Lesson 1: Safety and Teacher Demo

What makes a drone fly?

Key concepts:

- Safety
- Aerodynamics
- Parts of a drone

Objectives:

- Gain knowledge of the parts of a drone
- Safely interact with and fly a drone with a teacher-led demonstration.

Instructor Background: Grades 5 -12+

Time: 1 – 2 hours

Instructions:

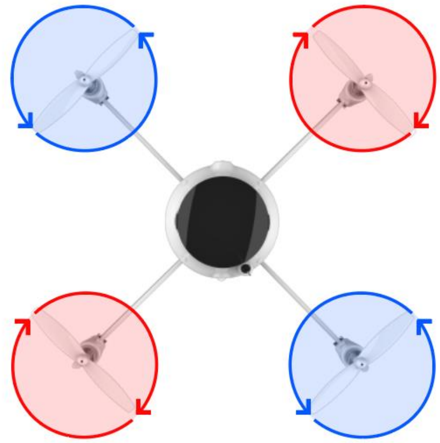
How to make a drone go up

On an airplane, the propellers face forward and push the plane in the forward direction. On a drone, the propellers point upwards and push the drone in the upward direction. The spinning blades of a drone push air downward. As **Newton's third law** states, for every action, there is an equal and opposite reaction. As the drone propellers push air down, air pushes up on the propellers creating **lift**, the force that opposes gravity. The faster the speed of the propellers, the more lift is created and the faster the drone goes up.

Summary:

- To make a drone go up, the force of lift needs to be greater than the force of gravity. If the force of lift is less than the force of gravity, the drone goes down. When the forces of lift and gravity are equal, the drone hovers in place.

How to make a drone turn



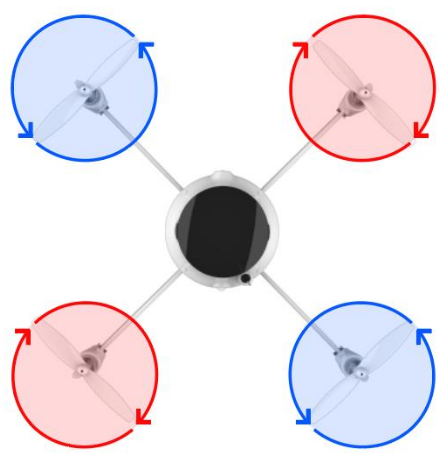
Your Circuit Scribe Drone has two sets of propellers rotating in opposite directions. In the image to the right, the top left and bottom right are spinning in the counterclockwise direction while the top right and bottom left are spinning in the clockwise direction. When the drone is stationary in the air, the propellers are all going at the same speed. (Remember, speed is a **scalar quantity**, meaning that each propeller moves at the same rate. Scalar quantities do not take into account the direction an object moves.)

One set of propellers has a negative angular momentum and the other set have a positive angular momentum. However, the net angular momentum at the drone body is zero.

To make a drone turn in a certain direction, the net angular momentum at the drone body should not equal zero. This happens when one set of propellers spins faster while the other set spins slower by the same factor. By increasing the speed of one set at the same rate that the other set is decreased, the overall upwards force remains the same. This ensures that while the drone rotates, it does not move up or down in the air.

Summary:

- To rotate the drone clockwise, increase the speed of the motors going clockwise and decrease the speed of the motors going counterclockwise. This will make the angular momentum of the drone body point in the clockwise direction.
- To rotate the drone counterclockwise, decrease the speed of the motors going clockwise and increase the speed of the motors going counterclockwise. This will make the angular momentum of the drone body point in the counterclockwise direction.



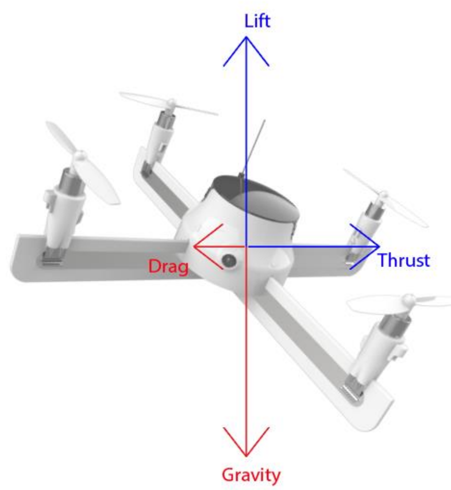
As your Circuit Scribe Drone flies, its propellers move at a certain speed and spin in a certain direction. The image to the right demonstrates that the top left and bottom right propellers are spinning in the counterclockwise direction, while the top right and bottom left propellers are spinning in the clockwise direction. When the drone is stationary in the air, the propellers are all going at the same speed. For the drone to turn clockwise, the clockwise propellers must move at a faster speed than the counterclockwise set. For the drone to turn counterclockwise, the counterclockwise propellers must move at a faster speed than the counterclockwise set.

Summary:

- To rotate the drone clockwise, increase the speed of the motors going clockwise and decrease the speed of the motors going counterclockwise. To rotate the drone counterclockwise, increase the speed of the motors going counterclockwise and decrease the speed of the motors going clockwise.
- To keep the drone from moving upward or downward while you are rotating it, ensure that, as the speed of one set of propellers increases, the other set is decreased. This keeps the overall lift force the same, as the amount of air being pushed down by the propellers remains constant.

How to make a drone move horizontally

For a drone to move in any direction, it needs **thrust**, a forward force. Below is a drone's free body diagram, or a picture representing the forces on the drone, as it moves to the right. The blue arrows, thrust and lift, are the forces applied by the motors. The red arrows, drag and gravity, oppose the force created by the motors. In particular, gravity is a naturally occurring force that points in the direction opposite to lift and drag is a force of friction that points in a direction opposite to thrust. The arrows in the free body diagram represent the net force in that direction as a result of all four motors. Each motor applies ¼ of the total thrust and lift.



Moving the drone in any direction is a balancing act. The total lift needs to remain the same as the weight of the drone to keep it at the same height. The total angular momentum needs to remain at zero, so the drone doesn't rotate. For the drone to move in a horizontal direction, it needs a forward component of thrust from the propellers. This can be accomplished by reducing the speed of two adjacent motors and increasing the speed of the other two motors by the same factor. For example, if you wish to move the drone to the right as pictured in the free body diagram above, the speed of the two motors on the left should be increased and the two motors on the right should be decreased.

Drone Safety Review

In a classroom full of kids excited to learn about drones, a flying object with propellers going at 15,000 rotations per minute. can pose a danger. Review the full list of safety rules on page __. Before turning on a drone in class, inform cadets of the dangers that come along with drone operation and the safety rules in place to prevent these dangers.

Rules:

- Only fly drones in a designated flight zone.
- Always keep a flying drone in sight.
- Do not fly in adverse weather conditions, such as in high winds or reduced visibility.
- Do not handle the drone while propellers are moving.
- Keep drones off the floor where they can be stepped on.
- Do not touch the hot motors after flying a drone.
- Never fly over people.

Attention Signal

An attention signal is an easy way to regain control of a noisy classroom and should be established at the beginning of flight school. Cadets should be instructed to land any flying drones, stop talking, and focus their attention on the instructor when signaled. Establishing an attention signal at the beginning of flight school sets the tone for the entire course. These signals inform cadets that although this is a fun learning experience, when the teacher is ready to give instructions, everyone needs to listen. An attention signal can be as easy as blowing a whistle. The whistle can be heard over the noise of a classroom and a swarm of drones and signals flyers to land their drones. . Other common attention signals include:

1. Teacher call: “Clap once if you can hear me,” Cadet response: a clap.
2. Teacher call: “One, two, three, eyes on me,” Cadet response: “One, two eyes on you”.

Activity 1: Forming groups and going over safety procedures

Materials:

- Safety worksheet
- Role cards
- Folders for cadets (flight academy portfolio)

Time: 10 - 15 minutes

Description:

In today’s lesson, cadets will form the groups that they will be in for the rest of Flight Academy. It is up to you, the teacher, whether groups are assigned or created by the cadets. In their groups, cadets will learn about drone safety. Cadets will learn about their roles during Flight Academy.

Plan Ahead:

If you choose to make the groups for Drone Academy, you should create the groups before class. Print out the role cards and prepare the folders for cadets. Each folder should have the safety work sheet and the printed rule agreement.

Step-by-step:

1. Introduce the attention signal and give the attention signal a few test rounds.
2. Have cadets get into groups. If you have created the groups, announce the groups now. If the cadets get to make their own groups, instruct them to form into teams of 3. Use the attention signal.
3. Go over the roles and display the role cards to the cadets. Let cadets know they will be assigned roles in subsequent lessons and will have the opportunity to switch roles over the course of each lesson. Let students know they will be referred to as cadets while in Flight Academy.
4. Assign each group a number. Write this number down so it doesn't change over the course of flight academy.
5. Give cadets a chance to come up with a team name.
6. Pass out the Flight Academy logs, one to each person. Have cadets write their own name, group number, and the team name on their log.
7. With the cadets sitting with their groups, go over drone safety including the "Drone Safety and FAA Guidelines" (located in the overview). Cadets can follow along online. (https://www.faa.gov/uas/recreational_fliers/).
8. Have cadets sign the printed rule agreement in their Flight Academy logs.
9. Have cadets complete the "Drone Safety" worksheet in their groups.
10. Ask cadets to place all materials for the Flight Academy in their flight portfolio let cadets know that their Flight Academy log should be returned to the teacher at the end of each class.

Activity 2: Teacher Demo

Materials:

- One Circuit Scribe Drone kit
- Mobile phone,
- Lesson one worksheet

Time: 15- 20 minutes

Description: In this activity, cadets will learn basic physics about how drones fly. A teacher will demonstrate a drone in class. Cadets will fill out a worksheet on the information they learned.

Plan Ahead: Set up a flying zone in the classroom. Charge a drone battery. Pass out lesson 1 handouts and the lesson 1 worksheet.

Step-by-step:

1. Pass out the “Parts of a Drone and Important Terms” handouts. Give cadets a few minutes to look over the handout.
2. One-by-one, take out the drone pieces, including the battery from the charging station, and inform the cadets of the name and purpose of each part. Once each part has been explained, assemble the drone in front of the cadets (using the PCB arms) so they will know how to put together their own drone when it’s time.
3. Pass out the “How a Drone Flies” handout.
4. Use the handout to teach cadets how drones take off, turn and move.
5. Review the safety procedures.
6. Have the class gather around the flying zone. Fly the drone up and down, left to right, and in a circle. Land the drone and put it away.
7. Pass out the “Lesson 1 Worksheet” for cadets to work on in their groups.
8. When the cadets are done with the worksheet, begin the discussion.
9. Remind cadets to return their Flight Academy logs with completed materials.

Class Discussion

Offer the cadets a question and answer session after the activities. Once all of the cadets’ questions are answered, begin to ask the discussion questions.

- Why do drones have two propellers that spin clockwise and two that spin counterclockwise?
- What could you change on the drone that would make it fly higher?
- How does a drone fly?
- Would the drone fly in space?
- What do you think causes the motor to make so much noise?

Drone Safety and FAA Guidelines

Name: ____ Date: ___________

Fill in the blanks with words from below.

Attention	Aviation	Vehicles	Line of sight
Ground	400ft.	Propellers	Private

1. FAA stands for Federal _____________ Administration.
2. Fly your drone at or below __________ when in uncontrolled or "Class G" airspace.
3. Do not intentionally fly over unprotected persons or moving _________.
4. Check and follow all local laws and ordinances before flying over __________ property.
5. Always keep your drone in your _____________________.
6. Never touch moving ___________.
7. Keep drones off the ____________ to prevent someone stepping on a drone.
8. Land drones and look at the teacher when you hear the ______________ signal.

True or False

9. You are not allowed to fly in controlled airspace (around and above many airports). _____
10. Drones should be flown near other aircraft, especially near airports. _____
11. During public events, you may fly over groups of people or stadiums full of people. _____
12. Drones may not fly near emergencies, such as any type of accident response, law enforcement activities or firefighting. _____
13. You may only fly near or over sensitive infrastructure or property, such as power stations, water treatment facilities, correctional facilities or government facilities, at night, when they are not in operation. _____

Drone Safety and FAA Guidelines

Name: ____ Date: ____________

Fill in the blanks with words from below.

Attention	Aviation	Vehicles	Line of sight
Ground	400ft.	Propellers	Private

1. FAA stands for Federal _______________ Administration.
2. Fly your drone at or below ___________ when in uncontrolled or "Class G" airspace.
3. Do not intentionally fly over unprotected persons or moving __________.
4. Check and follow all local laws and ordinances before flying over ___________ property.
5. Always keep your drone in your ________________________.
6. Never touch moving_____________.
7. Keep drones off the _____________ to prevent someone stepping on a drone.
8. Land drones and look at the teacher when you hear the ________________ signal.

