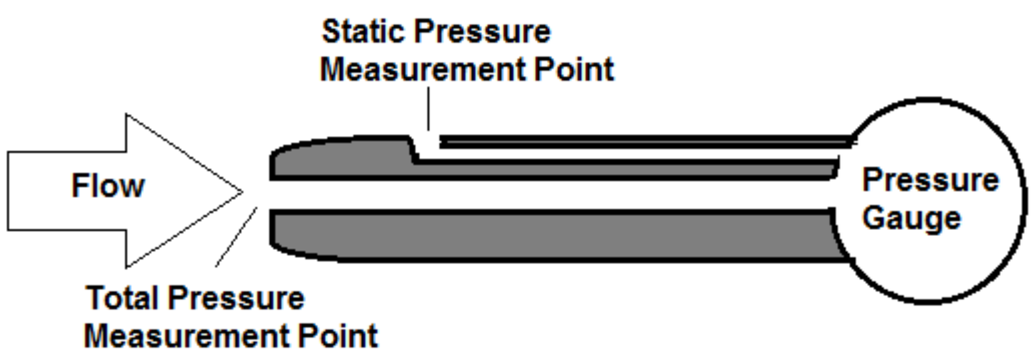
"The Wright Brothers were engineers first, pilots second."

The earliest aerospace engineers had to use clever tricks to figure out the behavior of airplanes. Without computers and GPS, they relied solely on their understanding of aerodynamics. These engineers designed a new method for determining plane's velocity; using pressure gauges called *Pitot-static tubes.* These instruments report to pilots their airspeed determined from the pressure of the air moving over them.

To understand how Pitot-static tubes work, several kinds of pressure must be defined. Static pressure is caused by the random movement of each molecule in non-moving air. To visualize this, imagine throwing a ball in a moving car. The ball will bounce randomly around the inside of the car, and would not injure anyone who might get hit by it. On the other hand, if that same ball flew out the car window and hit someone, it would hit them with a powerful force; due to the random velocity of its movement (static pressure) and the velocity of the car (dynamic pressure). This is an example of total pressure; pressure caused by adding the effects of static pressure and non-random motion. This, written as an equation, is as follows:

$$P_{static} + P_{dynamic} = P_{total}$$

Pitot-static tubes measure two things: the total pressure and the static pressure of the aircraft. The total pressure can be found when the plane is in flight. A tube facing the flow direction fills up with air. This causes the pressure to build up on a pressure gage. The static pressure is measured by a tube that does not face the flow direction, although air also builds up inside this tube. The pressure gauge measures this difference in these pressures to determine the dynamic pressure.



The question remains; how does this process help to measure velocity?

We know that the dynamic pressure relates in some way to the velocity. The exact relationship is as follows.

$$P_{dynamic} = \frac{1}{2} * \rho * Velocity^2$$

The symbol ρ represents the density of the air. When substituting the equation for dynamic pressure into the total pressure equation, the result is the equation for velocity. To get a clearer understanding of this process, try to derive this equation on your own!

$$Velocity = \sqrt{\frac{2 * (P_{total} - P_{static})}{\rho}}$$

You will be trying to determine the dynamic pressure, $P_{total} - P_{static}$, of an aircraft by using the X Plane and the above equation. The velocity will be given in miles per hour, which you are to convert into meters per second by multiplying it by 0.447. Additionally, you will need to find the air density at 3,000 feet using the chart below.

Elevation (ft)	Density (kg/m^3)
0	1.23
6000	1.03

Data Setup

1. Click on Settings -> Data Input and Output
2. Click the last two check boxes beside Speeds (line 3)
3. Click on the last two check boxes beside lat, long, altitude (line 20)

Quick-Flight Setup

- Aircraft: Cessna 172
- Airport: FQIN (elevation: 30 ft above sea level)
- Time: “day,” Weather: “clear”
- Click “FLY with these options!”

1. Take off, and ascend to 3,000 ft.
2. Pause the simulation, and record the number under Vtrue mphas. You can now find the dynamic pressure!

You may have noticed that the X Plane has two values; Vind and Vtrue, when stating the airspeed. These stand for “true” and “indicated” airspeed. The difference depends on the density of air being used as a frame of reference. Indicated (or equivalent airspeed) relies on the pressure at sea level. True airspeed relies on the density of the air at the aircraft’s current altitude. You will notice that, at sea level, the true and indicated airspeeds are the same.

Coefficients of Lift and Drag

"The Wright Brothers were engineers first, pilots second."

As we have learned earlier, level flight means that all of the forces working on an airplane are balanced: lift and weight are equivalent, just as drag and thrust are equivalent. When the plane is on the ground, however, the level flight is obviously not possible. Therefore, pilots must accommodate. Pilots have to increase the lift and thrust during takeoff but must also increase the drag during landing.
These basic concepts are simple, but there is a lot that must be done to calculate the actual values for lift and drag. These can change due to differences in payload, the aircraft's velocity, and the aspect ratio of the wings among other variables. To make the calculations easier, engineers take such variables into account: they replace the lift and drag values of the airplane with the coefficients of drag (C_{D-}) and lift (C_L).

Like drag itself, the coefficient of drag is made up of two components: parasitic and induced.

$$C_D = C_{D,0} + C_{D,i}$$

Another way this can be stated is as follows:

$$C_D = \frac{Drag}{q_\infty * S}$$

Every aircraft will have parasitic drag, but the exact amount of drag is difficult to calculate numerically. Engineers often must conduct wind tunnel experiments to find this value. However, the other type of drag can be calculated as follows:

$$C_{D,i} = \frac{{C_L}^2}{3.14 * AR}$$

From the above equation, it can be seen that the induced drag is caused by the lift of the aircraft's wings. Therefore, to calculate induced drag, the lift must first be calculated. The lift coefficient is given below:

$$C_L = \frac{Lift}{q_\infty * S}$$

In this equation, S is the wing planform area, which can be found by multiplying the aircraft's wingspan and the mean chord length. This produces the area of the wing. The other variable, q_∞ is called the *freestream dynamic pressure*. This is the pressure on the aircraft caused by the aircraft's velocity. This can be determined from the following equation, where ρ_∞ is the density of the air:

$$q_\infty = \frac{1}{2} * \rho_\infty * V^2$$

We are now going to use the X-Plane and calculate the actual numerical values of lift and drag of the Cessna 172 during both takeoff and landing. Open X-Plane.

Data Setup

1. Click on Settings -> Select Data Input & Output.
2. Click on the last two checkboxes at times (line 1)
3. Click on the last two checkboxes at speeds (line 3)
4. Click on the last two checkboxes at loc, vel, dist traveled (line 21)
5. Click on the last two checkboxes at lift over drag & coeffs (line 68)
6. Click on X to return to the plane.

Flight Setup - Takeoff

- Click on File -> Quick-Flight Setup
- Airport: KSEA, Aircraft Cessna 172SP
- Time: "day," Weather: "clear"
- Click "FLY with these options!"

1. Take off as steady as possible. Note the time that you take off under the data labeled "timer"
2. Once your plane is ascending steadily, click on Settings -> Data Input & Output
3. Select the Data See tab.
4. Deselect all check boxes on the bottom, except for V_{ind--} (in mph), cl, and cd.
5. Scroll to the time at which you lifted off, and record the values for V_{ind}, C_L and C_D

Flight Setup – Landing

Click on File -> Quick Flight Setup

- Airport: KSEA, Aircraft: Cessna 172SP
- Time: "day," Weather: "clear"
- Click "FLY with these options!"
- Select "P" on your keyboard to pause the simulation.

1. Click on "Location," and select "Select Global Airport"
2. Next to RWY 16, select 3nm
3. Prepare to land with your flaps down, and as steadily as possible
4. Just before landing, note the elapsed time under the data labeled "missn time"
5. Click on Settings -> Data Input & Output
6. Select the Data See tab.
7. Deselect all check boxes on the bottom, except for $V_{ind\text{--}}$ (in mph), cl, and cd.
8. Scroll to the time at which you landed, and record the values for V_{ind}, C_L and C_D

Using the equations on the previous page, you should now be able to calculate the numerical values for lift and drag during takeoff. Remember to change miles per hour (mph) into meters per second (m/s) by multiplying the mph value by 0.447! Here are several more values that you may need:

$S = 16.3\ m^2$
$\rho_\infty = 1.23\ kg/m^3$
AR = 7.44

Lift and Drag (numerical and coefficients)

	Takeoff	Landing
C_L		
Lift		
C_D		
Drag		

Keep in mind, the drag coefficient during landing should be higher than the drag coefficient during takeoff.
Bonus: calculate the parasite drag coefficient of this aircraft, using both the takeoff and landing values for C_D. Why might these values be different?
Though the lift coefficient is higher during landing, the actual numerical value of lift is smaller than during takeoff. Why is this?

Coefficient of Lift and Angle of Attack
As we learned earlier in lesson 3, the amount of lift a wing generates depends on its angle of attack. If the angle of attack is too high, it will cause the aircraft to stall. Now that each of us is familiar with the lift coefficient, we can easily show the relationship between lift and angle of attack.

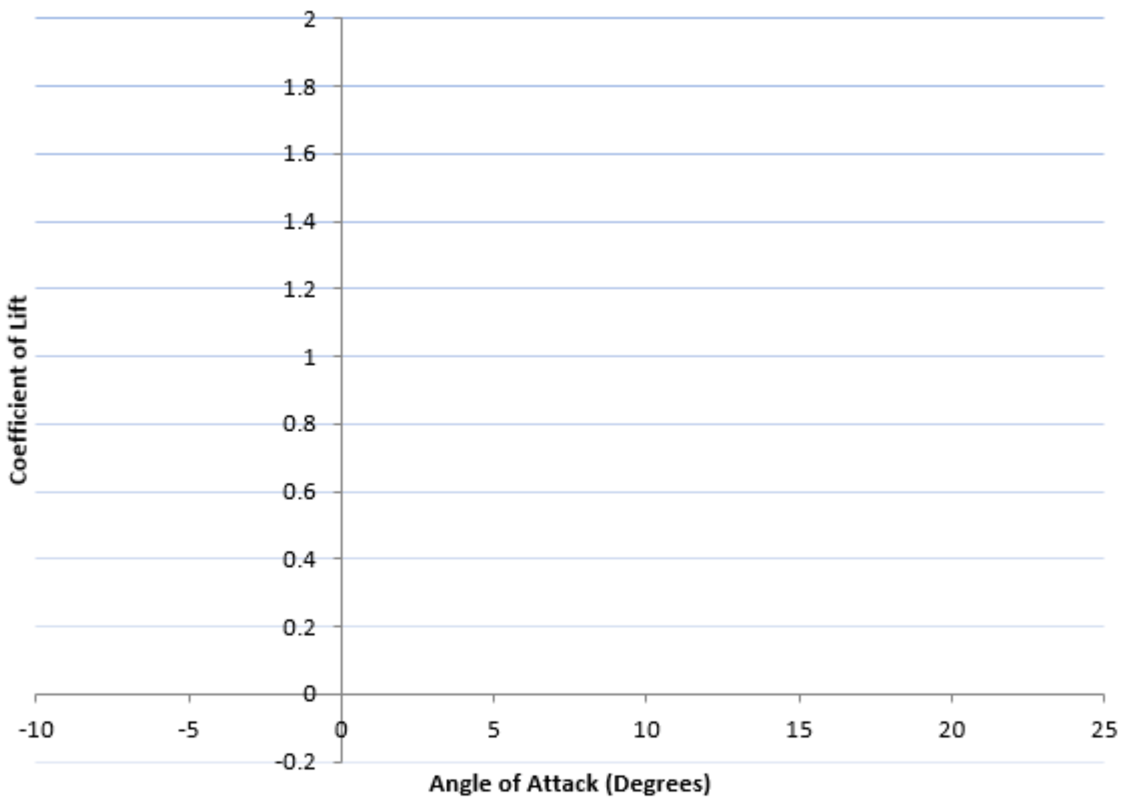
Data Setup
1. Click on Settings -> Data Input & Output
2. Click on the last two checkboxes at AOA, side-slip, paths (line 18)
3. Click on the last two checkboxes at Lift over drag & coeffs (line 68)

Flight Setup
- Click on File -> Quick-Flight Setup
- Airport: KSEA, Aircraft: Cessna 172
- Time: “day,” Weather: “clear”
- Click “FLY With these options!”

1. Take off as steadily as possible.
2. Once you are in level flight, alternate pitching your aircraft’s nose up and down. Be sure you pitch it enough so that your aircraft stalls! Do this several times.

Data Collection
1. After practicing these maneuvers, pause your flight by pressing P on your keyboard.
2. Click on Settings -> Data Input & Output
3. Select the Data See tab.
4. Deselect all check boxes except for cl and alpha.

Where you see alpha (your Angle of Attack) increase, hover over the line and record your C_L. Plot your C_L values for Angle of Attacks of -5°, 0°, 3°, 5°, 10°, 15°, and 20°. Feel free to round it off to the closest degree, or the closest C_L value.



For this aircraft, the coefficient of lift reaches zero at a negative angle of attack. This is caused by the wings' angle of incidence, which provides lift even if the plane is flying level.

After a certain angle of attack, the coefficient of lift decreases. What is happening here?

How could an engineer design the aircraft to achieve higher angles of attack without experiencing this loss of lift?

Engineering Of Flight

Aspect Ratio

"The Wright Brothers were engineers first, pilots second."

Introduction

As defined by Webster, Aspect Ratio is the ratio of span to mean chord of an airfoil. (You might hear this term when discussing TVs. Aspect Ratio in this case refers to the width to height ratio of the screen.)

This ratio is an important concept in designing airplanes. Aspect Ratio is the wingspan divided by the mean width of the wing or chord. Let's investigate how changing the Aspect Ratio of our plane impacts takeoff performance.

We will do some calculations before we begin. (We are, after all, engineers.) Then, we will select the appropriate wings and test the plane.

Mathematical Modeling

We will change the wingspan of our airplane without changing the airfoil. This will change the aspect ratio of our plane. Listed below are different wingspans with the same mean chords. Please calculate the Aspect Ratio (AR) for each wingspan. This is important because we do not want to try to take off in a plane that won't fly, and we don't want to waste fuel and time.

Remember, engineers are concerned about resources (time and money). We need the AR to stay in a range of 1.0 – 12. Please feel free to do this on a spreadsheet or use a calculator.