True or False

9. You are not allowed to fly in controlled airspace (around and above many airports). _____
10. Drones should be flown near other aircraft, especially near airports. _____
11. During public events, you may fly over groups of people or stadiums full of people. _____
12. Drones may not fly near emergencies, such as any type of accident response, law enforcement activities or firefighting. _____
13. You may only fly near or over sensitive infrastructure or property, such as power stations, water treatment facilities, correctional facilities or government facilities, at night, when they are not in operation. _____

Answer key: 1.- aviation 2. - 400ft 3. - vehicles 4. - private 5. - line of sight 6. - propellers 7. - ground 8. - attention 9. - T 10. - F 11. - F 12. - T 13. - F

Lesson 1 Safety Agreement Name ________________________________

Safety is of the utmost importance when piloting a Circuit Scribe drone. Below are some general measures that should be remembered whenever you or one of your fellow cadets is piloting a drone:

- Always keep a flying drone in sight.
- Always keep your drones off the floor when not in use.
- Keep a clear zone around any drone in use.
  - If a drone is on, stay away. Try to keep a radius of about 10 ft. clear of all people and objects while a drone is in the air.
- Do not fly in adverse weather conditions such as in high winds or reduced visibility.
  - Your Circuit Scribe Drone weighs 3.3 oz., making it light enough for wind to blow them away. A strong enough gust of wind can even blow your drone right at you or your cadets.
- Do not touch the motors after the drone has been in flight.
- Do not leave batteries plugged in overnight.

The Federal Aviation Administration also requires the following:

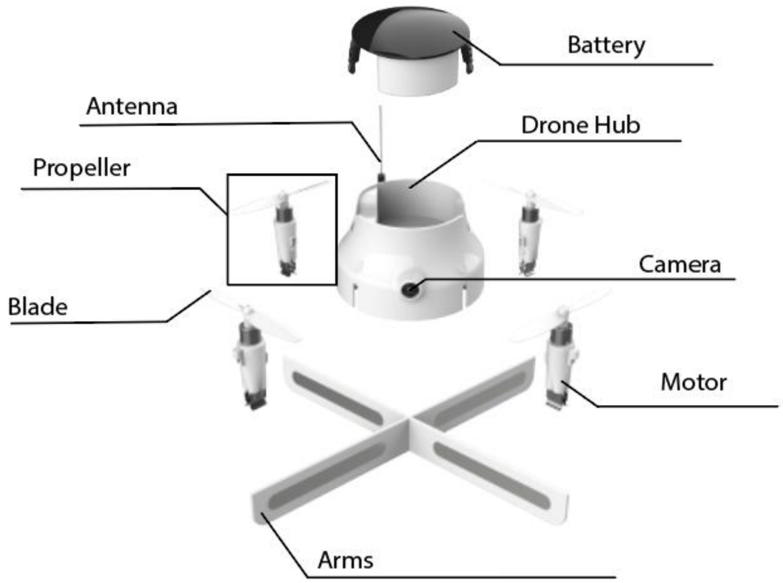
- Fly your drone at or below 400 feet when in uncontrolled or "Class G" airspace. (Your Circuit Scribe Drone flies up to 150 ft. in the air, so no need to worry about this one!)
- Do NOT fly in controlled airspace (around and above many airports).
- Never fly near other aircraft, especially near airports.
- Never fly over groups of people, public events, or stadiums full of people.
- Never fly near emergencies, such as any type of accident response, law enforcement activities, firefighting or hurricane recovery efforts.
- Never fly under the influence of drugs or alcohol.
- Do not fly near or over sensitive infrastructure or property, such as power stations, water treatment facilities, correctional facilities, heavily traveled roadways, government facilities, etc.
- Do not intentionally fly over unprotected persons or moving vehicles.
- Check and follow all local laws and ordinances before flying over private property.

Read the following statement and sign:

I understand and will follow the safety rules outlined in this lesson while enrolled in this Flight Academy. My drone flying privileges are dependent on my following of the rules.

Signature:____ Date:_______________

Name____________________



Lesson 1: Parts of a Drone and Important Terms

- **Antenna**: allows for communication from the mobile app to the drone. An antenna receives radio waves that move through the air.
- **Arms**: the physical and electrical connection between the propellers and drone hub. The arms have a conductive layer of ink that allows for the flow of electricity to the motors.
- **Battery**: the power source for your drone. Your Circuit Scribe Drone's battery is 12.5V at 250mAh.
- **Blade**: the plastic blade is spun by the motor to push air down.
- **Camera**: gives you a bird's-eye view of what your drone can see in 480p. Can take in-flight pictures via the app.
- **Drone hub**: the command center for your drone. Houses all the drone circuitry, camera, battery, and antenna.
- **Motor**: the component that converts electrical energy into mechanical energy. The mechanical energy makes the blades rotate.
- **Propeller**: This component that forces air down and makes the drone fly. It is a combination of the motor and blade.

Vocabulary list

- **sUAS**: small unmanned aircraft systems. Your circuit scribe drone is considered a sUAS by the FAA
- **FAA**: Federal Aviation Administration. The government entity that oversees aviation regulations in the United States
- **RPM**: rotations per minute. An attribute of motors that describes how fast they spin. Your circuit scribe drone has motors that are capable of 15,000 rpm
- **Lift**: the force opposing gravity that is applied by the drone's motors
- **Newton's third law**: for every action, there is an equal and opposite reaction.
- Angular momentum: for every action, there is an equal and opposite reaction.
- **Free body diagram**: a diagram typically used in physics to show the relative magnitude and direction of all forces acting upon an object
- **Scalar**: describes a quantity having only magnitude, and not direction.

Lesson 1 Handout: How a Drone Flies

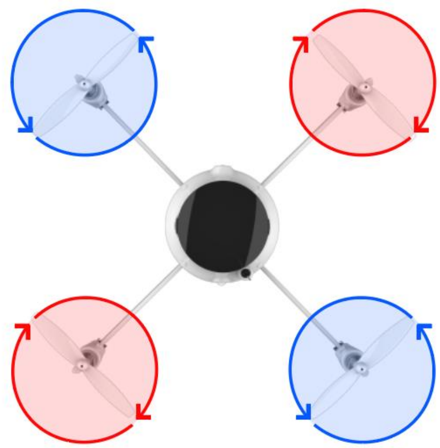
How to Make a Drone Go Up

On an airplane, the propellers face forward and push the plane in the forward direction. On a drone, the propellers point upwards and push the drone in the upward direction. The spinning blades of a drone push air downward. As **Newton's third law** states, for every action, there is an equal and opposite reaction. As the drone propellers push air down, air pushes up on the propellers creating **lift**, the force that opposes gravity. The faster the speed of the propellers, the more lift is created and the faster the drone goes up.

Summary:

- To make a drone go up, the force of lift needs to be greater than the force of gravity. If the force of lift is less than the force of gravity, the drone goes down. When the forces of lift and gravity are equal, the drone hovers in place.

How to Make a Drone Turn



Your Circuit Scribe Drone has two sets of propellers rotating in opposite directions. In the image to the right, the top left and bottom right are spinning in the counterclockwise direction while the top right and bottom left are spinning in the clockwise direction. When the drone is stationary in the air, the propellers are all going at the same speed. (Remember, speed is a **scalar quantity**, meaning that each propeller moves at the same rate. Scalar quantities do not take into account the direction an object moves.)

One set of propellers has a negative angular momentum and the other set have a positive angular momentum. However, the net angular momentum at the drone body is zero.

To make a drone turn in a certain direction, the net angular momentum at the drone body should not equal zero. This happens when one set of propellers spins faster while the other set spins slower by the same factor. By increasing the speed of one set at the same rate that the other set is decreased, the overall upwards force remains the same. This ensures that while the drone rotates, it does not move up or down in the air.

Summary:

- To rotate the drone clockwise, increase the speed of the motors going clockwise and decrease the speed of the motors going counterclockwise. This will make the angular momentum of the drone body point in the clockwise direction.

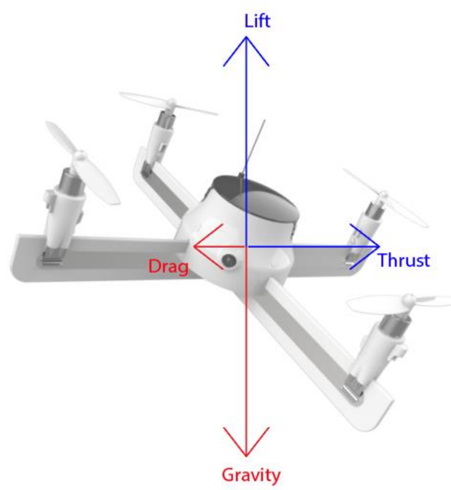
- To rotate the drone counterclockwise, decrease the speed of the motors going clockwise and increase the speed of the motors going counterclockwise. This will make the angular momentum of the drone body point in the counterclockwise direction.

Summary:

- To rotate the drone clockwise, increase the speed of the motors going clockwise and decrease the speed of the motors going counterclockwise. To rotate the drone counterclockwise, increase the speed of the motors going counterclockwise and decrease the speed of the motors going clockwise.
- To keep the drone from moving upward or downward while you are rotating it, ensure that, as the speed of one set of propellers increases, the other set is decreased. This keeps the overall lift force the same, as the amount of air being pushed down by the propellers remains constant.

How to Make a Drone Move Horizontally

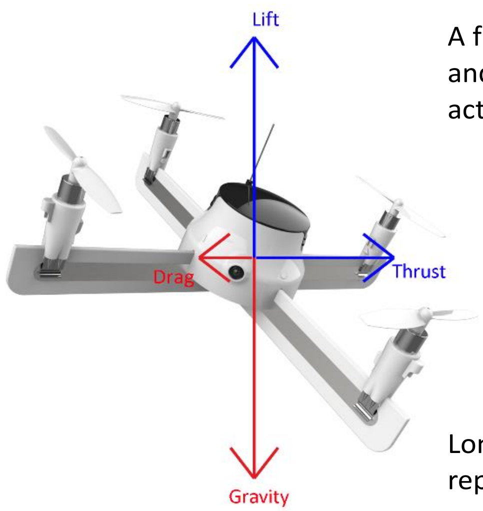
For a drone to move in any direction, it needs **thrust**, a forward force. Below is a drone's free body diagram, or a picture representing the forces on the drone, as it moves to the right. The blue arrows, thrust and lift, are the forces applied by the motors. The red arrows, drag and gravity, oppose the force created by the motors. In particular, gravity is a naturally occurring force that points in the direction opposite to lift and drag is a force of friction that points in a direction opposite to thrust. The arrows in the free body diagram represent the net force in that direction as a result of all four motors. In reality, each motor applies ¼ of the total thrust and lift.



Moving the drone in any direction is a balancing act. The total lift needs to remain the same as the weight of the drone to keep it at the same height. The total angular momentum needs to remain at zero, so the drone doesn't rotate. For the drone to move in a horizontal direction, it needs a forward component of thrust from the propellers. This can be accomplished by reducing the speed of two adjacent motors and increasing the speed of the other two motors by the same factor. For example, if you wish to move the drone to the right as pictured in the free body diagram above, the speed of the two motors on the left should be increased and the two motors on the right should be decreased.

Lesson 1 Worksheet

Name ____

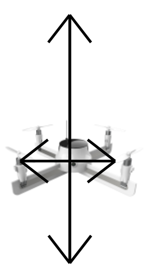
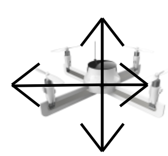
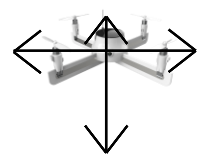
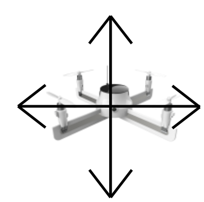


A free body diagram is a tool used in physics to show the relative magnitude and direction of forces acting on an object. A flying drone typically has 4 forces acting on it:

- Lift - the upwards force created by the motors.
- Gravity - the downwards force that opposes lift.
- Thrust - the forward force created by an unbalance in motor speeds.
- Drag - the backward force caused by wind resistance.

Longer arrows represent larger forces. In the example to the left, the arrows representing lift and gravity are the same length. This means the forces are equal. When lift and gravity are equal, the drone is vertically stationary, meaning it isn't moving up or down. The arrow representing thrust is longer than the arrow representing drag, this means the force of thrust is greater than the force of drag and the drone is moving to the right.

Exercise 1
Determine what direction the drone is moving in each of the examples below, based on the free body diagram.