Wingspan (ft)	Mean Chord (ft)	Aspect Ratio (AR)
4	4.8	
10	4.8	
20	4.8	
30	4.8	6.25 or 30/4.8
40	4.8	
50	4.8	
60	4.8	

After you complete your calculations, please eliminate (strike a line through the row) any of the options that do NOT fall within the AR range of 1.0-12

Plane Construction

1. Open Plane Maker
2. Select File - Open
   - If it asks you to save, select "Don't Save"
   - **Plane**: Click on Aircraft, select Extra Aircraft, Aircraft from Previous Versions, Experimental, Vans RVs, RV-10, RV-10.acf, Open Aircraft. See example below.
3. Save the file five times with the following five names:
   - **Plane**: yourfirstname10, yourfirstname20, yourfirstname30, yourfirstname40, and yourfirstname50
4. Select Standard, click on Wings and modify the wing of each plane according to the table below.

Plane	Wingspan	Wing1 semi-length	Wing 2 lat arm	Wing 2 vert arm
firstname50	50	25	24.95	0.25
firstname40	40	20	19.95	-0.05
firstname30	30	15	14.95	-0.35
firstname20	20	10	9.95	-0.65
firstname10	10	5	4.95	-0.95

Please note: firstname10 is yourfirstname10. For example, your name is Terry, then you would save RV10 as terry10. Next we are going to collect some data during these test flights.

Data Collection

1. Click on Settings.
2. Select Data Input & Output.
3. If not already present, select the Data Set Tab.
4. Click on the last two checkboxes at speeds (line 3).
5. Click on the last two checkboxes at loc, vel, dist traveled (line 21).
6. Click on the last two checkboxes at landing gear vert force (line 66).
7. Click X to return to the plane.

Test Piloting

Once you have built your five airplanes, fly each plane three times. Try to fly as consistently as possible. Remember to keep the pointer on the crosshairs until the plane lifts off. This will insure a consistent angle of attack. Be sure to record the Takeoff distance for each flight in the table below. Use your aspect ratio calculations from the previous table in the table below.

Wingspan 50

Trial	Wingspan	Mean Chord	Aspect Ratio	Takeoff Distance
1	50	4.8		
2	50	4.8		
3	50	4.8		

Average Takeoff Distance ________

Wingspan 40

Trial	Wingspan	Mean Chord	Aspect Ratio	Takeoff Distance
1	40	4.8		
2	40	4.8		
3	40	4.8		

Average Takeoff Distance ________

Wingspan 30

Trial	Wingspan	Mean Chord	Aspect Ratio	Takeoff Distance
1	30	4.8		
2	30	4.8		
3	30	4.8		

Average Takeoff Distance ________

Wingspan 20

Trial	Wingspan	Mean Chord	Aspect Ratio	Takeoff Distance
1	20	4.8		
2	20	4.8		
3	20	4.8		

Average Takeoff Distance ________

Wingspan 10

Trial	Wingspan	Mean Chord	Aspect Ratio	Takeoff Distance
1	10	4.8		
2	10	4.8		
3	10	4.8		

Average Takeoff Distance ________

Test Results

Once you have completed the Test Flying table, please complete the bar graph below.

Average Takeoff Trials

Average Takeoff Distance (ft)

Wingspan (ft)

Investigative Questions

As the Aspect Ratio increases, takeoff distance increases or decreases?

Shorter takeoff time indicates more or less lift?

What are the advantages of higher Aspect Ratio?

How could we increase the Aspect Ratio without changing the length of the wingspan?

More Test Flying

If you have not already, watch the landing Aspect Ratio video. You will land your 10 ft wingspan airplane three times. Next, land your 50 ft wingspan three times.

1. Follow these Quick-Flight Setup instructions.
   - Airport: KSEA
   - Time: "day"
   - Weather: "clear"
   - Click FLY with these options!
2. Location - Select Global Airport
   - Airport: KSEA
   - RWY 16
   - Final approach 3nm
   - Be ready to hit P to pause

Which plane is easier to land?

Which plane feels more precise at landing?

Why do sailplanes and gliders NOT have landing gear attached to the wings?

Do World War II fighter planes have a small or large Aspect Ratio? Why?

The engineering design process is almost always a series of tradeoffs. What are the advantages and disadvantages of increasing the Aspect Ratio of an airplane?

Wing Loading

"The Wright Brothers were engineers first, pilots second."

Introduction

We learned that weight impacts takeoff performance. Generally, the greater the airplane weighs, the longer the runway needs to be. What do airplane designers do when they need to carry a larger payload, but still take off on the same runway length?

All these issues are related to wing loading. Wing loading is the ratio of the plane's gross weight (W) divided by the surface area of the wing (S). This is similar to density, except it uses surface area, NOT volume. This ratio is an important concept in designing airplanes. Let's investigate how changing the wing loading of our airplane impacts flight performance.

We will begin by using the most important tools of scientists and engineers: critical thinking and math.

Mathematical Investigations

We will increase the wing area of the plane to see the impact on wing loading. Listed below are different wingspans with the same length chords. Please calculate the wing loading (w/s) for each wingspan. Please pay attention to the trend. Feel free to do this on a spreadsheet or use a calculator.

Wing Loading – Constant Weight VS Decreasing Wing Area

Gross Weight lbs	Wingspan ft	Mean Chord ft	Wing Area ft^2	Wing Loading lbs/ft^2
2500	50	5		
2500	40	5		
2500	30	5	150 or (30 x 5)	*16.67 or (2500 / 150)*
2500	20	5		
2500	10	5		

Complete the graph below.

Wing Loading vs Wing Area

Now, please calculate wing load when the wing area stays constant, and the gross weight decreases.

Wing Loading – Constant Wing Area VS Decreasing Gross Weight

Wing Area (S) ft^2	Gross Weight (W) lbs	Wing Loading W/S
150	2550	
150	2250	
150	2000	13.3
150	1750	
150	1500	

Complete the graph below.

Wing Load vs Gross Weight

Gross Weight

Investigative Questions

As the wing area increases, does wing load increase or decrease?

As the gross weight decreases, does wing load increase or decrease?

Fighter aircraft usually have a low aspect ratio. If we increase the payload of the fighter aircraft, will the wing load increase or decrease?

Our small private plane carries 6 passengers. The plane weighs 2900 lbs. The wingspan is 34 ft and the cord is 4.75ft. What is the wing area of the plane? What is the wing load?

The wing load of our plane is 15 lbs/sqft. The chord is 5 ft. The wingspan is 30 ft. What is the gross weight of the airplane?

I am building a plane that will weigh 8,000 lbs. The wing load is 17lbs/sqft. What's the wing area?

The wing load of our plane is 20 lbs/sqft. The gross weight of the airplane is 2,400 lbs. The chord is 4 ft. What is the wingspan?

Plane Construction

1. Open Plane Maker.
2. Select File - Open.
   - If it asks you to save, select "Don't Save"
   - **Plane**: Click on Aircraft, select Extra Aircraft, Aircraft from Previous Versions, Experimental, Vans RVs, RV-10, RV-10.acf, Open Aircraft. See example below.
3. Save the file three times with the following three names:
   - namewl15, namewl30, namewl60
   - Please note: namewl15 is yourfirstnamewl15. WL stands for wing load. For example, your name is Terry, and then you would save RV10 as terrywl15.
4. Select Standard, click on Wings and modify the wing of each plane according to the table.

Plane	Total Weight	Chord ft	Wingspan ft	Wing Loading lb/sqft	Maximum Weight	Wing1 semi-length	Wing 2 lat arm	Wing 2 vert arm
Namewl15	2,500	10	15		2800	7.5	7.45	-.85
Namewl30	2,500	5	30		2800	15	14.95	-0.35
namewl60	10,000	10	60		11,000	30	29.95	0.55

Test Piloting

Next we are going to collect some data during these test flights.

Data Collection

1. Click on Settings.
2. Select Data Input & Output.
3. Click on the last two checkboxes at speeds (line 3).
4. Click on the last two checkboxes at loc, vel, dist traveled (line 21).
5. Click on the last two checkboxes at landing gear vert force (line 66).
6. Click on X to return to the plane.

Quick-Flight Setup

1. Airport KSEA
2. Select your aircraft: namewl15.
   - Click on Aircraft, select Extra Aircraft, Aircraft from Previous Versions, Experimental, Vans RVs, RV-10
   - Time: "day"
   - Weather: "clear"
   - Click FLY with these options!
3. Take off 3 times. Be as consistent as possible.
4. Repeat for all three airplanes.

Be sure to record the takeoff distance for each flight in the following tables.

Test Piloting Data Collection

Wingspan 30ft.

Trial	Total Weight	Chord ft	Wingspan ft	Aspect Ratio	Wing Area sqft	Wing Load Lbs/sqft	Takeoff Distance
1	2,500	5	30				
2	2,500	5	30				
3	2,500	5	30				

Average Takeoff Distance_________

Wingspan 15ft.

Trial	Total Weight	Chord ft	Wingspan ft	Aspect Ratio	Wing Area sqft	Wing Load Lbs/sqft	Takeoff Distance
1	2,500	10	15				
2	2,500	10	15				
3	2,500	10	15				

Average Takeoff Distance_________

Wingspan 60ft.

Trial	Total Weight	Chord ft	Wingspan ft	Aspect Ratio	Wing Area sqft	Wing Load Lbs/sqft	Takeoff Distance
1	10,000	10	60				
2	10,000	10	60				
3	10,000	10	60				

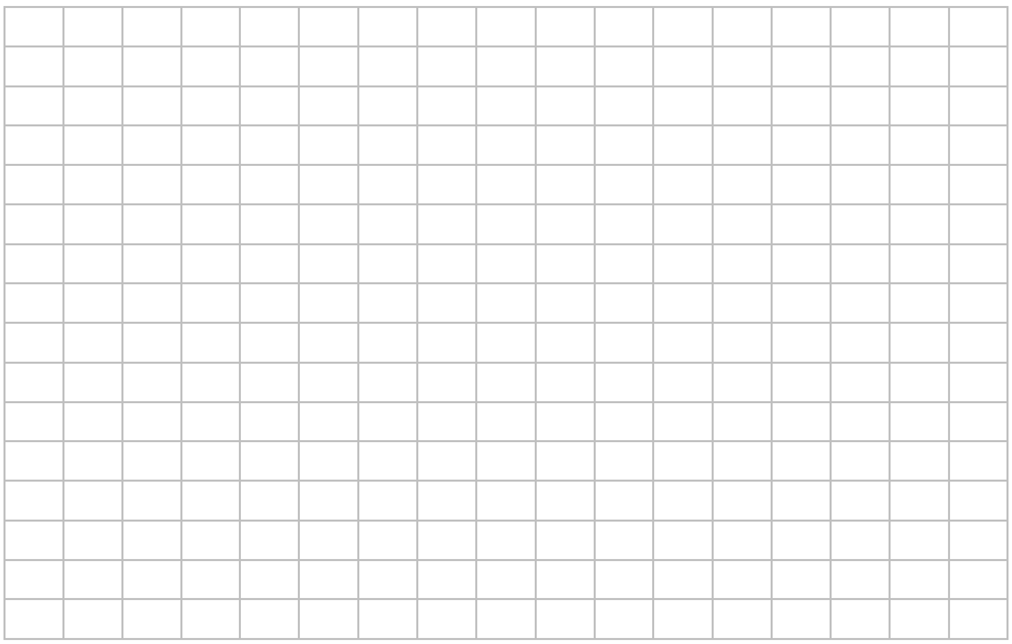
Average Takeoff Distance_________

Test Results

Once you have completed the Test Flying table, please complete the graph below.

Takeoff Distance vs Wingspan with a Constant Wing Load

Average Takeoff Distance (ft)



Wingspan with a Constant Wing Load of 16.67 lbs/sqft

Investigative Questions

Do all three planes have the same aspect ratio, wing load or wingspan?

Which plane reached 100 knots per hr the quickest? (This change in speed is known as acceleration.)

Which plane needed the shortest takeoff distance?

Which plane needed the longest takeoff distance?

Why did the planes behave differently? Consider all four forces.

Remember, the engineering design process is almost always a series of tradeoffs. This table summarizes these tradeoffs.

Wing Load	High	Low
Takeoff and landing distance	Longer	Shorter
Stall speed	Higher	Lower
Flight performance	Higher	Lower
Payload	Greater	Lesser

As you can see from the table above, a higher wing load means greater flight performance and larger payloads. It also means longer runways and higher stall speeds. Engineers have to consider all factors when designing an airplane and determining the wing load. In the next lesson, we will consider power loading, the ratio of weight to power.

Power Loading

"The Wright Brothers were engineers first, pilots second."

Introduction

about horsepower, specific fuel consumption, and range. We will also examine power loading, which is the ratio of weight to power. Just as they do with wing loading, engineers use this ratio to predict airplane performance. Finally, we will examine the performance tradeoffs associated with power loading.

Horsepower is a measure of power. An engine creates horsepower by changing the potential energy of fuel into the kinetic energy of turning pistons. These pistons turn a shaft that turns the propeller, which acts like a wing to pull the plane forward. The power of the engine is called brake horsepower. The prop converts about 80% of this power pulling the airplane forward. This is referred to as Thrust Horsepower. Finally, engines wear out quickly and gas mileage is diminished when they run at full power; therefore, airplanes are usually flown at 75% of Thrust Horsepower. We refer to this power setting as Cruise Horsepower.

Horsepower Summary
Brake Horsepower required equals the power to overcome drag.
Thrust Horsepower required equals the Brake Horsepower divided by 0.80 (propeller efficiency).
Cruise Horsepower required equals the Thrust Horsepower divided by 0.75 (avoiding full power).

You may be thinking right now, "Wow, it takes three calculations just to find out how much power is needed to fly?"

Well, yes, engineering requires math, not math genius, just a solid foundation in math. You can do it. Then you can earn a lot of money doing cool work like designing and flying airplanes.

We will increase the horsepower of the plane to examine its impact on weight to power ratio or power loading. Listed below are engines with different horsepower ratings. Please calculate the power to weight ratio. Please pay attention to the trend. Feel free to do this on a spreadsheet or use a calculator.

Power to Weight Ratio or Power Loading

Horsepower (ft*lbs)	Gross Weight (lbs)	Power Loading
150	2500	
200	2500	
250	2500	0.1 or 250/2500
300	2500	
350	2500	

Complete the graph below.

Power to Weight Ratio - PowerΔ

Power
Loading

ΔHorsepower

Now, please calculate the power to weight ratio when the power stays constant and the gross weight decreases.