1. ____________________ 2. ____________________ 3. ____________________ 4. ____________________

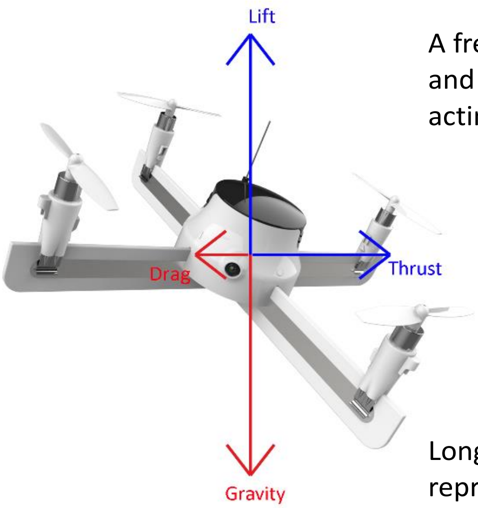
Exercise 2
Fill in the blanks below with words from the word box.

Word bank:		
greater	opposite	equal and opposite
adjacent	clockwise	angular momentum

5. As Newton's third law states, for every action, there is a(n)___________________________reaction.
6. To make a drone go up, the force of lift needs to be____________than the force of gravity.
7. A Circuit Scribe Drone has two sets of propellers rotating in_________________directions.
8. When the drone is stationary in the air, the propellers are all going at the same speed, so the net _______________________is equal to zero.
9. To rotate the drone__________________, increase the speed of the motors going clockwise and decrease the speed of the motors going counterclockwise.
10. Drones move by reducing the speed of two_______________motors, and increasing the speed of the other two motors by the same factor.

Lesson 1 Worksheet

Name ____



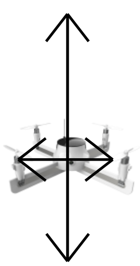
A free body diagram is a tool used in physics to show the relative magnitude and direction of forces acting on an object. A flying drone typically has 4 forces acting on it:

- Lift - the upwards force created by the motors.
- Gravity - the downwards force that opposes lift.
- Thrust - the forwards force created by an unbalance in motor speeds.
- Drag - the backwards force caused by wind resistance.

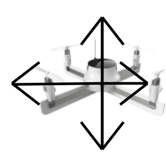
Longer arrows represent larger forces. In the example to the left, the arrows representing lift and gravity are the same length. This means the forces are equal to each other. When lift and gravity are equal, the drone is vertically stationary, meaning it isn't moving up or down. The arrow representing thrust is longer than the arrow representing drag, this means the force of thrust is greater than the force of drag and the drone is moving to the right.

Exercise 1

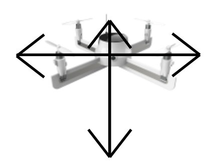
Determine what direction the drone is moving in each of the examples below, based on the free body diagram.



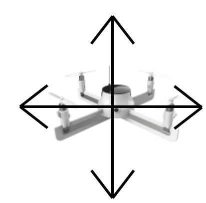
1. ______up______



2. ______left______



3. ______down______



4. stationary (not moving)

Exercise 2

Fill in the blanks below with words from the word box.

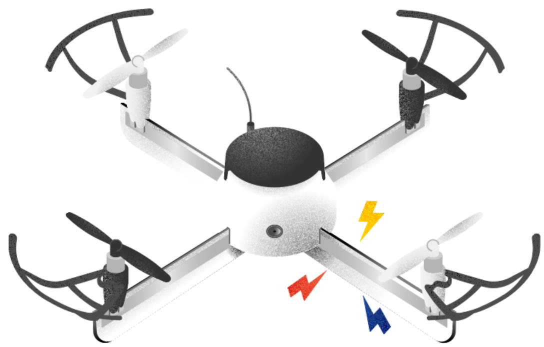
Word bank:		
greater	opposite	equal and opposite
adjacent	clockwise	angular momentum

5. As Newton's third law states, for every action, there is an ____equal and opposite____reaction.
6. To make a drone go up, the force of lift needs to be____greater____than the force of gravity.
7. A Circuit Scribe Drone has two sets of propellers rotating in____opposite____directions.
8. When the drone is stationary in the air, the propellers are all going at the same speed, so the net ____angular momentum____is equal to zero.
9. To rotate the drone____clockwise____, increase the speed of the motors going clockwise and decrease the speed of the motors going counterclockwise.
10. Drones move by reducing the speed of two____adjacent____motors, and increasing the speed of the other two motors by the same factor.

Lesson 2: Building your Drone - Part 1

Key Concepts:

- Weight vs Mass
- Force
- Acceleration



Objectives:

- Learn to use a scale
- Use math to determine an object's mass. Cadets measure resistance of PCB wings. Cadets put together and dismantle a drone with PCB wings.

Instructor Background: Grades 5 -12+

Time: 1 – 2 hours

Supplies:

1. Circuit Scribe Drone Builder Kit
2. Cardboard arms from lesson 3
3. iOS or Android-enabled Device
4. CS Pilot App
5. Extra Cardboard
6. Materials to make a drone course (cones, hula-hoop, table, etc.)

Instructions: What is the difference between weight and mass?

Mass vs. Weight

Weight is the mass of an object multiplied by the force being acted upon it. Mass is the amount of matter in a body.

Formulas

$$Force = mass * acceleration$$

$$Mass = \frac{force}{acceleration}$$

The attractive force between an object and the Earth is called gravity, and it is denoted as an acceleration = 9.8m/s^2 or 32 ft/s^2. The mass of any object on Earth can be found by dividing the object's weight by the acceleration of gravity. In SI (international units) weight is measured in Newtons (N), but in the Imperial system (which is used in the US) weight is measured in pounds (Lbs).

Using a scale

There are two common types of scales: a beam scale and a digital scale. Both types should be calibrated prior to use, however most digital scales this process is as simple as pressing "zero" or "tare" with nothing on the scale. Having the cadets perform this task will be up to the teacher's discretion, but it is recommended, especially if there will be multiple groups using the same scales.

The eight drone parts that will be weighed during the activity are: 2 drone PCB arms, 4 drone motors with motor guards, 1 battery and 1 hub.

Activity 1: Total weight of drone

Materials:
Per Group
- Beam or electronic scale
- Drone builder kit

Per Cadet
- Pen
- Flight Academy log with materials

Time: 35-40 min.

Description: Cadets will practice using scales and record the weight in metric and imperial units of each of the components for the drone in their flight logs. Then use the measured results to calculate the mass of the drone.

Plan Ahead: Before class place a scale and other materials on each of the worktables so that each team has one scale.

Roles:
1. Engineer - measuring and using the balance.
2. Project Manager - recording data.
3. Pilot - checking out/in drone, organizing materials, and comparing flight log notes.

Safety:
- Beam scales have moving parts that can pinch fingers and should be handled with care.
- Remind cadets not to plug in their batteries unless instructed to.

Step-by-step:
1. Introduce the concepts of weight and mass and the formula for weight: $F = ma$. Include example calculations for mass and weight (force). Explain the SI units for both weight and mass.
2. Demonstrate the proper way to use the scale that the cadets will use by measuring a common object like a pencil.
3. First demonstrate zeroing out the scale.
4. Weigh the pencil 3 times and explain how averaging multiple measurements help improve the accuracy of the result by reducing human error (possible mistakes).
5. Measure each drone component 3 times and record each measurement in grams in an example flight log.
6. Average the measurements and record the average in an example flight log.
7. Ask cadets to brainstorm and list what parts of the builder kit they should measure and those that they do not need to measure. List out the parts in the table provided. Let them know they should have the whole table filled.
8. Have the cadets follow the instructions on the activity handouts.
9. Each cadet should get a chance to measure at least one of the drone components.
10. Have cadets average their measurements and enter it into the data table.
11. Have cadets compare their calculations to other groups.

12. Give the cadets 5 minutes to read and discuss the discussion questions in their groups.
13. Have the cadets write answers to the discussion questions in their flight logs.
14. Have a question and answer session with the whole class where you discuss the questions as a class.

Class Discussion

Offer the cadets a question and answer session after the activities. Once all of the cadets' questions are answered, begin to review the discussions as a whole class.

Lesson 2 Activity Handout

Name ____________________________________

Description: In this activity, you will find the total weight and mass of the drone by using a scale. The weight of your drone determines things like how high the drone can fly and how long it will remain airborne. Knowing the mass and weight of your drone is also important due to laws concerning drones. The FAA mandates that all drones over 250 g and under 55 lbs. need to be registered. You will also find out if your drone needs to be registered with the FAA. Your group will use a scale to determine the mass or weight of your drone, depending on the type of scale your group has. Using the formulas below, you will be able to calculate whatever quantity your scale does not determine.

$$F = ma$$

$$m = \frac{F}{a}$$

Pre-Activity Questions - Before you get started with the activity answer the following questions as a group:

1. What quantity does your scale determine?

2. What formula will you use to determine the other quantity (either mass or weight)?

3. List the parts of the drone you think you should weigh (you should come up with 8).

Once you have answered the above questions complete the following steps. Each cadet in the group should complete each role and your group should have at least three measurement tables completely filled out:

Materials:
- Scale
- Pen/activity log

Roles: Take turns completing each role.
1. Pilot – check in/out the drone, keep group materials organized, compare and compute results.
2. Engineer – measuring and use the balance
3. Project Manager – record the data determined by the engineer

Steps:
1. The pilot should check out the drone.
2. The project manager should take out their project log.
3. The engineer should begin by zeroing the scale or triple beam balance (video for triple beam balance: https://www.youtube.com/watch?v=If5lQjffBfc).

4. The engineer should then weigh each part of the drone while the project manager records the values.
5. While the engineer and project manager are recording and determining scale values, the pilot should be helping keep drone parts organized into weighed and not yet weighed piles. After the first group has completed measurements, the pilot should begin working on calculating the unknown quantity (either mass or weight) on their tables and find the average.
6. After the first part is weighed, the engineer should re-zero the scale, place the part in the weighed pile and repeat until all parts are weighed and recorded.
7. The pilot should then collect all the drone parts and check them back in by striking out their row on the checkout list.
8. All cadets change roles and repeat the procedure.
9. Once all cadets have completed each role, they should complete their tables by computing the unknown quantity (either mass or weight) and compare answers with one another in the group. Once they have compared answers, they should, together, average the total weights and masses and record.

Post-Activity Questions:

1. What is the total mass of your drone?

2. What is the total weight of your drone?

3. Do you think the drone would weigh more or less on the moon? Why? (The gravitational constant on the moon 1.62 m/s^2)

4. Does it matter if you average the components' weight (or mass) first or average the total at the end?

5. Does it matter if you average the weight (or mass) before or after calculating it?

6. Does your drone need to be registered with the FAA?

7. Do you think, if you averaged the drone measurements of the entire class, you would have a more accurate or less accurate mass or weight? Explain your reasoning.

Lesson 2 Flight Log Handout

Name ____________________

Part Name	Weight (lbs.)	Mass (kg)
Arm 1		
Arm 2		
Black Motor 1		
Black Motor 2		
White Motor 1		
White Motor 2		
Battery		
Hub		
Total		

Formula: $F = m * a$

Discussion Questions:

- What is the mass of a drone?
- How much would the drone weigh on the moon? Gravitational constant on the moon 1.62 m/s^2

Quiz Questions:

- What is the formula for mass?
- Given Venus's acceleration constant of 8.87m/s^2 How much would a drone with a mass of 100 grams weigh on Venus?

Lesson 3: Building your Drone Part 2

Key Concepts:
- Problem Solving
- Conservation of Energy
- Measuring Resistance

Objectives: In this lesson cadets assemble the cardboard arms that come with the drone. Cadets review and learn about the physics of conductive ink and how electrical energy is converted into the mechanical energy that turns the drone's propellers and enables flight. At the end of this lesson Cadets will have earned their learners permit and be ready to begin flying lessons.

Instructor Background: What is a multimeter and how do I use one?

How to use a multimeter

A **multimeter** (sometimes called a digital multimeter or DMM) is a device used to measure different electrical properties. Basic multimeters will measure voltage, current, resistance, and sometimes other properties like capacitance and continuity. In this lesson cadets will be using their multimeters to measure **resistance**. Multimeters can either be auto ranging or manual ranging. If a multimeter is manual ranging, the user must set the multimeter to the appropriate range. You should select the range to be slightly higher than your intended measurement. Example 1: if you think your resistance is around 150 Ω you'll choose the 200 Ω range. Example 2, if you think your resistance is around 15,000 Ω you would choose the 20K Ω range. If you are using an auto ranging multimeter you will only need to choose the property you intend to measure (voltage, current, resistance, etc) and the multimeter will display it's most accurate result automatically.

Each multimeter works with two probes (usually wires with sharp metal tips or alligator clips at the ends). Plug the two probes into two of the three receptacles on the multimeter. The black probe always plugs into the hole labeled Common or "COM" - this is the ground probe. The red probe is most often plugged into the receptacle used to measure voltage, resistance, or small amounts of current. If you're measuring large currents and want to be sure not to damage the multimeter you'd plug the red probe into the high current (fused) receptacle. We will use the voltage (V) / resistance (Ω), small current (mA) receptacle for the entirety of flight academy. In order to measure resistance make sure your multimeter is set to the resistance Ω setting and simply place the probes on either end of the silver line you are measuring.