Wing Loading – Constant Horsepower VS Decreasing Gross Weight

Horsepower (ft*lbs)	Gross Weight (W) lbs	Power Loading
250	2500	
250	2250	
250	2000	0.125 or 250/2000
250	1750	
250	1500	

Complete the graph below.

Power to Weight Ratio – Weight Δ

Power
Loading

Gross Weight

Investigative Questions

As the gross weight increases, does power loading increase or decrease?

Our 275 hp airplane has a gross takeoff weight of 2500. What is its power to weight ratio?

Our small private plane carries 4 passengers. The plane weighs 2400 lbs. The airplane's required Brake Horsepower is rated at 150 hp. What is the required Thrust Horsepower? How powerful must our engine be to fly at 75% Thrust horsepower or Cruise Horsepower?

I have a power to weight ratio of 0.09hp/lb. The plane weighs 2600 lbs. What is the horsepower of the aircraft?

Plane Construction

1. Open Plane Maker.
2. Select File - Open
   - If it asks you do save, select "Don't save"
   - **Plane**: Click on Aircraft, select Extra Aircraft, Aircraft from Previous Versions, Experimental, Vans RVs, RV-10, RV-10.acf, Open Aircraft. See example below.
3. Save the file three times with the following three names:
   - namewp150, namewp300, namewp600
   - Please note: namewp100 is yourfirstnamewp100. (*wp* stands for weight to power ratio or power loading.) For example, if your name is Terry, then you would save RV10 as terrywp100.
4. Select Standard, click on Wings and modify the wing of each plane according to the table.

Plane	Horsepower	Total Weight	Power to Weight	Maximum Weight	Wing1 semi-length	Wing 2 lat arm	Wing 2 vert arm
namewp150	150	2,500	***.06***	3000	15	14.95	-0.35
namewp300	300	2,750	***.11***	3000	7.5	7.45	-.85
namewp600	600	3,000	***.2***	3,500	30	29.95	0.55

Test Piloting

Next, we are going to collect some data during these test flights.

Data Collection

1. Click on Settings.
2. Select Data Input & Output.
3. Click on the last two checkboxes at speeds (line 3).
4. Click on X to return to the plane.

Flight Setup

1. Follow these Quick-Flight Setup instructions.
   - Airport: KSEA
   - Aircraft: namewp150
   - Time: “day”
   - Weather: “clear”
2. Click on FLY with these options!

Flight Instructions

1. Establish and maintain level flight for 3 minutes. Be as consistent as possible.
2. Repeat for all three airplanes. Be sure to record the true airspeed for each flight.

Test Piloting Data Collection

30 ft. Wingspan

Trial	Total Weight	Wingspan ft	Chord ft	hp	Aspect Ratio	Wing Area	Wing Load	Power/ Weight	True Airspeed
1	2,500	30	5	150					
2	2,500	30	5	150					
3	2,500	30	5	150					

Average True Airspeed ________

45 ft. Wingspan

Trial	Total Weight	Wingspan ft	Chord ft	Hp	Aspect Ratio	Wing Area	Wing Load	Power/ Weight	True Airspeed
1	5000	45	10	300					
2	5000	45	10	300					
3	5000	45	10	300					

Average True Airspeed ________

60 ft. Wingspan

Trial	Total Weight	Wingspan ft	Chord ft	Hp	Aspect Ratio	Wing Area	Wing Load	Power/ Weight	True Airspeed
1	10,000	60	10	600					
2	10,000	60	10	600					
3	10,000	60	10	600					

Average True Airspeed ________

Test Results

Once you have completed the Test Flying table, please complete the bar graph below.

True Airspeed vs Wingspan

Average True Airspeed (knots)

Varying Wingspans with Consistent Power to Weight Ratios

Investigative Questions

Do all three planes have the same aspect ratio, wing loading, or power to weight ratio?

Which plane reached the highest cruise speed?

Was this high cruise speed due more to wingspan (lift) or horsepower (thrust)?

If we double the thrust (horsepower), do we double the airspeed?

Power and Range

As we increase the horsepower of an airplane, we increase performance. We also increase fuel consumption. Modern piston engines consume 0.50 pound of fuel each hour for each horsepower. Please calculate the fuel consumption and range for the engines listed below.

Horsepower	Fuel Consumption Per Hour	Range with 360 lbs of fuel
150		
200		
250		360 lbs/125 lbs/hr = 2.9 hr
300		
350		

Performance Tradeoffs

As you have learned, increasing thrust (horsepower) means improved performance at a cost of greater fuel consumption. Higher airplane performance typically means higher wing loading. Remember, high wing loading means longer runways and higher stall speeds. You will need to consider all these tradeoffs as you design your own airplane in the next lesson.

Airplane Design: Putting It All Together

"The Wright Brothers were engineers first, pilots second."

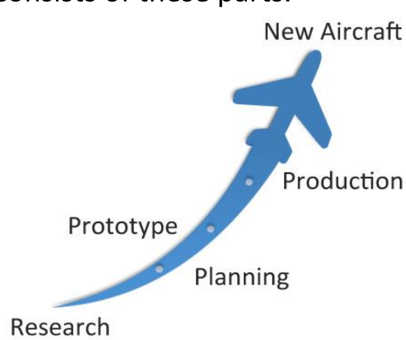
Introduction

You have learned a great deal about science, engineering, and aviation. You have flown a twin-engine airplane and landed on a carrier deck. You lengthened a wing and shortened a tail. Now let's put it all together and design your own airplane.

You know how it's sometimes hard to get started on a school project because you don't know where to begin? Plane design might seem that way right now, but we'll guide you through the steps so you can design and produce your own aircraft.

Engineering Design Process

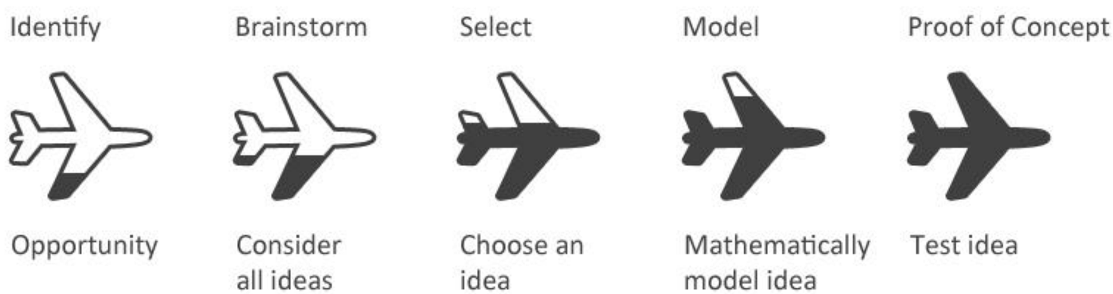
The Engineering Design Process consists of these parts.



Research

Research includes studying the underlying engineering, math, and science principles. You have been doing research with every Fly to Learn lesson you've completed. Research also includes looking at what other people and businesses are designing and building. You can also study what the public wants in an airplane. You might discover that people want an airplane that is faster or more fuel efficient than those for sale presently, or you might discover a new way to build airplanes that is cheaper than conventional methods. Remember, engineers are very concerned with costs, money, and time. If a project takes more time, usually costs increase; also, the engineer may not have time to wait.

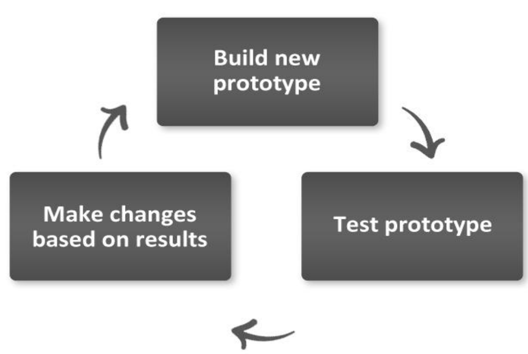
Planning
Planning consists of these steps.



You begin the planning process by identifying an opportunity. In engineering, a need or problem should always be considered an opportunity. That is not a bad philosophy for life in general. You then brainstorm to generate several possible solutions. You select your favorite solution and mathematically model your idea. It's better to do some calculations before constructions because you work smarter and faster with your brain than with your hands. After checking your calculations, build a proof of concept. A proof of concept demonstrates whether an idea is feasible or possible. A proof of concept is usually narrow in focus. For example, if you are designing a better airfoil, you would build a small section of the wing, not the entire wing, and certainly not the airplane.

Prototype
The prototype phase has a few steps that may be repeated many times. Your goal should be for the prototype to get better with each repetition or iteration. Iteration is an important part of the engineering process.

lesson12



Production

You build the airplane during the production phase.

Designing your airplane

You will put the engineering design process to work by designing your own airplane, building your design in Plane Maker, and flying your design in X-Plane. Let's assume during the research and planning phases you developed the following design specifications:

Airplane Performance Design Specifications

- Four-passenger airplane including the pilot
- Each passenger can bring twenty pounds of luggage
- 150 knot cruise speed
- 800 nautical mile range

Now, let's mathematically model your plane design. Since this is your first airplane, we will focus on the weight, wings, power, and range. Once we complete these calculations, you can build a prototype airplane in Plane-Maker.

We need to calculate the weight of your airplane because all the other design calculations are based on the weight of your airplane without the weight of the fuel.

Weight

- The average passenger weight 170lbs
- How much luggage will each passenger carry? ___lbs
- The average weight per passenger plus luggage? ___lbs
- How many passengers will the plane be carrying including the pilot? _____
- Total Payload Weight = number of passengers x average weight ___lbs

Modern airplane designers have learned through past experience that the airplane weight can be determined by dividing the Total Payload Weight by 30% or .3. This is an example of a rule of thumb. A rule of thumb is a rough estimation. Engineers often use rough estimations at the start of the design process.

- Gross Airplane Weight = Total payload weight divided by 30% ___lbs

Please note: Gross Airplane Weight or Takeoff Weight = empty airplane weight + payload weight + fuel weight.

ings

Now we need to calculate the size of the wings of our airplane. First, we will calculate wing loading and then determine wing area, aspect ratio, and finally wingspan.

Wing Loading

- Gross Airplane Weight (previously calculated) ____lbs.
- Standard Wing Loading or $w/s = 2.24 \times (\sqrt[3]{Gross\ Airplane\ Weight} - 6)$ ____
- High Wing Loading Range = $Standard\ Wing\ Loading \times 1.3$ ____
- Low Wing Loading Range = $Standard\ Wing\ Loading \times 0.7$ ____

Reminder: Higher wing loading means higher stall speeds and longer takeoffs and landings. Modern light planes exhibit wing loading less than 20lbs/sqft.

Wing Area

- Gross Airplane Weight (previously calculated) ____
- Wing Load Range (previously calculated) ____
- Wing Area (s) = $\frac{Gross\ Airplane\ Weight}{Wing\ Loading}$ ____

Wing Span

We need to decide on the aspect ratio (AR) first. The aspect ratio of modern light planes is 6 to 8. Let's use 7 as the aspect ratio.

- Aspect Ratio ____
- Wing Area (s) (previously calculated) ____
- Wing span (b) = $\sqrt{s \times (AR)}$ ____
- Chord =$\frac{s}{b}$ ____

Power

The power required equals drag x velocity. The calculations to determine power are beyond the scope of this lesson. Let's assume you need 150 horsepower. This kind of horsepower is called brake horsepower.

A modern propeller is 80% efficient in converting the brake horsepower into actual thrust. This kind of horsepower is called thrust horsepower.

- Brake Horsepower 150thp
- Thrust Horsepower = $\frac{Brake\ Horsepower}{80\%}$ ____bhp

We actually need more horsepower because we do not want to operate engines at full power. Engines running at full power wear out sooner, and they are less fuel-efficient; instead, we want to operate the engines at 75% of Thrust Horsepower. This horsepower is called Rated Horsepower.

- Thrust Horsepower (previously calculated) ____bhp
- Rated Horsepower = $\frac{Thrust\ Horsepower}{75\%}$ ____rhp

Range

Let's see how far we can fly our airplane on a tank of fuel. We begin by calculating how much fuel the plane will carry. We calculate the total fuel available by multiplying Gross Airplane Weight x 15%. Fifteen percent is another rule of thumb used by engineers to design airplanes.

- Gross Airplane Weight (W_G) (earlier calculation) ____lbs
- Total Fuel Available (W_F) = Gross Airplane Weight x 15% ____lbs
- Payload Weight (W_P) (previously calculated) ____lbs
- Empty Weight = W_G – (W_F +W_P) ____lbs
- Cruise Speed 150 knots
- Specific Fuel Consumption 0.5 lbs per per horsepower
- Range = = $\frac{Total\ Fuel\ Available\ x\ Cruise\ Speed}{Specific\ Fuel\ Consumption\ x\ Thrust\ Horsepower}$ ____ n. miles

Often we don't meet all of our design goals with the first design. If we don't achieve the necessary range, we can increase the amount of fuel, but then we will need more horsepower, which results in greater fuel consumption. Therefore, we will repeat this process several times to meet our design goals.

Prototype

We are now ready to build a prototype in Plane Maker. Since you are using Plane Maker, you can quickly build your prototype, a virtual airplane, by modifying the RV-10. This will allow you to quickly try out your designs safely and economically.

Complete the table below. Begin by entering your values in the second column. You will need to calculate ½ Wing Span value by dividing the Wing Span value by 2. Then open Plane Maker and the RV-10 airplane, and select Standard and the appropriate menus. Assign your values to the appropriate fields.

Plane Maker

Specification	Your Values	Standard Menu	Fields
Gross Weight		Weight & Balance	Maximum Weight
Fuel Weight		Weight & Balance	Fuel Load
Empty Weight		Weight & Balance	Empty Weight
Wing Span		Wings	Not Applicable
½ Wing Span (Calculate)		Wings	Semi-Length
Chord		Wings	Root and tip chords
Rated Horsepower		Engine Specs	Max allowable Power

Once you have completed your airplane, save it as *yournameprototype* and go fly it. Be sure to include the appropriate Payload Weight in the Weight and Balance section of X-Plane. If the plane performs well, you are ready for production.

If you want another challenge consider design a sport plane with the following requirements:

- 2 Passengers including the pilot
- 250 Thrust Horsepower
- Aspect Ratio between 6-8

Gliding

"The Wright Brothers were engineers first, pilots second."