Although cadets will only use the resistance measuring function of their multimeter, we recommend you learn all about the multimeter as it will be a useful tool in your toolkit for life. Note that when measuring voltage and current you'll need to choose between direct current (DC) and alternating voltage (AC) and similarly for voltage there are both DC voltage (like from a battery) and AC voltage like from a wall outlet. Multimeters often have a dedicated receptacle to measure high currents. For this curriculum we will not be using the high current (fused) receptacle.

How to assemble your drone's wings

During the second activity cadets will assemble the included cardboard arms in their kit. This process consists of coloring in the dotted lines on the arms with the included silver ink pen. Cadets can take turns using the pen included in their groups drone builder kit. If you have extra Circuit Scribe silver pens you can have group members can work in tandem. Conductivity of the drone arms is greatly increases the longer they dry, therefore putting the arms in a toaster oven the lowest setting to cure them will result in better conductivity quicker. The inclusion of a toaster oven also presents an excellent teaching moment as students can compare and contrast the conductivity of their drone arms pre and post curing (going through the toaster oven). In order to fly the drone, the arms should read at or below 1 ohm for each rectangle.

***** We highly recommend using a toaster oven in this lesson**

Activity 1: Line resistance test

Materials:
-Drone builder kit
-Multimeter
-Pencil
-Silver ink pens
-crayon
-8.5" by 11" paper
-rulers
-Flight academy portfolio with materials
-resistance log worksheet

Time: 20-35 min.

Description: In this lesson cadets will draw and measure resistance of different materials (pen, pencil, silver ink pen, crayon on paper). Cadets will also log their resistance measurements.

Optional: Cadets may choose to log the change (drop) in resistance over time compared to the resistance of the arms if done in different circumstances, like outside or durig the middle of the night.

Plan Ahead: Make sure every student has a ruler and access to plenty of markers and paper. Be sure to cut your papers in half before the lesson. Place activity materials on groups desk. Have students watch videos (https://www.youtube.com/watch?v=yEYvlh1KaFs) on measuring resistance before class. Feel free to use the table we included in the Lesson materials or have students plan and make their own!

Roles: In this lesson everyone's role is an engineer.

Safety:
-The ends of the multimeter probes can be sharp and should not be used to poke anyone.
-Toaster ovens get hot. It's important that cadets keep the temperature low enough to not toast or burn the wings of the drone. Also don't touch the oven case while in use and never touch the heating elements. Take appropriate safety measures seriously, and be sure to unplug the toaster oven when not in use.

Step-by-step:

1. If your students do not have a firm grasp on basic circuit theory review the material covered in the Instructor background section with them first.
2. Make sure each student has a "How to Measure resistance with a multimeter" handout, a "Multimedia Multimeter" worksheet, and "Line Test" log.
3. Have students quietly read the handouts for around 5-10 minutes.
4. Go over how to use a multimeter to measure resistance with your cadets.
5. Draw a 5 cm long line of silver ink on paper. Explain to cadets how to best use the silver ink pen by holding the pen upright (as near to vertical as possible) and applying light pressure.
6. Demonstrate how to measure the resistance of the line with the multimeter.
7. Explain the activity to your cadets.
8. Cadets will begin the activity drawing lines of different lengths on their papers and taking turns measuring the resistance.
9. Once cadets have finished drawing the lines as instructed they should each test and log the resistance measurements for the PCB arms.
10. (optional) Cadets place drawings in toaster oven to cure ON THE LOWEST HEAT SETTING.
11. Cadets should begin working on the discussion questions at the end of the activity worksheet. Cadets should keep answers in their Flight Academy Log.
12. (optional) After 10-20 minutes have passed have students remove their test sheets from the toaster oven and measure and log the resistance.

Activity 2: Building your drone!

Materials:
-Drone builder kit
-Conductive ink pen
-Paper
-Pencil
-Drone Physics WS

Time: 20-35 min.

Description: Cadets take turns making their arms testing the resistance. Cadets practice battery charging routine.

Plan Ahead: Refer students online to the drone builder blueprints as only one print copy comes per builder kit.

Roles: All cadets are an engineer in this activity.

Safety: Care should be taken to not cut, bend, or pierce batteries. LiPo batteries should also not be left charging unattended for long periods of time. If a battery is bulging or damaged it should be disposed of properly at an electronics waste processing facility. Do not charge a battery that is damaged or looks inflated. Doing so could be a serious safety and fire hazard.

Step-by-step:
1. Once cadets have finished measuring all of the different resistances and logged them on their worksheets, they should begin constructing a drone arm. (Have some cadets start this exercise earlier if cadets have to share silver ink pens).
2. Cadets should fill out the area inside the rectangle on an arm on both sides. Cadets should take care to draw a uniform and thick layer of ink on the arms. Holding the pen upright with light pressure will deposit the most ink, and note that if spots are missed they should allow the wings to dry before trying to apply a second coat - overwriting too soon could wipe away ink that hasn't dried yet.
3. Once their arms have been filled in cadets should measure and log the resistance of their creations.
4. (Optional) Cadets should then cure their arms in a toaster oven (20m at 100 degrees Celsius) and measure/log the changed resistance
5. Inform the cadets that they should aim for 1 ohm of resistance between where the hub connects and where the motor connects on their newly constructed arm.
6. Allow cadets time at the beginning of the next lesson to add another layer of silver ink to their arms if they are still not in spec - which is under 1 Ω per arm.
7. Each group should have at least two pairs of arms, each under 1 Ω of resistance by the start of lesson 6.

Class Discussion

Offer the cadets a question and answer session after the activities. Once all of the cadets' questions are answered, begin to ask the discussion questions

- What materials were the most conductive, the least?
- How does the resistance of each material change as the lines get longer, wider, shorter, etc.?
- Does it matter which way you measure resistance (i.e. which probe goes first?)

- How does a multimeter work?

Lesson 3 – Vocabulary

Conductive – allows for the flow of electrical current.
Resistance – limits or slows the flow of electrical current.
Voltage – potential energy that pushes electrons and allows current to flow.
Current – the flow of electrons.
Dissipate – to disappear or dispel.

- As electrical energy flows, energy is “dissipated” in the form of heat.

Load – the element in a circuit that dissipates electrical energy.
Ohm’s Law – $A = \frac{V}{\Omega}$

- the mathematical relationship that specifies how current, voltage and resistance are related to each other in an electrical circuit.

Multimeter – a device used to measure multiple electrical properties, usually current, voltage and resistance.
Short Circuit – a circuit without a load.
Open Circuit – a circuit with a broken connection.
Ground – the point of lowest potential energy in a circuit; the 0V point.

How to Measure Resistance with a Multimeter

What is a Multimeter?

A multimeter (sometimes called a digital multimeter or DMM) is a device used to measure different electrical measurements. Multimeters can generally measure current (or amperage), resistance (or conductivity), and voltage. In this lesson you will be using multimeters to measure resistance.

Multimeters can either be auto-ranging or manual-ranging. If a multimeter is manual-ranging, then the user must set the multimeter to the right place value for a reading. For instance, if what you are measuring is known to be under 200 ohms, set the multimeter to the 200 Ω (ohms) setting. If it is closer to 20,000 ohms, set it to the 20k Ω setting. In order to use a manual-ranging multimeter, you must know the approximate resistance value you are measuring. If you are using an auto ranging multimeter, you will only need to set the multimeter reading to “ohms (Ω)”, and the multimeter will determine the correct place value.

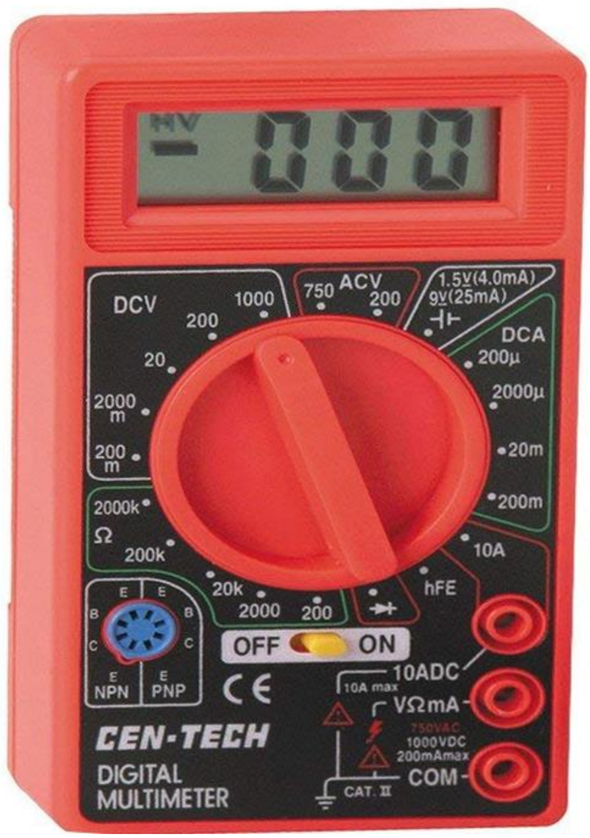
The probes for the multimeter (the wires with sharp metal tips) plug into the three red holes on the right side. The black probe always plugs into the hole labeled “COM” – this is the ground probe. The red probe can either plug into the middle or the top red hole depending on what functionality is wanted. The top hole is for measuring high alternating currents, the middle hole is for measuring small currents, resistance and volts. We will use the middle red hole for the entirety of flight academy.

Although you will only use the resistance measuring function of the multimeter, you should be familiar with the other measurements the multimeter can make, in case you are curious. On the device above the “DCV” section is for measuring “direct current voltages”. “ACV” is for measuring “alternating current voltages”. The section next to ACV is for capacitance measurements. Next to that is DCA for measuring “direct current amperage”. The setting labeled 10A is for measuring high alternating currents. Next to that hFE is for measuring the gain of a transistor. Then, finally, the diode symbol (the triangle with a vertical line at the end) is for measuring the forward voltage of a diode. The blue circle with holes in it is used to determine the leads of a transistor (whether they are base, emitters, or collectors).

How Does It Work?

The multimeter reads resistance by sending a small constant current through your circuit, this causes a voltage drop. The multimeter reads the voltage drop and is able to calculate the amount resistance using ohms law!

Using Your Multimeter



To measure resistance with your multimeter:

1. Set the multimeter to the resistance measuring settings.
2. If you have an auto-ranging multimeter you can skip this step. If not, make sure you set the multimeter to the correct place value. In your case, 200 will suffice.
3. Make sure the probes are properly plugged into the correct holes in the multimeter.
4. Take a probe (either red or black it doesn’t matter) and touch it to the end of one of the lines whose resistance you are measuring.
5. Take the other probe and touch it to the other end of the line whose resistance you are measuring.
6. Take note of the measurement.

Troubleshooting/Tips:

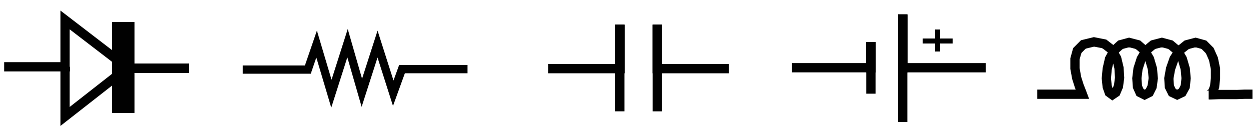
- Make sure your probe is making contact with the surface whose resistance you are attempting to measure.
- Make sure you are on the correct place value setting.
- Make sure your probes are plugged in all the way.
- Try turning the multimeter on and back off.
- Try measuring the resistance of something known (i.e. a resistor), if you believe your multimeter is not accurately reading measurements.
- Check and make sure your batteries are plugged in correctly.
- Make sure you are measuring from the ends of your surface you will not get the whole resistance measurement otherwise.

Multimedia Multimeter

In this activity, you will use the material you have learned about series and parallel circuit connections, as well as your knowledge of how a multimeter works.

Schematic Symbols

Diode Resistor Capacitor DC Power Inductor



Activity: Line Test

Draw and label the above schematic symbols with your materials – each symbol on a half sheet of paper. Measure the resistance and measure the length (approximate if curvy lines) of each conductive line you draw. Log at least ten measurements of data in the table. If the material on your drawing is not conductive, you do not need to measure the resistance or length of the line.

Bonus:

Calculate the average conductivity of each material per 1 cm.

Mixed Media Multimeter

In this activity, you will use the material you have learned about series and parallel circuit connections, as well as your knowledge of how a multimeter works.