The earliest form of unpowered fixed-wing aircraft were known as gliders. Inspired by the flight of birds, the earliest aerospace engineers used gliders to gain an understanding of aerodynamics.

Glider design relies on many of the same principles as aircraft design but must be slightly altered to account for the lack of propulsion. Minimization of weight, drag, and maximization of lift are always required. Smooth, curved edges are required to improve aerodynamics since both parasite drag and induced drag decrease the efficiency of the glider. Neither can produce the thrust needed to overcome this drag. They even utilize the same control surfaces as aircraft. So what makes them so different?

Other than the obvious lack of propulsion, gliders are different from planes in the following ways:

1. Increased aspect ratio. The wingspan of gliders is much longer in order to increase the lift they generate, as well as decrease the effects of lift-induced drag. In response, gliders have a higher maximum Lift-to-Drag ratio. However, there are structural limits to the length of the wingspan; they are too long, and the glider's wings may buckle.
2. General purpose. While aircraft have a variety of uses, they are mostly used for travel. Since gliders fly without power, they are not suited for rapid travel. They are often used to acquaint new pilots with aircraft controls, for sightseeing, or for novelty.
3. Ballasts. Because gliders are so light, the center of gravity may easily be changed with undesirable consequences. Some gliders use a weight, called a ballast, which can be added to shift the plane's center of gravity and allow them to fly.
4. Methods of increasing altitude. Gliders must be towed by a powered aircraft or launched off a high surface to achieve flight. Additionally, they are only able to greatly increase their altitude by using atmospheric phenomena called thermal convection currents. These are currents of hot air that rise straight up into the atmosphere. Interestingly, some birds also use these currents to minimize the energy needed to stay

aloft.

All airplanes can function as gliders if their engines are turned off. However, powered airplanes are not nearly as efficient as gliders in their ability to stay aloft. Gliding performance is measured by a quantity known as *glide ratio*. A glide ratio of 30:1 means it can travel 30 meters horizontally while only falling 1 meter. Most gliders today have ratios of 50:1, as compared to the 15:1 ratio of most jet aircrafts flying today. Powered aircraft also descend more quickly than gliders due to their higher weight and, consequently, higher wing loading.

Knowing that Drag = W * sinΘ and Lift = W * cosΘ, we can find the relationship between glide angle and L/D ratio as:

$$\tan\theta = \frac{1}{(L/D)}$$

Now, we are going to find the glide angle and glide ratio for the Cessna 172 using X Plane.

Data Input & Output

1. Select the last two boxes beside lat, lon, altitude (line 20)
2. Select the last two boxes beside loc, vel, dist traveled (line 21)
3. Select the last two boxes beside lift over drag & coeffs (line 68)

Quick-Flight Setup

- Airplane: Cessna 172
- Airport: KSEA
- Time: “day,” Weather: “clear”
- Select “FLY with these options!

1. Under “Location,” select “Select Global Airport,” click 3nm next to RWY 16
2. Immediately select P on your keyboard to pause the simulation. Pull off on your throttle entirely. Press P to unpause.
3. Make sure your airplane is in level flight, and press P again. Note the L/D ratio of your aircraft, and the distance traveled so far. This distance is your “starting distance.” You can now calculate the glide angle. Also note the altitude (labeled alt ftagl, or feet above ground level). You will need this in order to find the glide ratio.
4. Steadily descend. Don’t worry, as you will likely miss the runway. When you first touch the ground, select P to pause your simulation. Note the “final distance” traveled. Using the final distance traveled and your starting altitude, you can now find the glide ratio.

5. Repeat this two more times, to adjust for the variability in your descent.

Complete the table below.

L/D ratio	Glide Angle (º)	Distance Traveled (ft) = Final Distance – Starting Distance	Glide Ratio

Gliding Design
Using all of the information you have learned about gliders and the wing configuration of aircraft, you are now going to build a glider in Plane Maker based on a modified Cessna 172. Your glider will be able to travel 5 miles (26,400 ft), but does not need to land on a runway. You may change the aircraft in any way you would like, which includes altering the wings, fuselage, or the engine. You are allowed to adjust certain settings in X Plane as well, within reason. Weight, Center of Gravity, and Weather are all good opportunities for your plane to excel, but be warned about the potential consequences!

Your aircraft is to start in flight 3 NM away from KSEA. Immediately pull off the throttle and rely solely on the behavior of your glider. Remember to take note of your L/D ratio when you begin your flight. You will need to conduct test flights to generate the numbers helpful in calculating your glide angle and glide ratio. If your aircraft does not meet the requirements, you are to return to Plane Maker and refine your design.

To assure the structural integrity of the aircraft, your wings are to be no longer than 20 ft each and have a mean chord length that does not exceed 6 ft. To make sure you have created an effective glider, your glide angle is not to exceed 5 degrees, and your glide ratio must be at or above 30. Your glider must have both a cockpit and landing gear.
The table below may be of use.

Trial	L/D Ratio	Glide Angle	Distance Traveled	Glide Ratio	Success?
1					
2					
3					
4					
5					

What aspects of your glider made the biggest difference in your glider's glide ratio?

Jets vs. Propeller Aircraft

"The Wright Brothers were engineers first, pilots second."

Aircraft come in all different sizes, but every plane relies on one of two primary methods of propulsion: via jet engines, or piston-propeller engines. Piston-propeller aircraft are distinguished by having at least one propeller, and jet planes generally have two or more jet engines. The performance of these aircraft is dramatically different, as you will soon find out. Further on in this section, you will find out why these planes have different characteristics.

Piston-prop aircraft are used for lower-velocity flights, and are not suited well for quick travel. Usually, general aviation aircraft, which are used for leisure and not for profit, utilize propellers. Propeller-driven aircraft are more affordable to average pilots, but do not perform as well as jets. These aircraft take longer to achieve higher altitudes and reach a much lower maximum altitude than jets. They can, however, fly for longer amounts of time than a comparatively sized jet.

Jet aircraft are used for quickly travelling long distances. Their engines produce thrust, which directly pushes them forward: piston-prop aircraft produce power to rotate their propeller, which then pushes the plane forward. These aircraft are used commercially since they are more expensive to maintain. They can, however, ascend quickly and to higher altitudes, where their engines work most effectively. Therefore, more fuel is used by these aircraft.

Range and Endurance of Jet and Piston-Prop Engines
Engineers often measure the performance of aircraft by determining their range and endurance. Range is the maximum distance the aircraft can travel on a full tank of fuel; endurance is the maximum time that an aircraft can fly on a full tank of fuel. However, these values do not necessarily occur at the same time!

Both jets and propeller-driven aircraft require specific conditions to maximize their range and endurance.

1. An entirely full fueled tank. The plane cannot fly as far if its tank is half full!
2. Minimization of fuel use. This means the aircraft must be flying in the way for which it was designed, be it the appropriate velocity, altitude, etc
3. Flight at a maximum lift to drag ratio. This ratio is found by dividing the lift by the drag. Higher numbers mean less drag, which is always desirable while in flight.
4. Flight at “ideal conditions,” which vary for the two types of aircraft.

Propellers require a higher air density to run efficiently, which occurs at lower altitudes: their engines are similar to those found in a car. Jet aircraft fly more efficiently at higher altitudes, since their engines were optimized to compress air at lower densities. As a result, propeller-driven aircraft fly at lower altitudes and lower speed. Jet aircraft fly best at higher altitudes with higher velocities.

Using XPlane, we can easily see the differences in endurance of these two aircraft on a full fuel tank. Range, however, requires taking off on a full fuel tank and flying in level flight until the fuel runs out. Try this on your own!

Quick Flight Setup

- ✈ Select File -> Quick Flight Setup
- ✈ Airport KSEA, Aircraft Cessna 172SP
- ✈ Time: “day,” Weather: “clear”
- ✈ Select “FLY with these options!”

1. At the top of your screen, scroll to Aircraft -> Weight and Fuel
2. At the bottom right hand corner, select “set to max gross”
3. Beside the fuel total slider, you will see a white text box with a number. This is the number of hours this jet can fly on maximum fuel.
4. Record the weight of the fuel (just above the fuel TOTAL slider) and the time this aircraft can fly.
5. Repeat the same process, except select the aircraft “Cirrus TheJet”

As you can see, despite having less fuel, the propeller-driven aircraft can fly for longer on one tank than the jet. These numbers have no bearing on the efficiencies of these engines, however!

To determine the efficiency of the engine, engineers use a quantity called "specific fuel consumption," or SFC, for propeller-driven aircraft. Thrust-specific fuel consumption, or TSFC, is the jet equivalent. This relates the fuel consumed to the power (or, in the case of jets, thrust) produced by the aircraft's engine. These equations are simplified versions for determining these numbers.

$$Propeller\ SFC = \frac{lb\ of\ fuel}{(horsepower) * (time)}$$

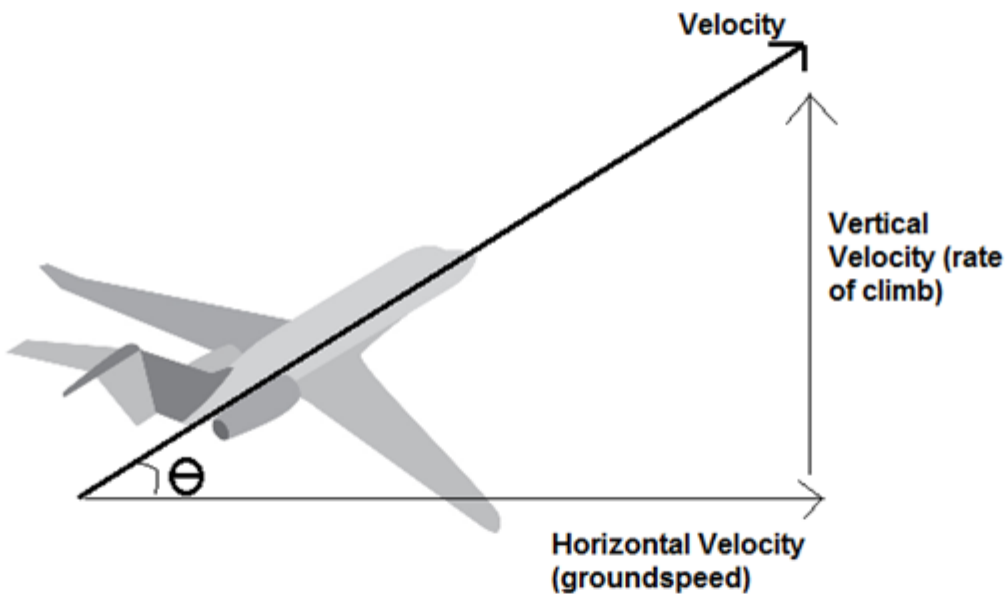
$$Jet\ TSFC = \frac{lb\ of\ fuel}{(thrust) * (time)}$$

Using the equations for SFC and TSFC above, calculate the SFC of the Cessna 172, and TSFC of Cirrus TheJet. The Cessna 172 has a power of 160 hp, and the Cirrus has a thrust of 1800 lb.

Would increasing the size of the fuel tank in a propeller aircraft make it more efficient?

What effects do you think increasing SFC or TSFC would have on the range of each aircraft?

Rate of Climb and Time to Climb
Airplanes in a climb have two different components of velocity: one in the horizontal direction, and one in the vertical direction. The vertical component is called *rate of climb*, and, much like the horizontal component, varies drastically depending on an aircraft's engine type.



Using the image above and basic trigonometry, we notice that the equation for rate of climb can be given as:

$$\frac{R}{C} = Velocity * \sin(\theta)$$

Time to climb is a quantity related to the rate of climb.

$$t_{climb} = \frac{change\ in\ altitude}{R/C}$$

You will be using your rate of climb to predict how quickly each aircraft will take to reach an altitude of 6,900 ft, which is 5,000 ft above the KSEA airport (elevation: 1,900 ft). It is very important to use consistent units, so you will have to convert miles to feet, and hours to minutes.

Data Setup

1. Click on Settings -> Data Input & Output
2. Click the last two check boxes under speeds (line 3)
3. Click the last two check boxes under AoA, side-slip, paths (line 18)
4. Click the last two check boxes under loc, vel, dist traveled (line 21)

Quick Flight Setup

- Select File -> Quick Flight Setup
- Airport: KSEA, Aircraft: Cessna 172SP
- Time: “day,” Weather: “clear”

1. Take off, and enter a steady climb. Record the Vind airspeed in mph, and the vpath angle in degrees. Make sure to convert the Vind airspeed into ft/s!
2. Determine this aircraft’s rate of climb using the equation above.
3. From here, use the second equation to determine the time to climb.

Quick Flight Setup

- Select File -> Quick Flight Setup
- Airport: KSEA, Aircraft: Cirrus TheJet
- Time: “day,” Weather: “clear”

1. Take off, and enter a steady climb. Record the Vind airspeed in mph, and the vpath angle in degrees. Make sure to convert the Vind airspeed into ft/s!
2. Determine this aircraft’s rate of climb using the equation above.
3. From here, use the second equation to determine the time to climb.

Note: To take off in Cirrus TheJet, you will need to move the yellow slider in the bottom right-hand corner of the cockpit controls. Select B on your keyboard to turn off the brakes. See the picture if you cannot find this.

Which one of these aircraft was able to ascend more quickly, and why?

Runway Design

"The Wright Brothers were engineers first, pilots second."

Engineers must keep many details in their plan when designing airports.

1. The typical aircraft that will be using the runway. Larger, heavier aircraft need a long runway to generate enough lift to take off and need more time to slow down to taxiing speed when landing.
2. Altitude of the airport. The density of the air is higher at sea level than at higher elevations, and planes are able to lift off in a shorter distance at low elevations.
3. The climate of the airport makes a difference. If an airport is in a location that experiences chronic rain or snow, the runway must be longer to account for the slickness of the runway. Also, if an airport is in a warm location, the air's density is lower than in a cooler location, and the runway must be longer.
4. Material of the runway. Grass has a higher coefficient of friction than asphalt, and planes need a longer runway to generate enough speed to lift off.

We have discussed the distance of takeoff in regards to payload weight, aspect ratio, and wing loading in depth. We can now demonstrate the effects of altitude, runway material, and weather on takeoff distance.

Quick Flight Setup

- ✈ Select File -> Quick Flight Setup
- ✈ Airport: Benbecula (elevation: 19 ft, length 6023 ft, material: asphalt)
- ✈ Aircraft: Cessna 172
- ✈ Time: "day," Weather: "clear"
- ✈ Select "FLY with these options!"