Series and Parallel Circuits

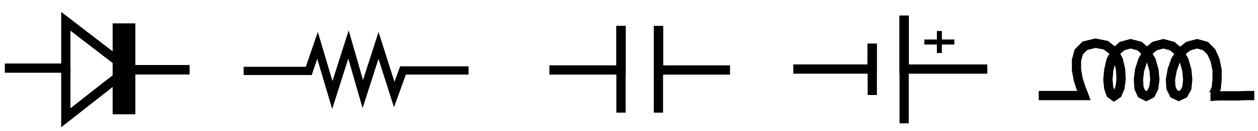
Series and parallel are circuit connection types.
Parallel connections come together at two points.
Series connections come together at one point.

Ground

Electricity flows to ground in a circuit. The ground is the point of lowest electrical potential.

Schematic Symbols

Diode Resistor Capacitor DC Power Inductor



Activity: Line Test

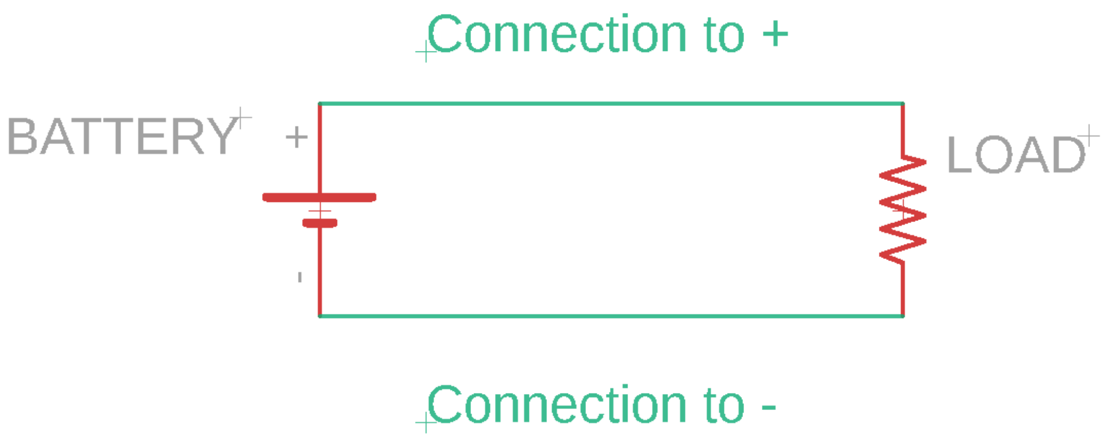
Draw and label the above schematic symbols with your materials – each symbol on a half sheet of paper. Measure the resistance and measure the length (approximate if curvy lines) of each conductive line you draw. Log the data in a table. If the material on your drawing is not conductive, you do not need to measure the resistance or length of the line.

Bonus:

Calculate the average conductivity of each material per 1 cm.

Drone Physics

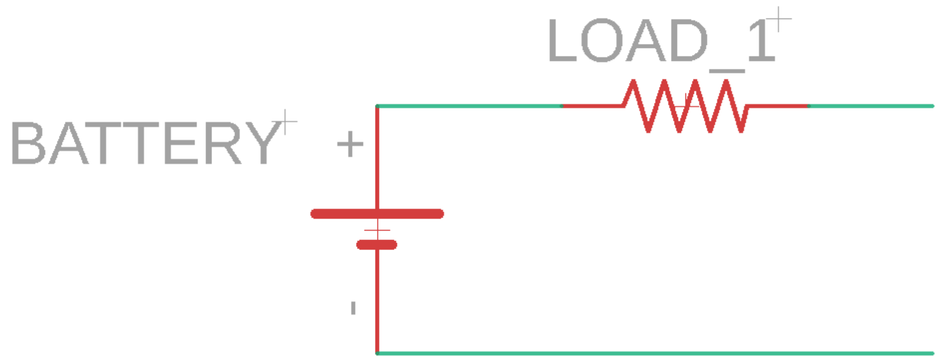
Basic Circuit Theory (In Pictures and Blurbs!)



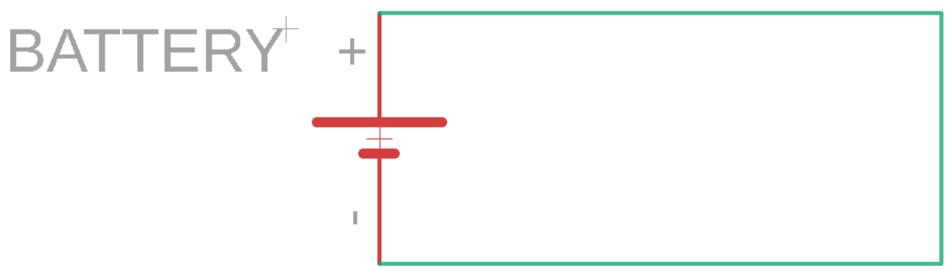
- Above is the most basic circuit it contains a load (a resistor), a battery, and wires (the green lines).
- Current flows from “+” to “–” (ground) through load.
- The “+” is your full voltage (i.e. 9 V for a 9 V battery) and “-” is 0 volts.
- Loads help to dissipate (dispel the electrical energy) the electrical energy provided by the battery in the form of heat (voltage has to be 0 at the ground terminal).
- Wires are conductive; they allow current to flow.
- The amount of current that flows depends on your battery voltage and your load’s resistance. This is known as Ohm’s law and is described mathematically by this equation:

$$\boldsymbol{A = \frac{V}{\Omega}}$$

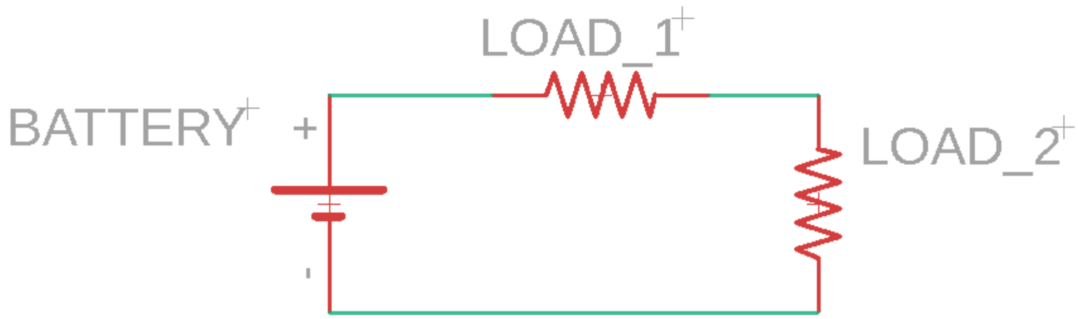
- As your resistance decreases, the amount of current increases, and, as your resistance increases, the amount of current decreases. Therefore, current is inversely proportional to resistance.



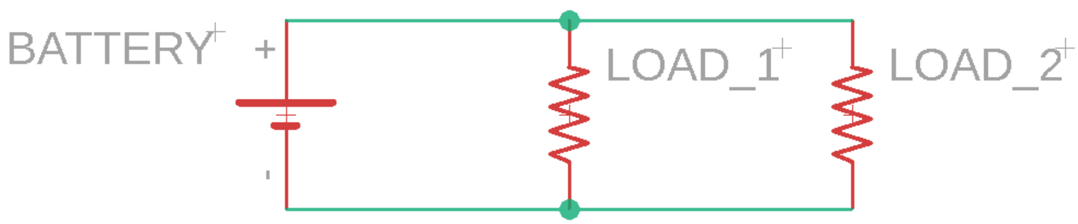
- Above is an open circuit. It does not have a connection between “+” and “–” on your battery.
- No current can flow in an open circuit.
- The open circuit is like having an infinite resistor where the break in the wire is.



- Above is a short circuit, which does not have a load.
- Short circuits are very dangerous. An infinite amount of current flows in this system, causing your battery to potentially burn out and catch fire.



- Above is a series circuit.
- A series circuit has components that connect with one point of connection.

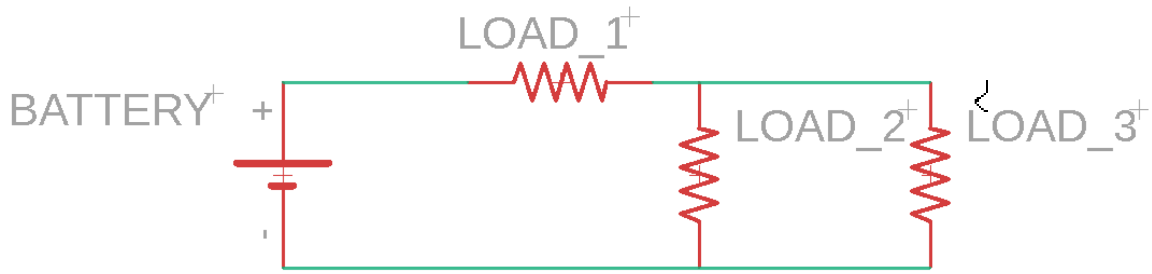


- Above is a parallel circuit.
- A parallel circuit has components that connect with two points of connection.

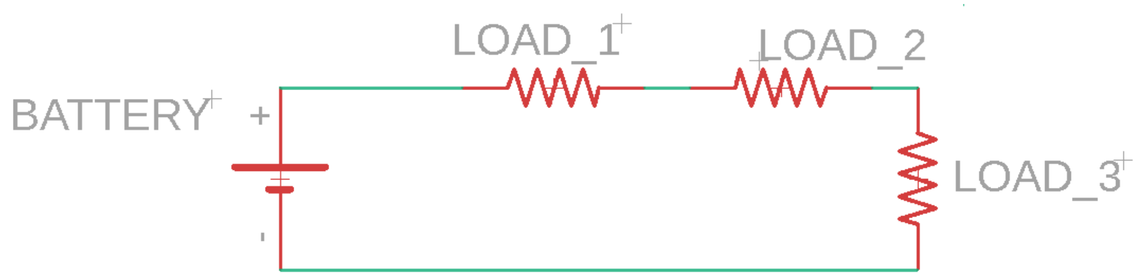
Ohm’s Law

Before starting this worksheet, make sure you have read the Drone Physics handout and the Multimeter worksheet to understand Ohm’s law and your multimeter. Use your knowledge to solve the following problems!

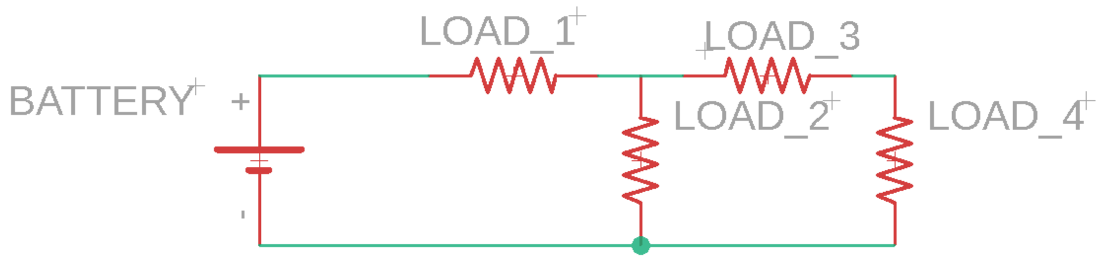
1. Label each connection as series or parallel. (There will be both on a circuit!)
    - Example: Load_2 and Load_3 are in parallel. Load_1 is in series with the parallel combination of Load_2 and Load_3.



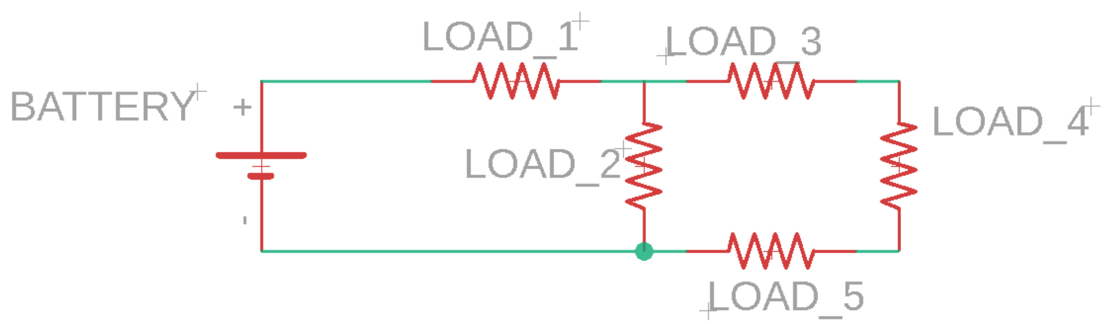
a.



b.



c.