Take off, and note the V_{true} airspeed and liftoff distance.

Without changing the payload or any other settings, enter Quick-Flight setup and change the airport to Guaymaral (elevation: 8389 ft, length 5643 ft, material: asphalt).

Then lift off, and note V_{true-} and liftoff distance. What do you notice?

Now, return to Benbecula airport, but this time:

1. Select Aircraft -> Aircraft & Situations
2. Select "grass field take off"
3. Take off, and note the distance required.

How does it compare to the initial asphalt take-off?

Engineering your airport

Now it is your turn to step into the airport engineer's role. You have been tasked to design a runway that will accommodate the takeoff and landing of a Boeing 747: the world's first jumbo jet. You get to choose the airport's altitude and the runway's material. The required length of the runway is the maximum of two values: the liftoff distance and the landing distance.

You will need to be aware of several parameters about the plane to find these distances. These are:

- $C_{L,max}$: 2.0
- Takeoff weight: W_T = 3,200,000 N
- Landing weight: W_L = 1,600,000 N
- Slowest landing speed: V_{land} = 70 m/s
- Wing planform area: S = 500 m^2
- Profile drag: $C_{D,0}$ = 0.02
- Thrust available at takeoff: T = 800,000 N

To find the liftoff distance, you can use the following equation:

$$Liftoff\ distance = \frac{1.44 * {W_T}^2}{9.81 * \rho_\infty * S * C_{L,max} * T * (1 - \mu_r)}$$

The quantity μ_r is the rolling coefficient of friction for liftoff. For dry asphalt, $\mu_r = 0.02$; for soft material like grass, $\mu_r = 0.1$; for tightly packed turf, $\mu_r = 0.06$.

The air's density, given by quantity ρ_∞, depends on the altitude of the airport. Some values are given in a table on the next page, but you are able to choose any value within that density range for your airport's location.

Finding the landing distance is a little more complex, and you will need to follow several equations:

$$Landing\ distance = \frac{1.69 * {W_L}^2}{9.81 * \rho_\infty * S * C_{L,max} * [D + (\mu_l * W_L)]}$$

$$D = \frac{1}{2} * \rho_\infty * {V_{land}}^2 * S * C_{D,0}$$

As with the liftoff equation, the quantity μ_l is the rolling coefficient of friction for landing. For dry asphalt and tightly packed turf, $\mu_l = 0.4$; for grass, $\mu_l = 0.2$.

You will also need to take into account a "factor of safety" for your runway. A safety factor is necessary, due to the variety of issues that may be experienced during takeoff and landing, which includes poor weather and pilot error. Make your final length 20% longer than the maximum distance that the aircraft actually needs for takeoff and landing.

Since the 747 can be simulated in XPlane, try taking off and landing at an airport with similar specifications (altitude and terrain) as yours. Compare these results with your calculations – other than variations in your takeoffs and landings, what could be some reasons your results are different?

Air Density at Various Altitudes

Altitude (m)	ρ_∞ (kg/m^3)
0	1.225
4000	0.819
8000	0.526

Supersonic Flight

"The Wright Brothers were engineers first, pilots second."

While watching certain action movies, you may have heard the characters refer to aircraft using their Mach numbers. This is not just made up in movies: Mach numbers relate the aircraft's velocity relative to the speed of sound in air: 767 mph. The relationship is given below. For example, Mach 5 is when an aircraft has a velocity five times the speed of sound, which is almost 4,000 miles per hour!

$$Mach\ Number = \frac{Velocity}{Speed\ of\ Sound\ in\ Air}$$

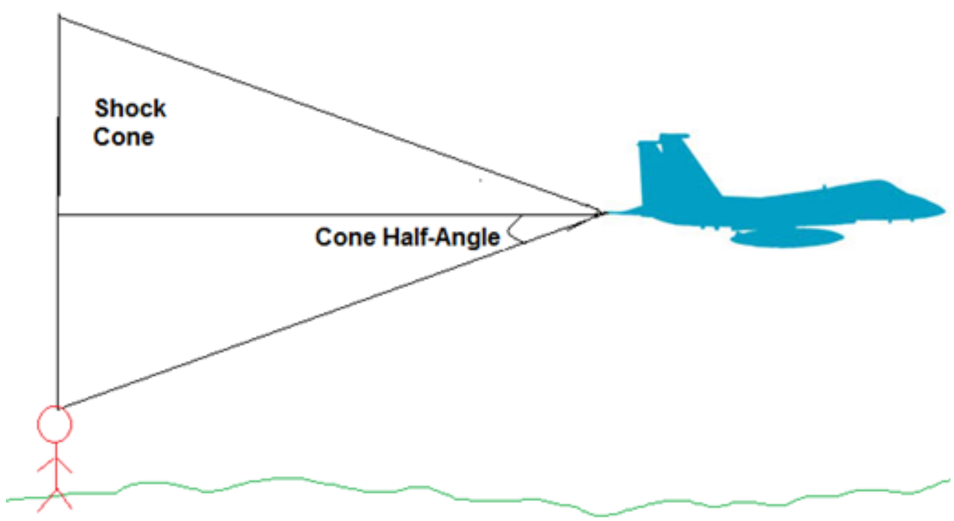
Mach numbers can also be defined in substances other than air. The speed of sound in water, for example, is needed for finding the Mach number of hydrodynamic vessels, such as undersea missiles.

Some different categories of aircraft are defined by their Mach numbers. Subsonic aircraft travel much more slowly than the speed of sound, or less than Mach 1. If you were to yell at somebody a mile away, your voice would reach them before the aircraft would. Most planes you will ever ride in fly at subsonic speeds.

Supersonic aircraft fly more quickly than the speed of sound; Mach numbers are greater than 1. These aircraft are not usually used for commercial flight, but they have been used in the past! The Concorde, shown below, was capable of traveling at Mach 2. It could travel from New York to London in less than 4 hours, where subsonic jets would need about 7 hours to make the flight.

Sonic flight occurs when aircraft fly exactly at the speed of sound. Usually, engineers do not design aircraft to fly at this speed since an aircraft can behave very strangely at these speeds.

Shock Waves
When supersonic aircraft accelerate to speeds faster than the speed of sound, something interesting happens. Shock waves are caused by a buildup of air pressure in front of the aircraft traveling just below Mach 1. The pressure buildup occurs in several waves, and these waves become compressed. At speeds of Mach 1 and above, they are compressed into a single wave. This wave travels along the length of the airplane until it reaches the plane's tail. When that happens, the shock wave travels outward in cone-like shape. When that cone-like shape reaches somebody standing on the ground, they hear what is called a sonic boom.



The angle of the cone is determined by the aircraft's Mach number.

$$Cone\ Half Angle = \arcsin\left(\frac{1}{Mach\ Number}\right)$$

The distance between the observer on the ground and the airplane's tail is given by the hypotenuse of the right triangle made between the cone's half angle and the airplane's altitude. Dividing this distance by the aircraft's velocity will give you the time it would take this sound to reach the observer.

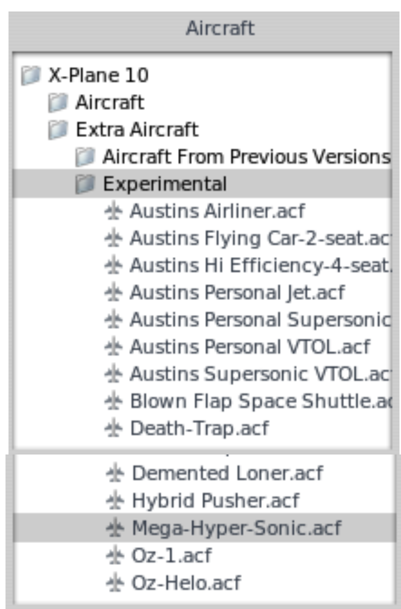
Now, let's find these numbers using X Plane. You are going to calculate the distance a supersonic aircraft has flown before its sonic boom can be heard from the ground.

Data Input & Output

1. Select the last two checkboxes at speeds (line 3)
2. Select the last two checkboxes at lat, lon, altitude (line 20)

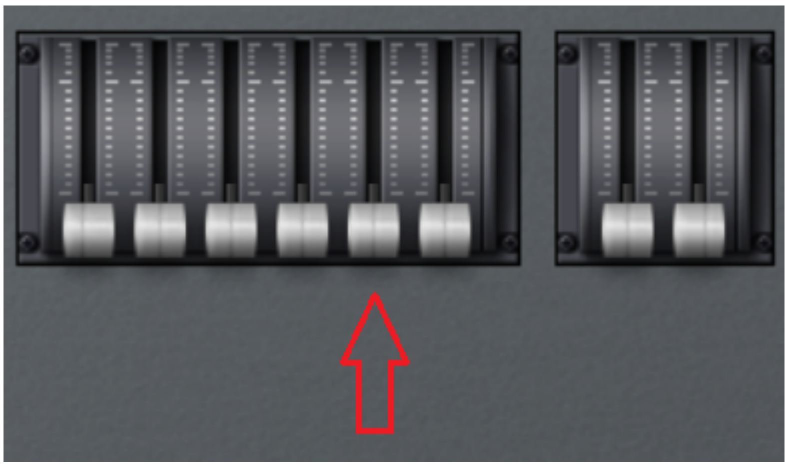
Quick-Flight Setup

You will select an experimental aircraft called Mega-Hyper-Sonic. To find this aircraft, please navigate the aircraft menu as shown below.



1. Airport: KLAX (Los Angeles International), Aircraft: Mega-Hyper-Sonic
2. Time: “day,” Weather: “clear”
3. Select “FLY with these options!”

4. Now, take off. In the bottom right-hand corner, you will see a series of levers. Select the fourth lever from the right and drag it upwards. All eight levers should now be flipped up, and the aircraft is fully throttled.



5. Select B to turn off your brakes, and take off steadily.
6. Ascend to 5,000 ftagl. Using your velocity and the speed of sound in air (767 mph), find your aircraft’s Mach number and cone half angle.
7. Using your altitude and cone half angle, you can now find the distance at which the shock wave is felt on the ground. Hint: draw a right triangle and use trigonometry!

Using this distance and the aircraft’s velocity, how long will it take for this sound to reach the ground?

GAMA Aviation Design Challenge

Introduction

Welcome to the sixth annual General Aviation Manufacturers Association (GAMA) Aviation Design Challenge. This competition is designed to promote Science, Technology, Engineering and Math (STEM) skills through aviation in high schools across the United States. The winning team will get a once-in-a-lifetime opportunity to experience general aviation manufacturing firsthand. This accelerated and hands-on program not only develops students STEM abilities, it also helps build leadership and critical thinking as students work in groups to solve complex challenges. The following chapters help students as they start to apply and modify what they have learned in the first 10 lessons.

GAMA Aviation Design Challenge Workflow

Congratulations for participating in the GAMA (General Aviation Manufacturers Association) Aviation Design Challenge! This document will help you to prepare for the competition.

Step 1 - Defining Roles

Designing an airplane is a team effort, therefore, assigning roles and responsibilities is the first order of business. These roles will help establish the responsibilities of each team member and encourage everyone to take ownership for the project.

Listed below are some of the suggested roles. You may need to combine or change roles based on the needs of your team.

Chief Pilot - This person will be responsible for conducting the test flights and reporting his /her findings to the other team members.

Chief Engineer - This person will be responsible for building and later modifying the aircraft model.

Design Engineer - This person will be responsible for creating and iterating the design.

Program Manager - This person will be responsible for keeping the team members working in the right direction and is ultimately “responsible” for the success or failure of the team.

Finally, as a coach/teacher or advisor, you must direct each team member to decide what success means to them. You should ask each team member to define success. Other issues to deal with will be: how will the team measure success for team and team members.

Step 2 - Research

Research the mission
Review the challenge rules
How is the mission scored?
What are the competition constraints? What can you NOT do?
What can each of the team members listed above do to improve their part of the project and how much of an impact can this have on the final team performance?

flytolearn

Research the aircraft - Use the internet and aviation sites to research payload and performance capabilities of the aircraft used in the competition. Be sure to include airfoil data and prop details
How would the stock (or unmodified) competition aircraft perform given the design objectives?
What typical overall score would you obtain using a stock or unmodified aircraft?
What can be refined in about the design or operation of the aircraft to improve the score?

Step 3 - Design

Conceptual Design
Why is the shape of a jet airliner different than that of a fighter aircraft? Why does a sailplane (glider) have long narrow wings and an acrobatic aircraft has short wings?

Each of these aircraft have been designed for different functions. Jet airliners carry passengers on long distances; fighters must be fast; sailplanes can soar along the winds, and acrobatic planes need to be maneuverable.

The shape or forms of these aircraft are dictated by their functions or how they will be used. This concept is known as “form follows function or function dictates form.”
The idea of Form follows function is an important consideration that is considered during the conceptual design portion of the development stage.

What is the required range, desired payload, and flight path terrain of the competition?
What do you want the aircraft to be capable of doing and not doing?
How long should the flight take?
How much fuel is an acceptable amount to burn?
What would you do to make improvements on the competition aircraft? Some suggestions could be:

- Change the geometry (wing shape) of the wing?
- Modify the tail size, shape or location?
- Modify or change the power plant?
- Modify the propeller or other thrust systems?

Preliminary Design

This is the prototyping phase of the aircraft. We prepare as many design configurations as possible. This phase consists of three parts:

Create or modify prototype

Test prototypes

Analyze the test results

Repeat the process several times incorporating what you learned in the last iteration. This is the most difficult part of the design process. It is vital to have a design notebook (physical or digital) to ensure an orderly process. This will allow us to compare all of the results.

Be sure to fly the airplane consistently. This will help you to appreciate what test pilots have to do in the sky.

Prototype Modifications

Payload
Start with the payload.
This is an easy variable to change, observe and record the results. This will help the team develop the process or workflow for documenting their results.

Wing
Alter wing geometry including wingspan(length of the wing), chord (width of the wing), aspect ratio (wingspan/chord)
Change wing dihedral (wing angle)
Modify wing tips

Tail
Change the horizontal and vertical stabilizers
Change the tail location

Powerplant
If rules permit, change the different kinds of power plants (piston, turboprop, jet)

Modify the propeller

This is not meant to be a complete list of the areas where changes can be made. It is best to assume that you can change anything on the airplane unless specified otherwise in the rules.

Detailed Design

You are now polishing your design. It should not be necessary for you to go back and make any significant changes (i.e. change the wing geometry). At this point, you are also confirming the experimental data you gathered in the preliminary design phase.

If you have not already combined all of your design components, this should now be completed to create your nearly-finished airplane.

Preliminary Flight Testing

- Begin at 20% payload weight (weight of empty plane multiplied by 20%) and fly it while recording data.
- Conduct three flights.
- Add weight and repeat flights while increasing the weight until you can no longer takeoff.

Step 4 - Test Flight

Your team should now be focused on the optimal flight plan for the challenge. Any considerations?

How fast should you fly?
How high should you fly?
How should you land (gliding, full power or normal)

Step 5 - Aircraft Design Challenge Submission

Submit your design to GAMA along with all of the other required paperwork. Try to submit your work at least 24 hours before the official deadline. Unfortunately, internet access occasionally breaks down. You never want that to happen to you or any of your team members.

Setting Up A Challenge Flight

You can prepare for the challenge by setting up your very own flights with criteria that you establish. You will find these challenges fun and exciting. Let's get started.

Under File choose Quick-Flight Setup:

- **Plane**: Click on Open Aircraft, select General Aviation, and double-click Cessna 172SP, Cessna_172SP.acf
- **Weather**: Set Time to "day" and Weather to "clear."
- **Airport**: Exit Quick-Flight Setup.

Click on Location on the menu bar and Select Global Airport. Select KSEA, RWY 34R

- Select **Local Map**
- Click on **TAKEOFF RWY 34R**
- Click on Exit

Select Special on the menu bar

- Select **Fly To Learn – Aviation Challenge**
- Enter **KSEA** to Departure airport ID
- Enter **KBFI** to Arrival airport ID

This time will leave the criteria alone, but you can change the distance, payload, fuel, and time of your challenge. For now, please click on X to exit.

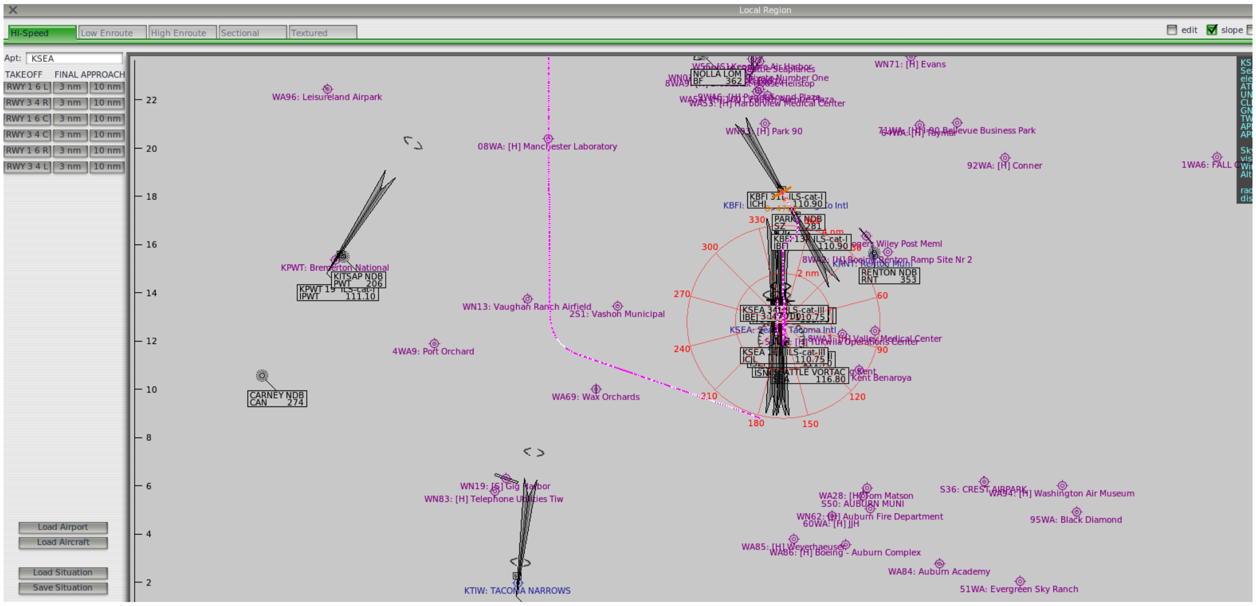
You will return to your cockpit, but now Fly-To-Learn mission [ENGAGED] appears at the top right hand corner of your display.

Click on Location on the menu bar again

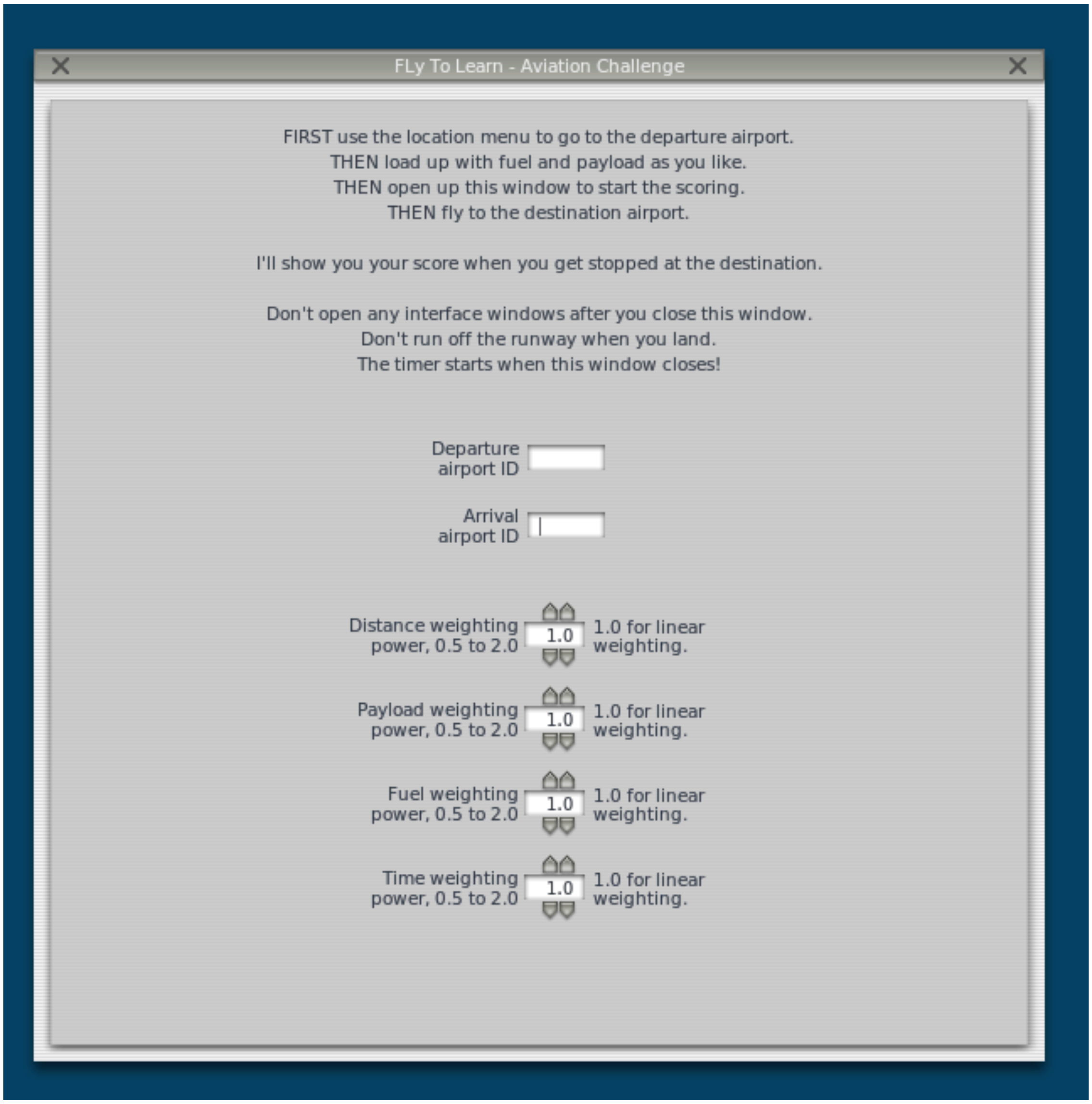
- Select **Local Map (**you can also press the **M key)**
- You will see an orange plane. The orange plane is you. Find the Boeing Field airport, which is just north of your position. You are flying to this field. Check on your location often by pressing the **M key** to see your position.
- Click on Exit

Fly The Challenge!

Local Map – Seattle Tacoma International - KSEA



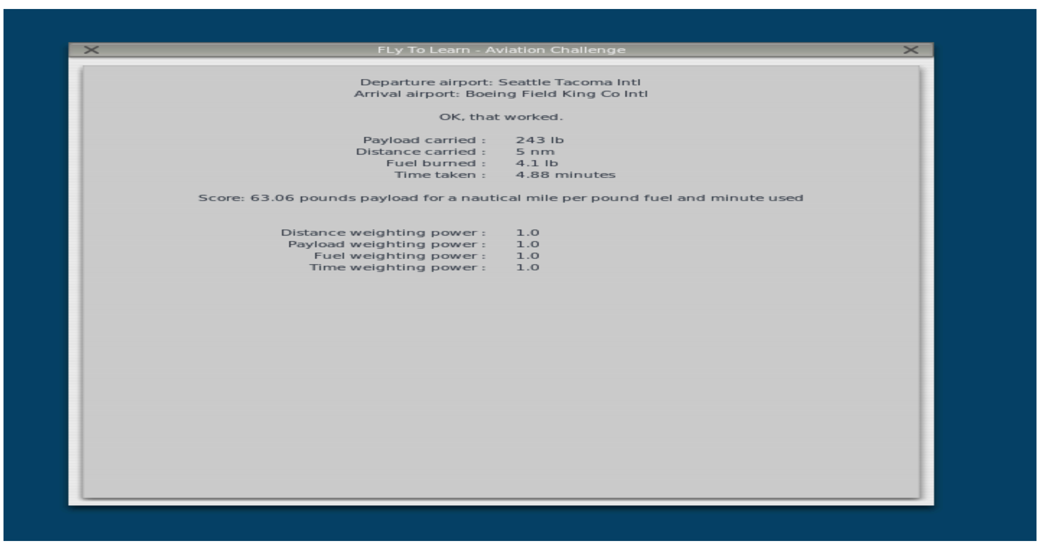
FTL– Aviation Challenge Setup Screen



FTL– Aviation Challenge Setup Screen Completed

FTL– Aviation Challenge Mission

FTL– Aviation Challenge Mission Results



How To Export Flight Data Into Spreadsheet

"The Wright Brothers were engineers first, pilots second."

While we use the graphing function included with the X-Plane for much of our work sometimes, we need to see all of the data more clearly. The best way to do that is to export the flight data into a spreadsheet.

Data Collection

1. Click on Settings.
2. Select Data Input & Output.
3. If not already present, select the Data Set Tab.
4. Click on the last **three** checkboxes at loc, vel, dist traveled (line 21).
5. Click on the last **three** checkboxes at landing gear vert force (line 66).
6. Click X to return to the plane.

You should pilot your plane down the runway and then execute the takeoff. Once you are off the ground, exit the program.

Microsoft Excel ® Users

Locate the Fly To Learn X-Plane folder on your computer
Open the X-Plane folder
Locate the data.txt file

Open the data.txt file with Excel ®
Start up Excel
Under File click on Open
Be sure to enable all readable files
Select data.txt
Text Import Wizard will appear
Click on Delimited as the file type that best describes your data and then click Next
Under delimiters select Other and type **|** in the provided space (you find this symbol above the backward slash symbol below the backspace key on your keyboard). Then click Next.
Click Finish

Google Sheets ® Users

Locate the "Fly To Learn X-Plane" folder on your computer
Open the X-Plane folder
Locate the data.txt file

Importing the data.txt file into Google Sheets ®

Upload the data.txt file into Google Drive
Create a Sheets file in Google Drive
Open the Sheets file
Click on the Import File
Under Import Action select--Create a new spreadsheet
Under Separator Character select Custom
Type **|** in the provided space (you find this symbol on your keyboard, above the backward slash symbol below the backspace key)
Click Yes under Convert text to numbers and dates
Click on Import
At the top of the page, click on Open Now
You are good to go!

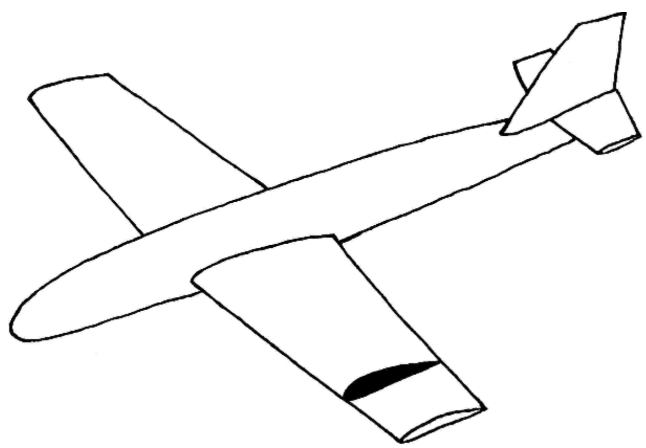
Airfoil Selection

"The Wright Brothers were engineers first, pilots second."

Introduction

As defined by Webster, an airfoil is a body (such as an airplane wing or propeller blade) designed to provide a desired reaction force when in motion relative to the surrounding air.

The airfoil of a wing or propeller is the shape of the wing you see if you cut a slice through the wing. The cut-out shape you see from the side is the airfoil section at that point in the wing.



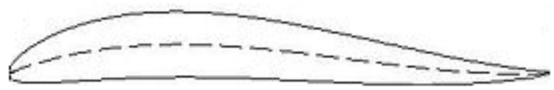
Most aircraft have different airfoils at the root of the wing (closest to the fuselage) than they do at the tip of the wing. Often the wing not only changes in shape along its length, but also in the angle the wing has relative to the aircraft. These design decisions are made to improve the characteristics of the wing over the entire range of flight speeds and conditions. They impact the strength of the wing, the amount of force on the wing along its span, and where the wing will stall first.

The selection of an airfoil is, in some ways, not important at all, but in other ways it's one of the most important choices a designer can make. One can argue that the airfoil is unimportant, because nearly any slender shape you choose can lift the airplane. However, the selection of the airfoils is very important: it will determine several characteristics of the airplane wing, including the lift coefficient, drag coefficient, and stiffness of the wing.