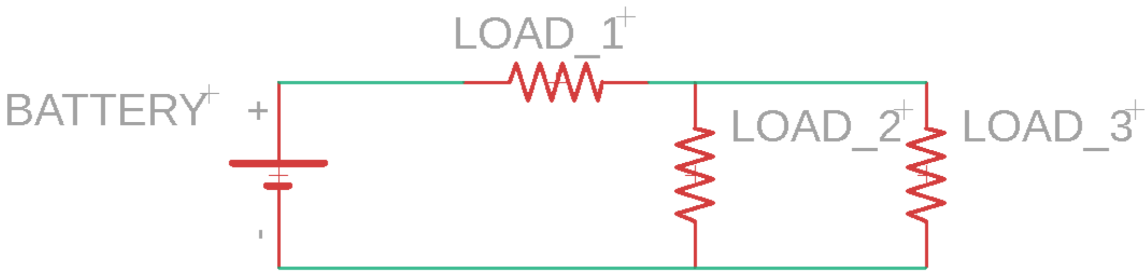


2. Answer each question about Ohm's law and circuit theory.
    a. Explain why you never want to connect a wire between two terminals on a 9 V battery.
    b. Explain why your series circuit won't work if you removed a load. Do you think a parallel circuit would still work if you removed a load? Why or why not?
    c. How does a multimeter work?
    d. If you add more silver ink to your drawing, will the resistance go up or down, explain your reasoning?

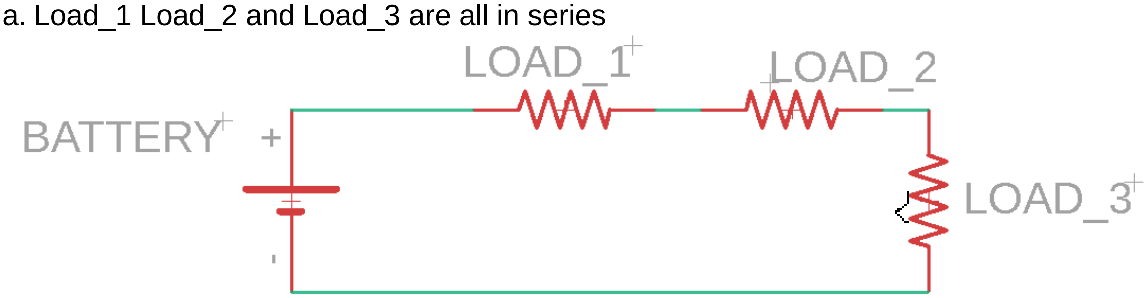
Ohm's Law

Before starting this worksheet, make sure you have read the Drone Physics handout and the Multimeter worksheet to understand Ohm's law and your multimeter. Use your knowledge to solve the following problems!

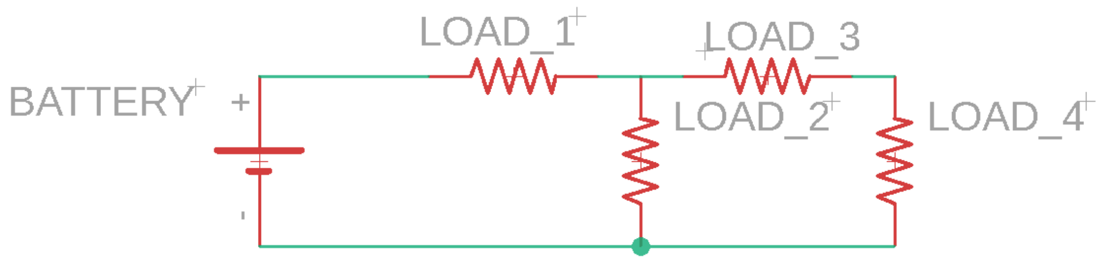
1. Label each connection as series or parallel. (There might be both on a circuit!)
    - Example: Load_2 and Load_3 are in parallel. Load_1 is in series with the parallel combination of Load_2 and Load_3.



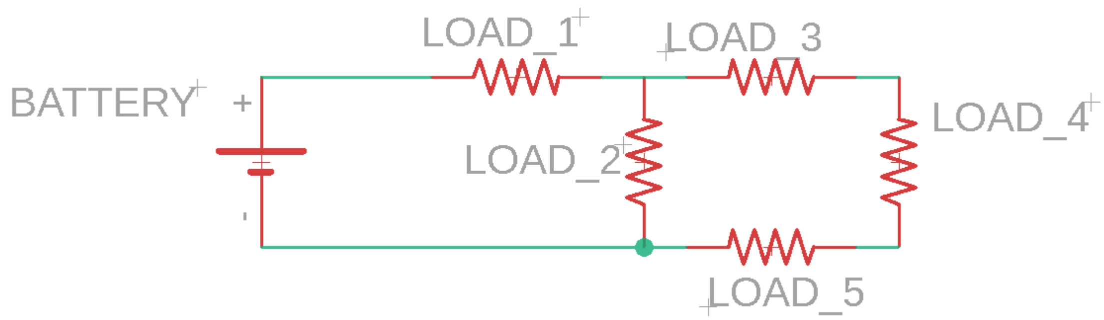
a. Load_1 Load_2 and Load_3 are all in series



b. Load_3 series with Load_4; Load_1 in series with parallel combination of Load_2 and series combination of Load_3 and Load_4



c. Load_3 series with Load_4 and Load_5; Load_1 in series with parallel combination of Load_2 and series combination of Load_3, Load_4 and Load_5



2. Answer each question about Ohm's law and circuit theory.
   a. Explain why you never want to connect a wire between two terminals on a 9 V battery.
      i. This creates a short and can damage the battery due to the infinite flow of current. In this system, there is not enough resistance to drop the electrical energy of the battery to 0 V.
   b. Explain why your series circuit won't work if you removed a load. Do you think a parallel circuit would still work if you removed a load? Why or why not?
      i. If you remove a load in a series circuit you have an open circuit, if you remove a load in a parallel circuit, you still have a normal, closed circuit.
   c. How does a multimeter work?
      i. The multimeter reads resistance by sending a small constant current through your circuit and causing a voltage drop. The multimeter reads the voltage drop and can calculate the amount resistance using Ohm's law.
   d. If you add more silver ink to your drawing will the resistance go up or down, explain your reasoning?
      i. This depends on how much ink you are adding. More ink usually means less resistance, but, if you add more ink and more distance to the line you are drawing, then it would increase the resistance!

Lesson 4: Drone Flight Academy 1

In this lesson, cadets will learn about drone controls and how to connect to the drone with their mobile devices. Cadets will fly their drones outside, using the PCB and cardboard arms that they made, and perform several test maneuvers. Cadets should take note of their flights in their flight logs.

Key Concepts:

- Digital literacy - learning new software
- Spatial perception and orientation
- Problem solving

Objectives:

- Cadets will complete flight maneuver checklist.
- Cadets will take flight log notes.
- Cadets will become familiar with the pre-flight check procedure.

Instructions:

Flying Safety Recap

Review these safety procedures to the students again.

- Always keep a flying drone in sight. Don't lose track of the drone.
- Keep the drones off the ground when not in use (to prevent them from being stepped on).
- Always keep a clear flying zone.
    - Try to keep a 10 ft radius clear of people and objects while flying the drone
- Do not fly in adverse weather conditions, such as in high winds or reduced visibility.
    - Your Circuit Scribe Drone weighs 3.3 oz., making it light enough for wind to blow them away. A strong enough gust of wind can even blow your drone right at you or your cadets.
- Do not touch the motors after the drone has been in flight, as they may be hot to the touch.
- Never leave the battery plugged in for extended periods of time or overnight.
- The cadet in the "engineer" role must always turn off the drone before fixing or putting anything back together.

Group Member Roles

The cadets must have a Drone Learners Permit in order to fly. The Drone Permit proves that the student has went over and learned all the safety rules and mechanics of a drone from the previous lessons. Each member will have a chance to become a pilot and fly the drone (if time allows it), so cadet must have their own battery. The pilot uses their battery for their respective test flights. The role of the engineer is to fix the drone and put it back together in case the pilot crashes their drone. The cadet with the "Engineer" role must turn off the drone before conducting any maintenance. The cadet with the "Project Manager" is in charge of safety; they must advise the pilot if they are getting too close to anyone or if the group breaks any safety rules.

Safety is the utmost priority for Circuit Scribe and it is the teacher's job to enforce safety and revoke any permits for the day if any safety rules are violated.

The roles are switched each time the drone battery dies. From a full charge, the battery lasts for approximately 5 minutes of constant flight time, not including any crashes or repairs.

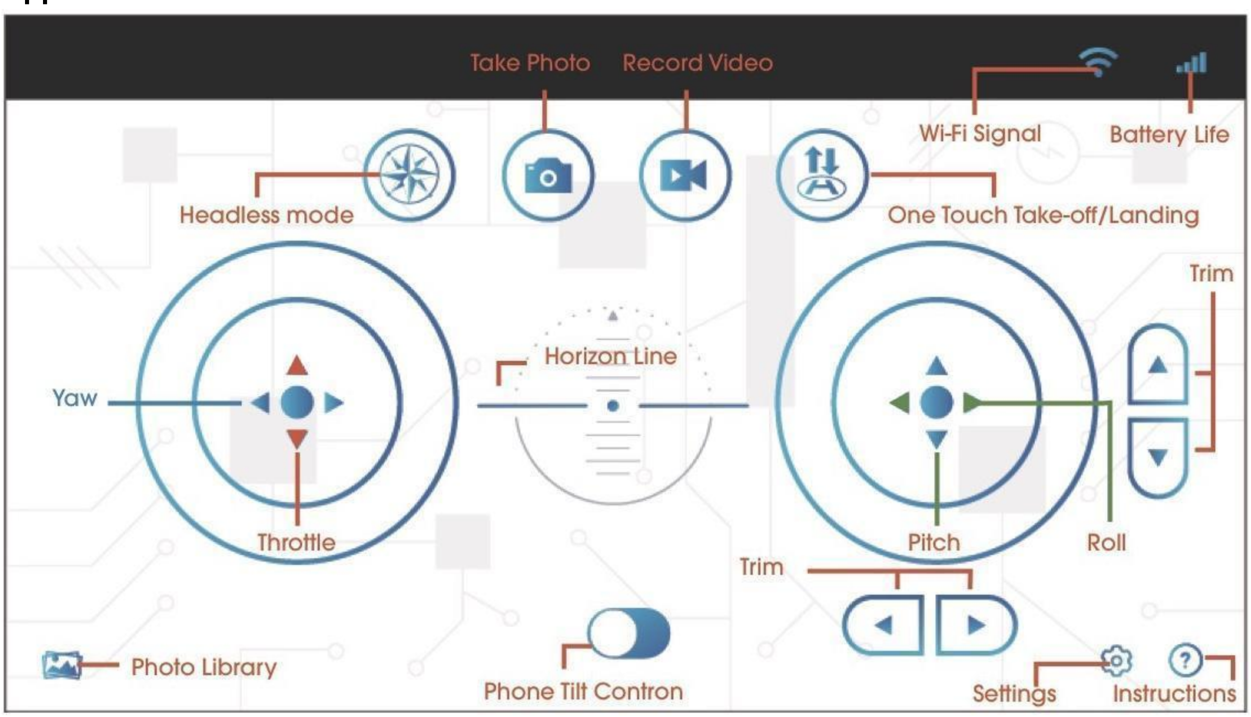
Drone Connection and Controls:

Connecting to the Drone

Before connecting to the drone, make sure the drone is built and the battery is installed in the drone hub. Install the 'CS Pilot' app in the iOS App Store or Android's Google Play Store. To turn on the drone, press and hold the black button underneath the drone until the RED LED is blinking.

Go to the phone's Wifi Settings and select the drone's Wifi Hotspot. Once connected, go to the 'CS Pilot' app. The RED LED should stop blinking when the 'CS Pilot app' is open and the drone is connected. If the RED LED keeps blinking, the battery may not be charged.

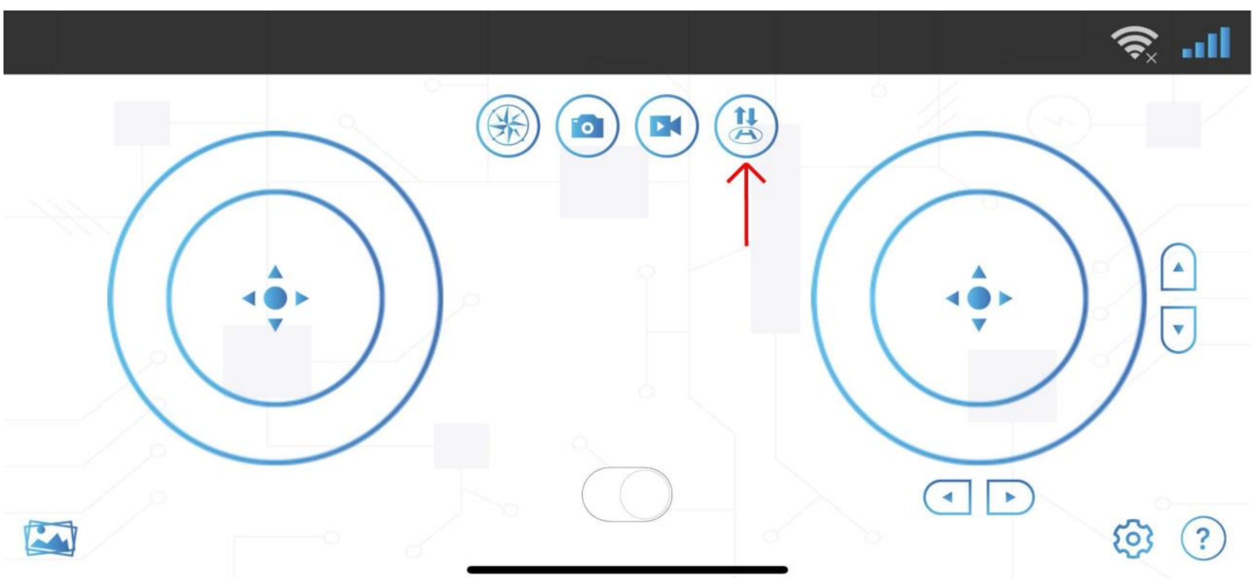
App Overview



Controlling the Drone

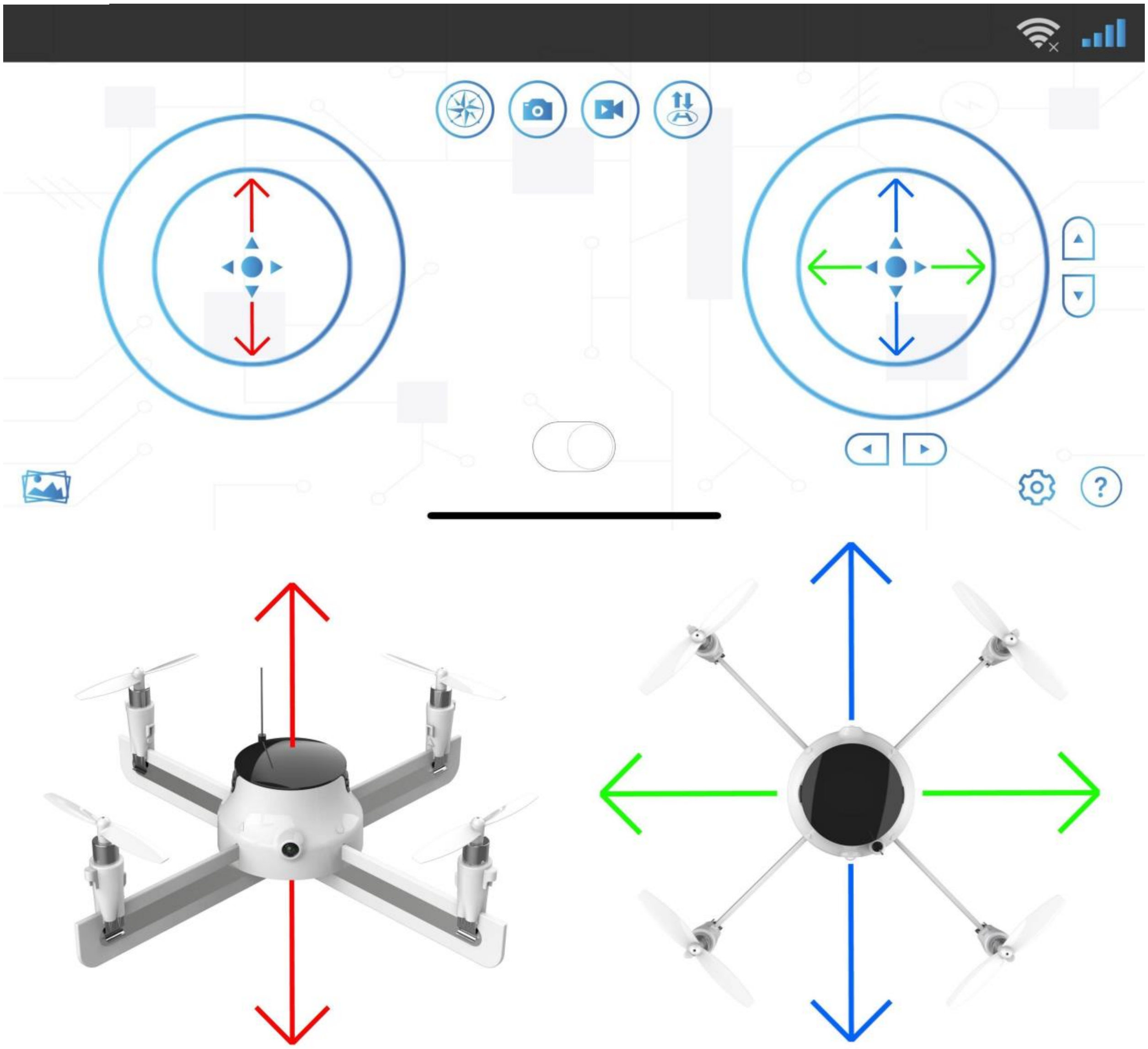
Place the drone in the fly zone with the RED LED facing the pilot. To turn on the drone, pull both joysticks to the bottom corners of the screen until the propellers begin to spin.

To lift off/land, press the takeoff/land icon which is the rightmost icon on the top center of the app.



To turn off the propellers, push both joysticks to the center of the screen.

The left joystick changes the yaw and altitude of the drone (up/down). The right joystick changes the pitch and roll (right, left, forward, backwards).



At the beginning of class, each group member needs to be randomly assigned a role assignment (engineer, pilot, project manager) to prevent any disputes within the group regarding who gets to fly first.

At this point, the cadets should have finished building the cardboard drone arms from Lesson 3. Have each group make their drone with the PCB or cardboard arms, depending on which day, and each group should have their flight log with them before heading outside for a test flight. Each cadet is responsible for their own battery.

To prevent any unauthorized drone flying in the classroom, the cadets must understand that turning on the drones in the middle of the classroom will result in their permit being revoked and will prevent them from flying for that lesson.

Pre-Flight Check Procedure

Before the flight test, the cadets should log the current conditions of the flying zone and the drone into the flight log. That includes the type of wing arms the drone is using, the weather conditions, and the length of the flight time.

Maneuver Lessons Day 1

Practice:

1. Turning on, taking off, landing, and then disarming the drone three times.
2. Moving the drone forward and backwards, left and right.
3. Flying around in a circle, free-flying the drone to get used to the controls.

Maneuver Lessons Day 2

1. Take off in the center of the fly zone then fly around the perimeter of the fly zone (from cone to cone) and land back at the center.
2. Fly in a circle while changing the altitude of the drone

Landing Procedure (End of Class/Lesson)

At the end of the lesson or class, each group should place the flight logs and other materials back into the portfolio. Have each group disassemble their drone for the next class period or lesson. The engineer of each group is in charge of collecting and charging the batteries at the designated charging station in the classroom.

Activity 1: Drone Flight Academy Day 1 (Outside)

Materials:

- Drone Permit
- Flight Log
- Constructed drone's PCB arms - **Day 1**
- Constructed drone's cardboard arms - **Day 2**
- Cones or indicating markers
- Timer/stopwatch
- Clipboard for flight log (optional)

Time:

30-45 min.

Description:

Cadets fly their drones with PCB/cardboard (Day 1/Day 2) arms after reviewing safety guidelines and the drone application in class.

Plan Ahead:

Designating a Fly Zone

For the most optimal flying conditions, find a flat, open field away from any cars, streets or obstacles. Using cones or indicating markers, place a cone at each corner of a 10x10 foot square. Make as many fly zones as there are groups and be sure to number them for each group. Be sure to keep the fly zones at a safe distance from any hazardous obstacles.

Avoid flying near any cars or a populated playground. The fly zones should be spaced out enough to prevent any rogue drones from crashing into other cadets.

Roles:

- Engineer – responsible for turning off the drone, which must be done before conducting any maintenance, fixing the drone and putting the drone back together, in case the pilot crashes their drone.
- Project Manager – responsible for safety. They advise the pilot if they are getting too close to anyone or if the group breaks any safety rules. They are also responsible for carrying the drone and necessary materials to the designated flying zone.
- Pilot - responsible for flying the drone and recording flight info into the flight log. They also complete a secondary safety check after being approved by the project manager and the pre-flight checklist.

Safety:

- Always keep a flying drone in sight. Don't lose track of the drone.
- Keep the drones off the ground when not in use to prevent from stepping on them.
- Always keep a clear flying zone.
    - Try to keep a 10 ft. radius clear of people and objects while flying the drone.

- Do not fly in adverse weather conditions such as in high winds or reduced visibility.
  - Your Circuit Scribe Drone weighs 3.3 oz., making it light enough for wind to blow them away. A strong enough gust of wind can even blow your drone right at you or your cadets.
- Do not touch the motors after the drone has been in flight, as it may be hot to the touch.
- Never leave the battery plugged in for extended periods of time or overnight.
- The engineer role must always turn off the drone before fixing or putting anything back together.

Step-by-step:

1. Assign starting roles for each group member.
2. Instruct the engineer to assemble their drone with the PCB arms. Instruct them to raise their hands when finished to check their work. Once their work has been checked, have them disassemble their drone.
3. Instruct the pilot to review the app use and the connecting instructions in their flight log.
4. Instruct the project manager to checkout their battery and prepare their flight log.
5. After 3-5 minutes, call an attention signal and have each role switch repeat until every student has completed each role.
6. Call an attention signal and review the safety guidelines again.
7. Go over the Drone Connection and Controls as a class.
   a.) Remind students that turning on the drone in the classroom will result in a penalty.
8. Practice the attention signal and continue outside to the designated flying zone.
9. Before having students split off in their groups to their flying zones, demonstrate the Pre-Flight Checklist and then the beginning practice maneuvers (i.e. takeoff/land, move around). Instruct students to change roles when their battery is drained.
10. Monitor students as they complete safety checks and their pre-flight checklist.
11. Monitor the groups and have them switch roles each time a battery dies.
12. At the end of the lesson, have the groups clean up their designated fly zones. Continue back to the classroom.
13. Instruct each group’s engineer to disassemble the drones and return them, the project manager to gather their group’s batteries and charge them at the designated charging station and the pilot to fill out any flight log information needed.

Discussion Questions: What was the most difficult part of flying the drone? How did you overcome that difficulty?

Quick Step-by-Step Overview of Lesson

Day 1

1. Assign roles for each group member.
2. Have the engineer assemble their drones with the **PCB** arms.
3. Go over safety again. More information can be found in the 'Safety' section.
4. Go over the Drone Connection and Controls section.
    a.) Remind students that turning on the drone in the classroom will result in a penalty.
5. Go over beginning practice maneuvers (i.e. takeoff/land, move around).
6. Make sure everyone meets the requirements in the checklist:
    a.) Students must have a permit to fly.
    b.) There must be designated fly zones set up outside; one for each group. More information on setting up a designated fly drone can be found in the 'Designated Fly Zone' section.
    c.) Students must fill in the Pre-Flight Checks in their flight logs before flying the drones.
7. Monitor the groups and have the roles switch each time a battery dies.
8. At the end of the lesson, clean up the designated fly zones.
9. Each group needs to disassemble the drones and the engineers need to gather their group's batteries and charge it at the designated charging station.

Day 2

1. Re-assign the roles for each group member.
2. Have the engineer assemble their drones with the **cardboard** arms.
3. Go over safety again. More information can be found in the 'Safety' section.
4. Make sure everyone meets the requirements in the checklist:
    a.) Students must have a permit to fly.
    b.) There must be designated fly zones set up outside; one for each group. More information on setting up a designated fly drone can be found in the 'Designated Fly Zone' section.
    c.) Students must fill in the Pre-Flight Checks in their flight logs before flying the drones.
5. Monitor the groups and have the roles switch each time a battery dies.
6. At the end of the lesson, clean up the designated fly zones.
7. Each group needs to disassemble the drones and the engineers need to gather their group's batteries and charge them at the designated charging station.

Lesson 5: Making Custom Wings

In this lesson, students will be able to get creative and design their own drone wings. One of the coolest features of the Circuit scribe drone is the ability to make custom wings out of cardboard. Students will be introduced to engineering drawings and will create an engineering drawing for the wings they design.

Key Concepts:

- Resistance
- Technical Drawings
- How to use a Multimeter
- Art and Design

Objectives:

- Cadets will create custom cardboard wings for their drone and make an engineering, or technical, drawing of them.
- Cadets will measure the resistance of their wings and calculate the current supplied to the motors.