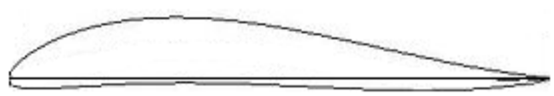
Mathematical Model

The airfoil can be thought of as two shapes working together. The first shape is a curved line, called the camber line. This is a line that is drawn down the middle of the airfoil, equidistant from the top surface of the wing and the bottom surface of the wing. The shape of the camber line has a strong influence on the maximum lift coefficient of the wing.

The camber line is not to be confused with an airfoil's chord line: a straight line drawn from the start of the camber line to the end of the camber line.



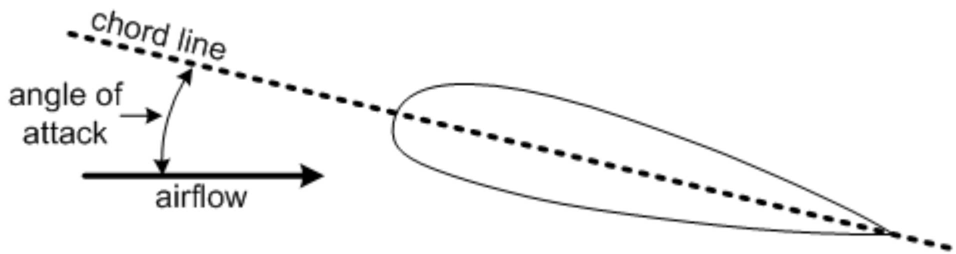
Camber Line



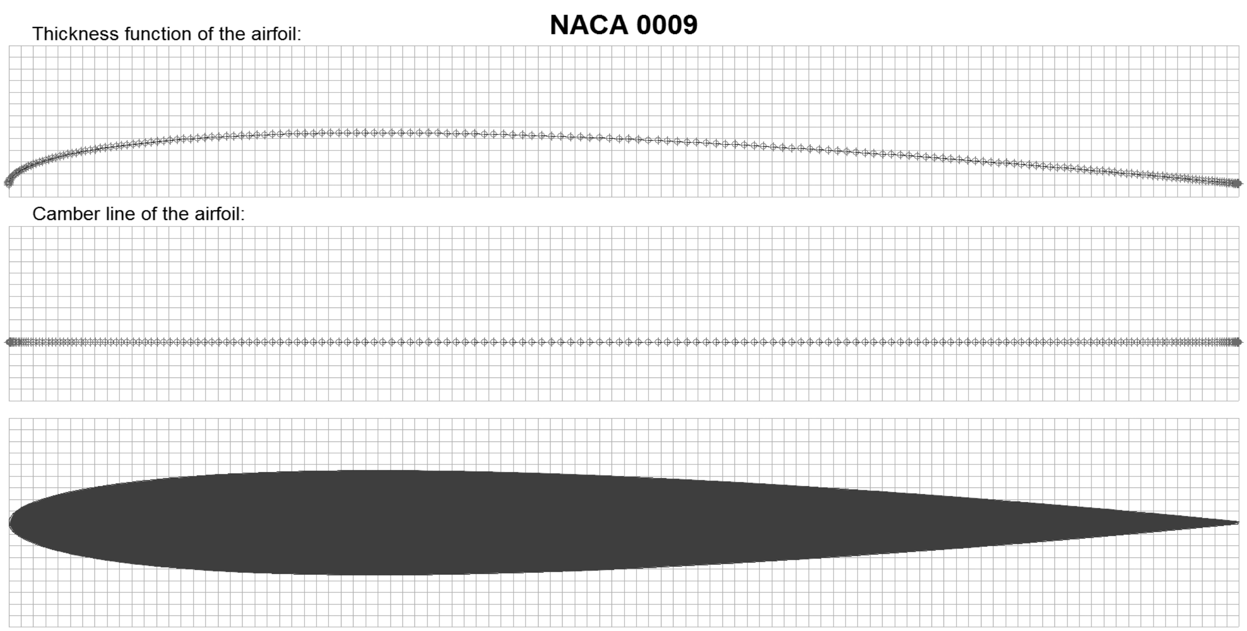
Chord Line

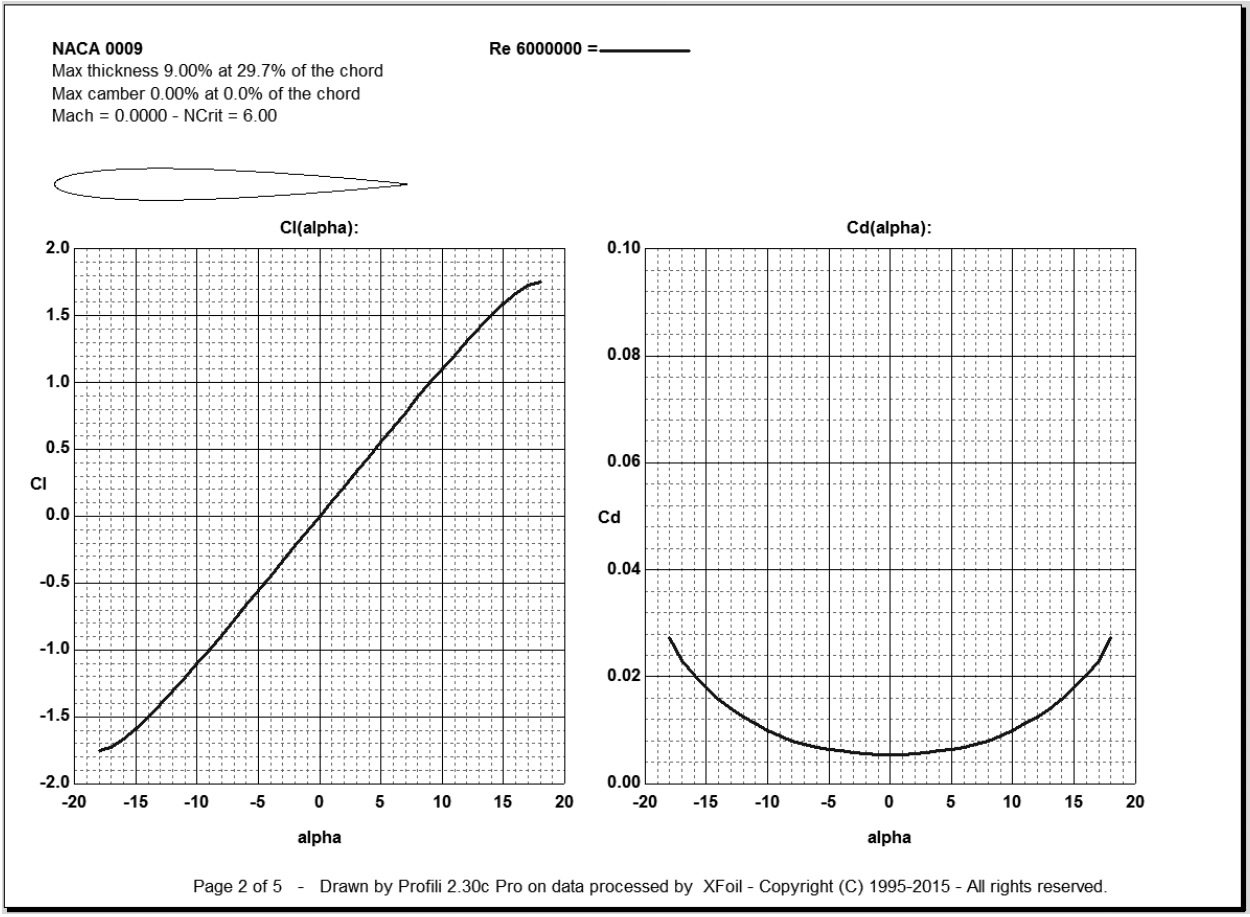
The second shape is a curved teardrop form which is stretched around the camber line. When the two shapes are added mathematically they form the airfoil. Mathematically, there are an infinite number of airfoil shapes. The teardrop shape has a strong influence on the drag and stall characteristics, as well as the stiffness of the wing as a structure.

Since there are an infinite number of airfoil shapes, it is impossible to describe the characteristics of them all. In the early days of aviation, there was an effort to provide some basic mathematical descriptions of airfoils, so designers could choose from a library of airfoils. These became known as NACA (National Advisory Committee for Aeronautics) airfoils. They first used 4 digits to describe the airfoils, but then later 5 digits as they understood airfoil shapes even better. More recently, they were revised again to refine these designations.

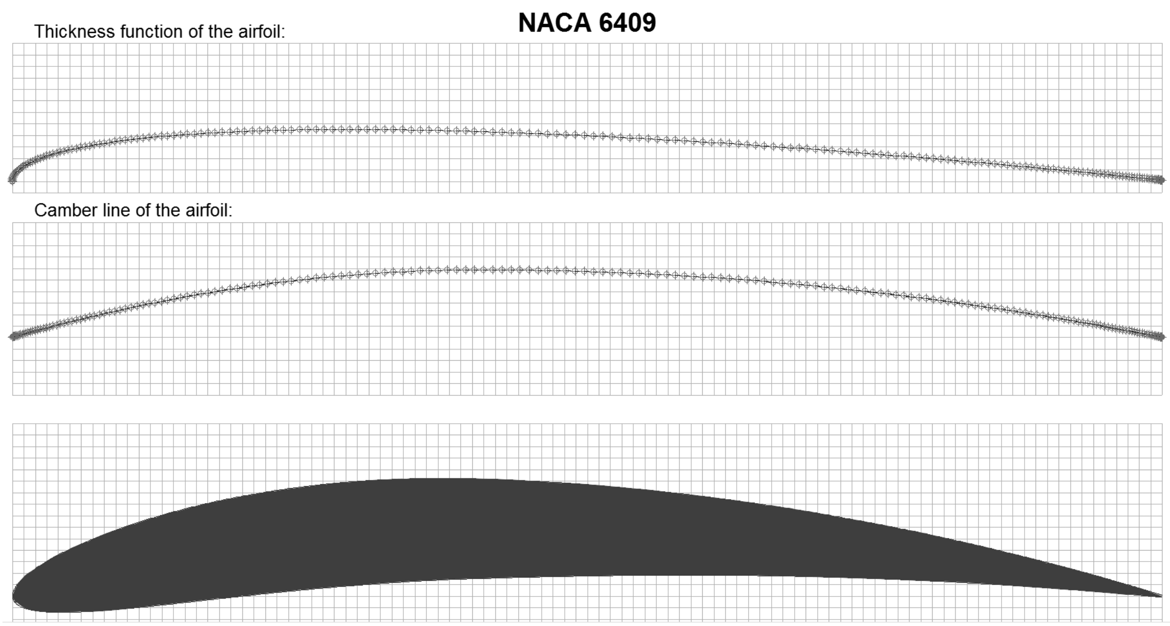


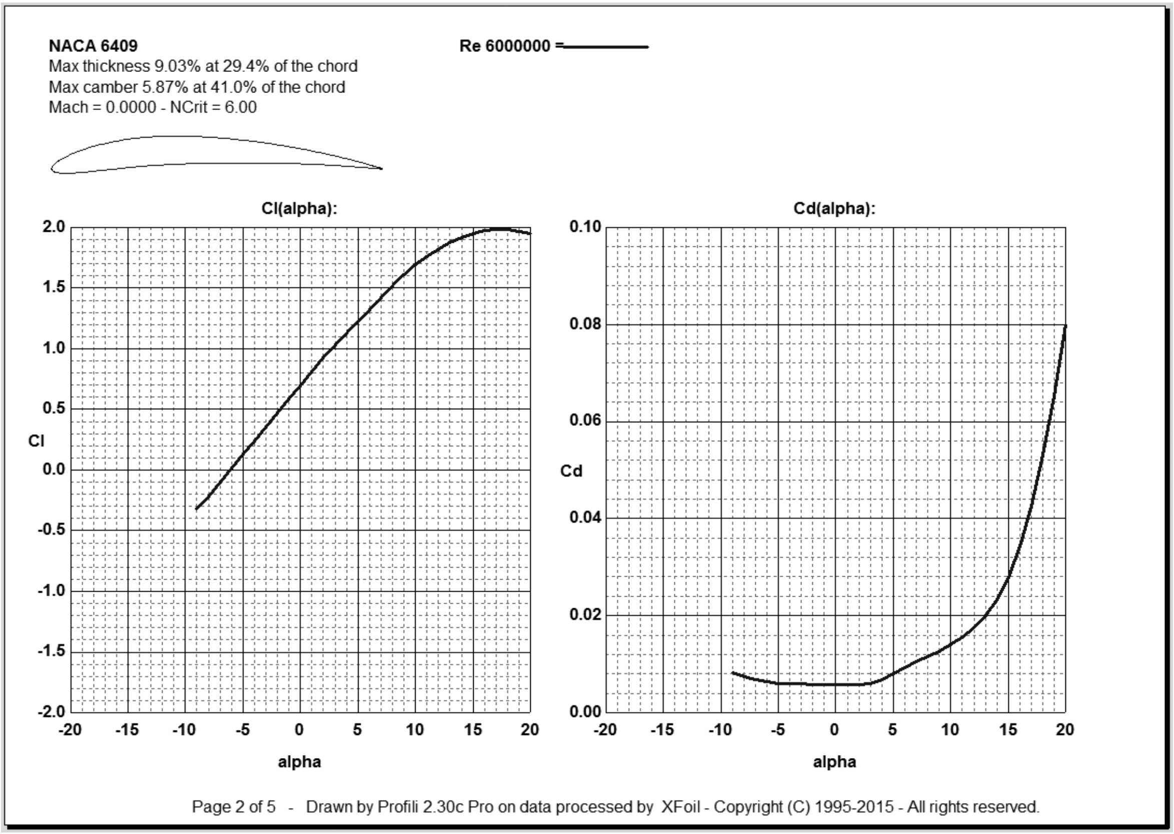
Here is an airfoil with a camber line that is a straight line; its camber line is the same as its chord line. In this scenario, lift and drag curves are functions of angle of attack only. The angle of attack is the angle of the relative wind to the angle of the chord line of the wing. These are symmetrical airfoil: the top and bottom surfaces are the same shape. Notice that the airfoil lift coefficient can be positive or negative depending upon the angle of attack ("alpha" in the below graphs).



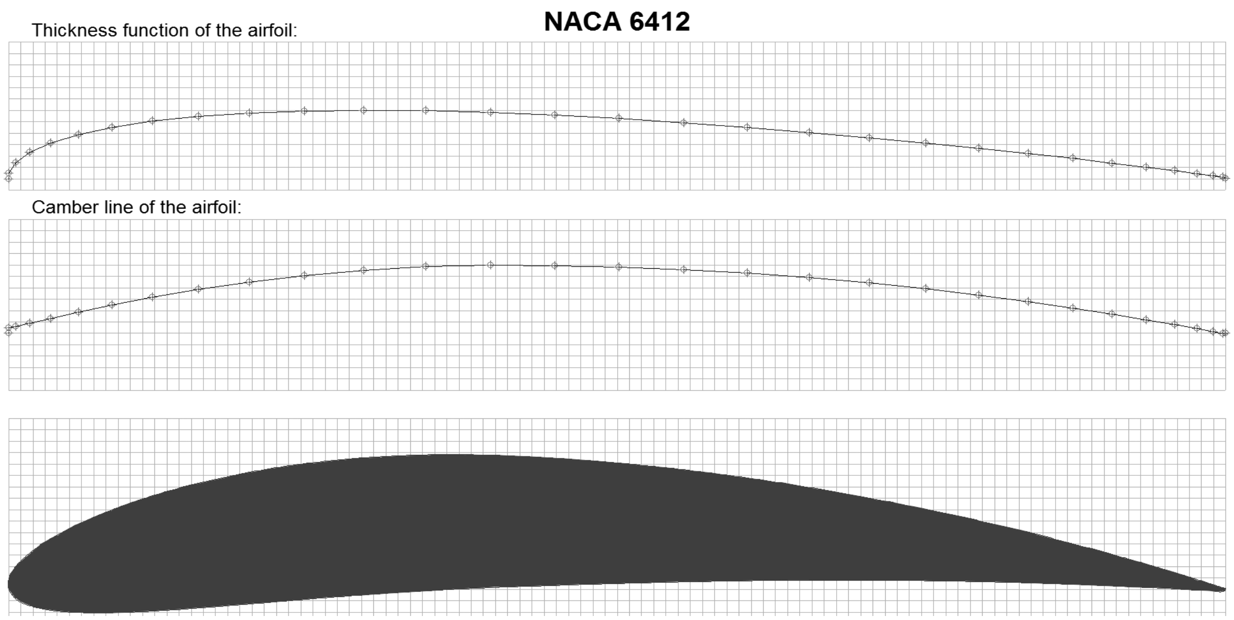

NACA 0009
Max thickness 9.00% at 29.7% of the chord
Max camber 0.00% at 0.0% of the chord
Mach = 0.0000 - NCrit = 6.00
Re 6000000 =
Cl(alpha):
Cl
alpha
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-20
-15
-10
-5
0
5
10
15
20
Cd(alpha):
Cd
alpha
0.10
0.08
0.06
0.04
0.02
0.00
Page 2 of 5 - Drawn by Profili 2.30c Pro on data processed by XFoil - Copyright (C) 1995-2015 - All rights reserved.

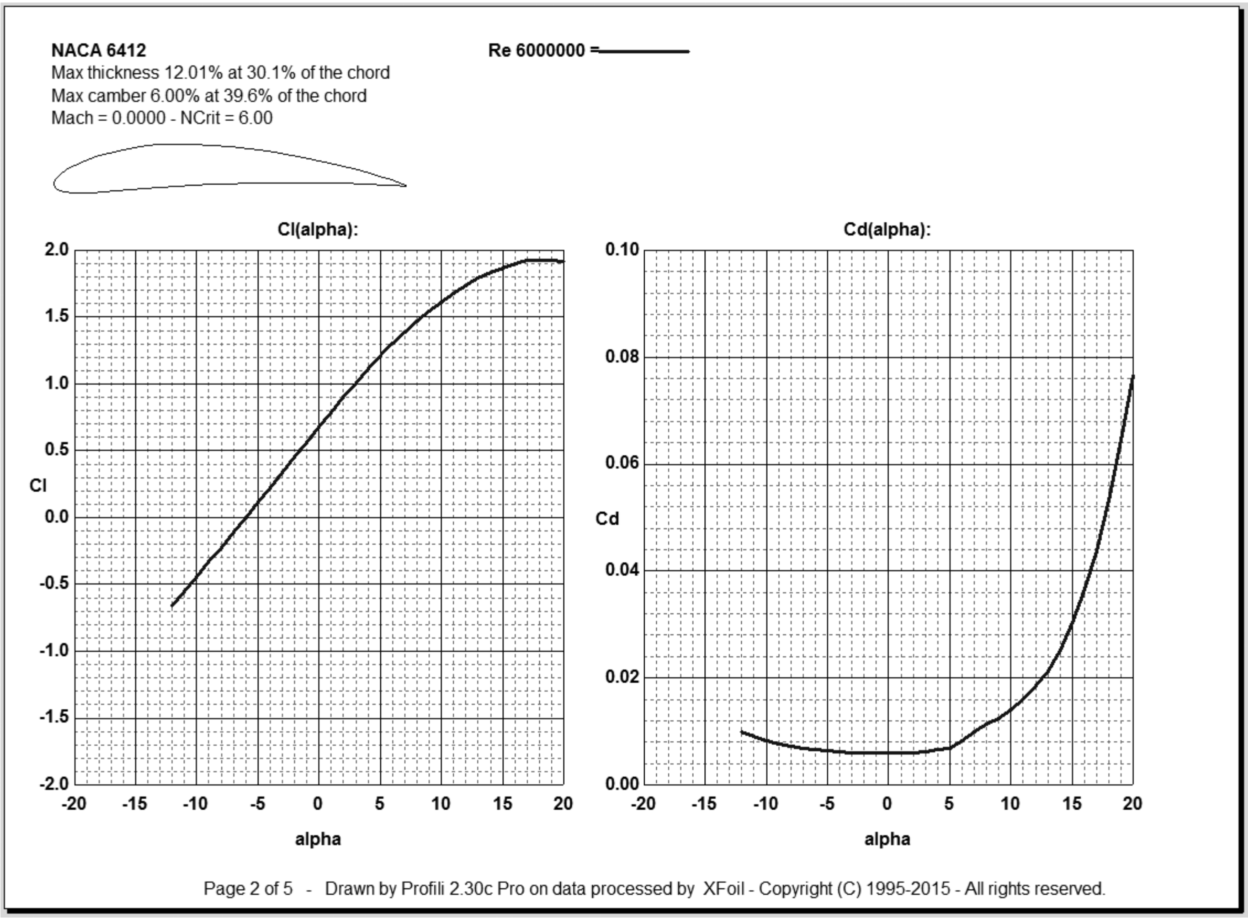
Here is an airfoil with the same teardrop shape, but a curved camber line. Notice how the lift and drag coefficients are different.




NACA 6409
Max thickness 9.03% at 29.4% of the chord
Max camber 5.87% at 41.0% of the chord
Mach = 0.0000 - NCrit = 6.00
Re 6000000 =
Cl(alpha):
Cl
alpha
Cd(alpha):
Cd
alpha
Page 2 of 5 - Drawn by Profili 2.30c Pro on data processed by XFoil - Copyright (C) 1995-2015 - All rights reserved.

Here is an airfoil with the same camber line as above, but a thicker tear drop shape.

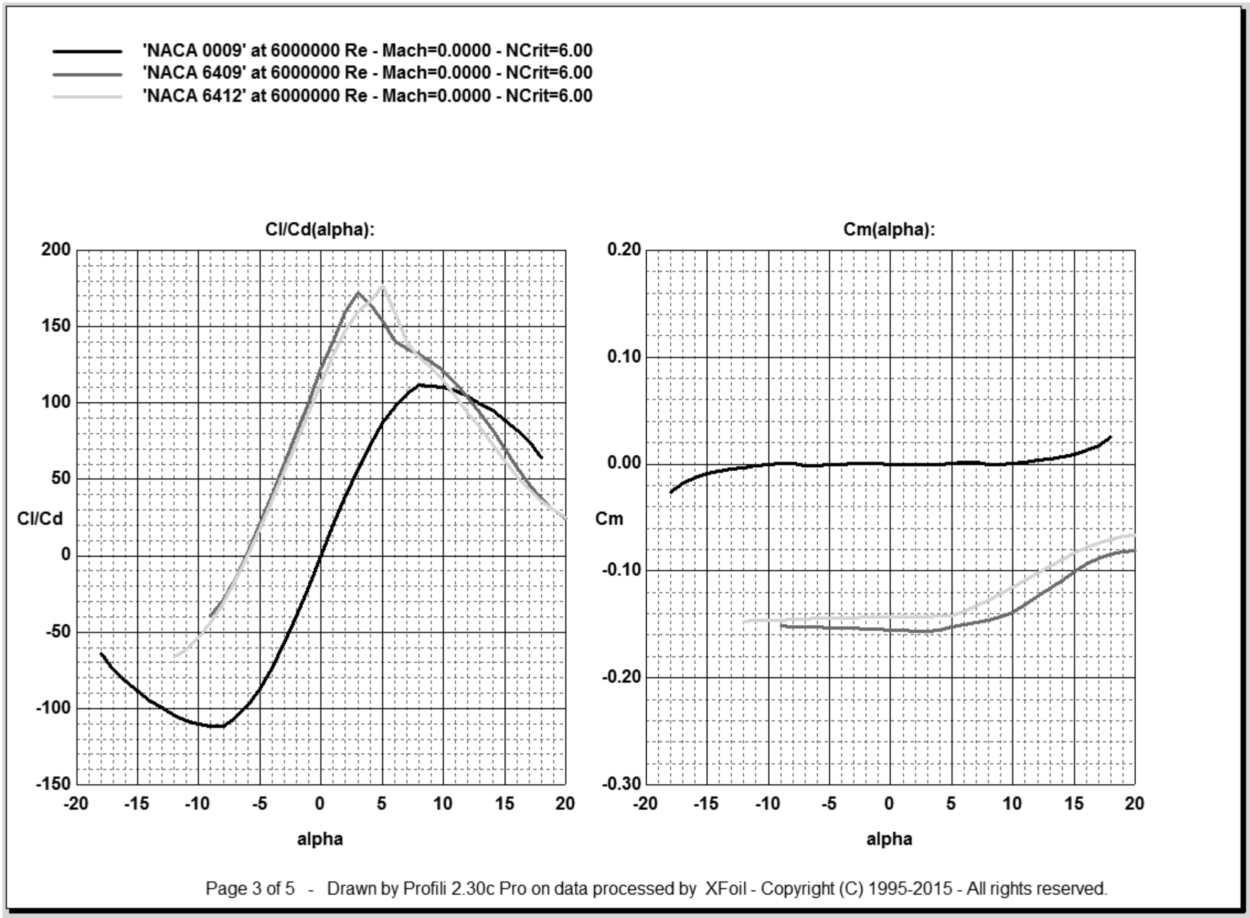




What is different about the three airfoils' lift and drag curves, and why might these be important differences?

All three airfoil shapes produce lift. Therefore, any of them will make an airplane fly. So, why use different shapes?

In addition to the lift and drag coefficients, there's a related coefficient called Moment Coefficient. The moment coefficient is how much torque, or rotational force, that the wing produces when it produces lift. The wing is literally trying to twist the nose of the airplane up or down when it produces lift. Let's compare the coefficient of lift with the coefficient of drag, and see how it impacts the moment coefficient.



As you can see from the graphs above, there is a significant difference between Cl/Cd ratios between the symmetrical airfoil and the cambered airfoil. There is also a very large difference in the moment coefficient between these two.

If the wing is trying to twist the nose down while producing lift, what must we do to balance the torque?

When would you choose a symmetrical airfoil?

Why would you choose a non-symmetrical airfoil?

Is it possible for a wing to produce upward lift when the airplane is upside down?

If the NACA 6409 airfoil has a nearly equivalent Cl/Cd ratio to the NACA 6412 and a similar moment coefficient, why would we choose the thicker airfoil, which causes structural stiffness, ability to hold fuel, Lighter weight?

Let's look at some of the airfoils using Airfoil-Maker. Open each of the airfoils below and look at the lift, drag, and moment curves. Each of these was chosen for different flying surfaces on the Cessna 172. Open the Cessna 172 model in Plane Maker, go to the export tab and airfoils. Reference the model while looking at the airfoil curves in Airfoil Maker. Why do you think each of these was chosen? Provide a reason below.

NACA 2412	
NACA 0009 (symmetrical)	
Clark Y (good propeller)	

Let's see what changing the airfoils on the Cessna 172 does to the flight characteristics of the airplane. Change the airfoils of the wing as below and look at the stall speed and maximum speed of the airplane with the airfoil changes.

Wing Airfoils – Root and tip NACA 2412	Stall Speed	Maximum speed
Trial #1		
Trial #2		
Trial #3		
Average		

Wing Airfoils – Root NACA 2412 and tip NACA 0006	Stall Speed	Maximum speed
Trial #1		
Trial #2		
Trial #3		
Average		

Wing Airfoils – Root and tip NACA 0006	Stall Speed	Maximum speed
Trial #1		
Trial #2		
Trial #3		
Average		

Beside the differences in the stall and maximum speeds did you notice any other differences in the behavior of the airplane?

Can you choose other airfoils for the wing root and tip of the Cessna 172 which will improve some aspect of its flying characteristics? Tell us why you chose those airfoils and what flight characteristic was improved by your choice.

The best airfoil for any airplane depends upon what characteristic or regime of flight is most important to the mission of that airplane.

In the table below rank the importance of each airfoil characteristic for each of the aircraft from 1 to 6, with 1 being most important. Be prepared to justify your rankings.

Aircraft type	Maximum Cl	Cl/Cd	Cm	Cd	Stiffness/weight	Volume in wing
Sailplane						
STOL aircraft						
Jet fighter						
Airliner						

Additional resources:

Fly To Learn
flytolearn.com

GAMA Aviation Design Challenge
https://gama.aero/opportunities-in-ga/aviation-challenge/

There is a website which lists many of the airfoils used on various aircraft listed for your reference, called “The incomplete Guide to airfoil usage”

http://m-selig.ae.illinois.edu/ads/aircraft.html

There is also another linked website which has many of the airfoil shapes as data files which can be imported into analysis programs to compute the lift, drag, and moment coefficients for the airfoil of interest.

http://m-selig.ae.illinois.edu/ads/coord_database.html