Instructor Background: Grades 5 -12+

Supplemental Information:

Engineering Drawings - An engineering drawing is a type of technical drawing used to define the requirements for engineering products or components. It’s similar to a blueprint for architects. In general, an engineering drawing has an outline of the product or part, dimensions, dimension lines and arrows. An engineering drawing, also called a technical drawing, helps facilitate communication between engineers and manufacturers as the drawing clearly shows all parts and dimensions.

Activity 1: Making Cardboard Wings

Materials:

- Cardboard
- X-acto knife (optional)
- Scissors
- Pen/pencil
- Ruler
- Paper
- Silver ink pen

Time: 20-30 minutes

Description:
In this activity, each cadet will have the opportunity to design and construct a set of custom drone wings.

Plan Ahead:
Although there is a cardboard sheet for every drone kit, you should collect extra cardboard to use for making wings. Any corrugated cardboard will work as wings, as long as it is not bent.

Safety:
An x-acto knife is great for cutting out cardboard but can also be dangerous. Decide whether you feel that your students can safely use an x-acto knife in the classroom or not. If you decide your cadets can safely use x-acto knives, establish safety rules like only walk with a x-acto that has a lid on, cut away from yourself, and don't play with the knives.

Step-by-step:

1. Describe the activity and introduce technical drawings.
2. Have cadets sketch out their wings on the cardboard. They should make sure to include a small cut out on the top of one wing and on the bottom of the other wing. These small cutouts will interlock the wing. Students can look at the cardboard fill-in wings for an example.
3. In the cadets' portfolio, have each cadet create a technical drawing for their wings. They should use a ruler to find the dimensions of their wings including the height of the tallest part of the wing, the height at the shortest part of the wing, the width of the wings and any other important parts.
4. After finishing their technical drawing, instruct cadets to carefully use a x-acto knife or scissors to cut out each wing.

5. Cadets can now use the Circuit Scribe pen to fill in the wing where the traces should go. Each trace should be about ¼ inch wide. Remind cadets to fill in the traces on both sides of both wings.

Activity 2: Measuring Resistance and Calculating Current to Motors

Materials:

- Cardboard wings
- Multimeter
- Toaster oven
- Oven mitts
- Timer

Time: 15-20 minutes

Description: In this activity, students will measure the resistance of their wings, use heat to lower the resistance if needed, and calculate the current going to each motor using Ohm's law.

Plan Ahead: Heating Circuit Scribe ink makes other components in the ink evaporate and leaves behind the silver. This can make the ink more conductive. If your classroom doesn't have access to an oven, you may consider finding a toaster oven for your class to use for the day.

Safety: Toaster ovens become hot to the touch after being turned on. Have an aid or student helper be in charge of putting the wings in and out of the oven with safety mitts on.

Step-by-step:

1. Have students measure the resistance of each of their traces with the multimeter. They should measure all of the 8 traces, left and right on the front and left and right on the back for each wing.
2. Write down the measured resistance in their portfolio. If a trace has a resistance higher than 2 ohms, tell students to look for any blank or thin spots of ink and fill them in again.
3. If the resistance is still higher than 2 ohms, the wings can be heated up to decrease resistance. Have the cadet put on oven mitts and place their wings in the oven. Wings should be put in an oven on its lowest setting for 10-15 minutes.
4. Now pass out the Lesson 5 worksheet, a multimeter and a drone kit to each group, and have students calculate the current going to each of the motors.

Discussion Questions:

- Which do you think will fly better, the PCB wings or the wings you made?
- What strategy did you use to design your wings?

Lesson 6: Drone Flight Academy 2

In this lesson, cadets will learn about drone controls and how to connect to the drone with their mobile devices. Cadets will fly their drones outside, using the PCB and cardboard arms that they made in Lesson 5, and perform several test maneuvers. Cadets should take note of their flights in their flight logs.

Key Concepts:
- Digital literacy - learning new software
- Spatial perception and orientation
- Problem solving

Objectives:
- Cadets will complete flight maneuver checklist.
- Cadets will take flight log notes.
- Cadets will become familiar with the pre-flight check procedure.

Instructions:

Flying Safety Recap
Review these safety procedures to the students again.
- Always keep a flying drone in sight. Don’t lose track of the drone.
- Keep the drones off the ground when not in use (to prevent them from being stepped on).
- Always keep a clear flying zone.
  - Try to keep a 10 ft radius clear of people and objects while flying the drone
- Do not fly in adverse weather conditions, such as in high winds or reduced visibility.
  - Your Circuit Scribe Drone weighs 3.3 oz., making it light enough for wind to blow them away. A strong enough gust of wind can even blow your drone right at you or your cadets.
- Do not touch the motors after the drone has been in flight, as they may be hot to the touch.
- Never leave the battery plugged in for extended periods of time or overnight.
- The cadet in the “engineer” role must always turn off the drone before fixing or putting anything back together.

Group Member Roles
The cadets must have a Drone Learners Permit in order to fly. The Drone Permit proves that the student has went over and learned all the safety rules and mechanics of a drone from the

previous lessons. Each member will have a chance to become a pilot and fly the drone (if time allows it), so cadet must have their own battery. The pilot uses their battery for their respective test flights. The role of the engineer is to fix the drone and put it back together in case the pilot crashes their drone. The cadet with the “Engineer” role must turn off the drone before conducting any maintenance. The cadet with the “Project Manager” is in charge of safety; they must advise the pilot if they are getting too close to anyone or if the group breaks any safety rules.

Safety is the utmost priority for Circuit Scribe and it is the teacher’s job to enforce safety and revoke any permits for the day if any safety rules are violated.

The roles are switched each time the drone battery dies. From a full charge, the battery lasts for approximately 5 minutes of constant flight time, not including any crashes or repairs.

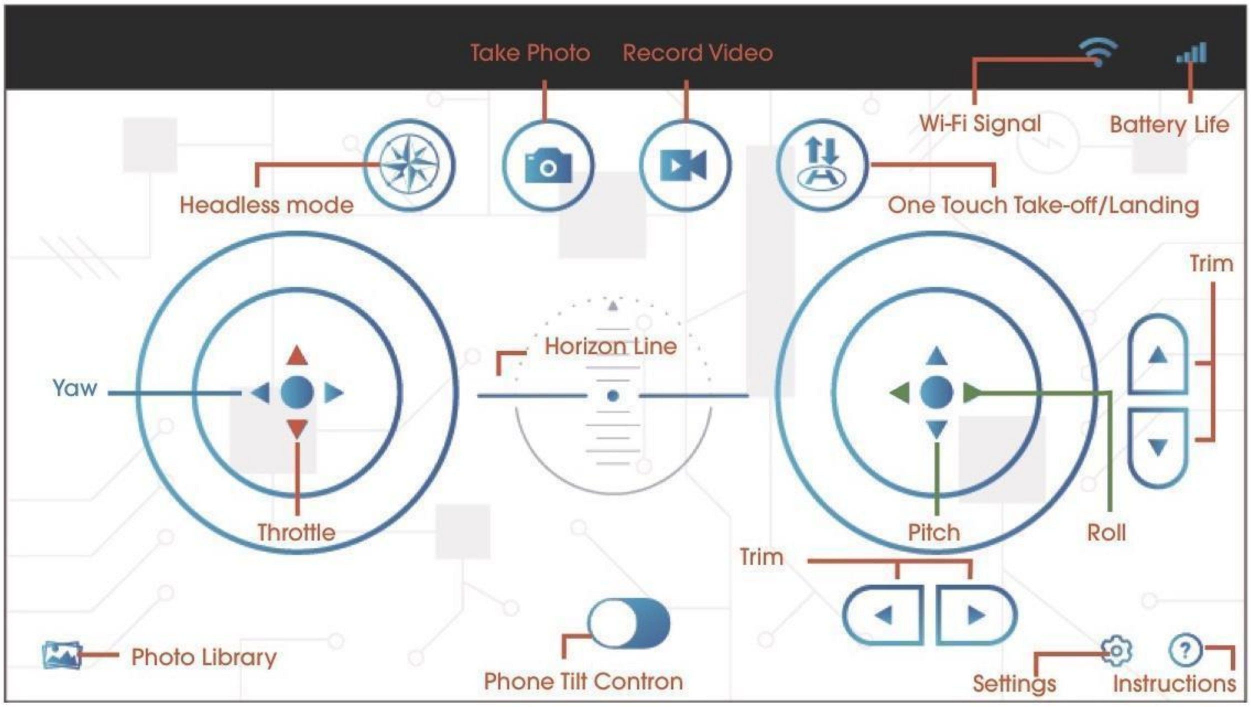
Drone Connection and Controls:

Connecting to the Drone

Before connecting to the drone, make sure the drone is built and the battery is installed in the drone hub. Install the ‘CS Pilot’ app in the iOS App Store or Android’s Google Play Store. To turn on the drone, press and hold the black button underneath the drone until the RED LED is blinking.

Go to the phone’s Wifi Settings and select the drone’s Wifi Hotspot. Once connected, go to the ‘CS Pilot’ app. The RED LED should stop blinking when the ‘CS Pilot app’ is open and the drone is connected. If the RED LED keeps blinking, the battery may not be charged.

App Overview



For more information over drone controls, refer to Lesson 4 and the Lesson 4 handout.

At the beginning of class, each group member should be assigned a role assignment (engineer, pilot, project manager) at random, to prevent any disputes within the group of who gets to go first.

The students should each have their own custom arms made from Lesson 5. Each group should have their flight log with them before heading outside for a test flight. Each cadet is responsible for their own battery. To prevent any unauthorized drone flying in the classroom, the cadets must understand that turning on the drones in the middle of the classroom will result in their permit being revoked and prevent them from flying for that lesson.

Pre-Flight Check Procedure

Before the flight test, the cadets should log the current conditions of the flying zone and the drone into the flight log. That includes the type of wing arms the drone is using, the weather conditions, and the length of the flight time.

Maneuver Lessons

1. Test the new drone arms by taking off and landing. Check if propellers are functioning correctly.

2. Moving the drone forward and backwards, left and right. Watch if the drone is leaning to one side.
3. Flying around in a circle, free-flying the drone to test the drone's robustness.

Landing Procedure (End of Class/Lesson)

At the end of the lesson or class, each group should place the flight logs and other materials back into the portfolio. Have each group disassemble their drone for the next class period or lesson. The engineer of each group is in charge of collecting and charging the batteries at the designated charging station in the classroom.

Activity 1: Drone Flight Academy Day 1 (Outside)

Materials:

- Drone Permit
- Flight Log
- Custom-made arms for Drone
- Cones or indicating markers
- Conductive ink pens
- Multimeter
- Timer/stopwatch
- Clipboard for flight log (optional)

Time:

30-45 min.

Description:

Cadets fly their drones with their custom-made arms after reviewing safety guidelines and the drone application in class.

Instructions:

Designating a Fly Zone

For the most optimal flying conditions, find a flat, open field away from any cars, streets or obstacles. Using cones or indicating markers, place a cone at each corner of a 10x10 foot square. Make as many fly zones as there are groups and be sure to number them for each group. Be sure to keep the fly zones at a safe distance from any hazardous obstacles.

Avoid flying near any cars or a populated playground. The fly zones should be spaced out enough to prevent any rogue drone from crashing into other cadets.

Roles:

- Engineer – responsible for turning off the drone, which must be done before conducting any maintenance, fixing the drone and putting the drone back together, in case the pilot crashes their drone.
- Project Manager – responsible for safety. They advise the pilot if they are getting too close to anyone or if the group breaks any safety rules. They are also responsible for carrying the drone and necessary materials to the designated flying zone.
- Pilot - responsible for flying the drone and recording flight info into the flight log. They also complete a secondary safety check after being approved by the project manager and the pre-flight checklist.

Safety:

- Always keep a flying drone in sight. Don't lose track of the drone.
- Keep the drones off the ground when not in use to prevent stepping on them.
- Always keep a clear flying zone.
  - Try to keep a 10 ft. radius clear of people and objects while flying the drone.
- Do not fly in adverse weather conditions such as in high winds or reduced visibility.
  - Your Circuit Scribe Drone weighs 3.3 oz., making it light enough for wind to blow them away. A strong enough gust of wind can even blow your drone right at you or your cadets.
- Do not touch the motors after the drone has been in flight as it may be hot to the touch
- Never leave the battery plugged in for extended periods of time or overnight
- The engineer role must always turn off the drone before fixing or putting anything back together.

Step-by-step:

1. Assign starting roles for each group member.
2. Instruct the **Pilot** to assemble their drone with their own custom-made arms.
3. Instruct the **Engineer** to check the Pilot's work when they are finished.
4. Instruct the **Project Manager** to checkout their battery and prepare their flight log.
5. Call an attention signal and review the safety guidelines again.
6. Go over the drone connection and controls as a class.
   a.) Remind students that turning on the drone in the classroom will result in a penalty.
7. Practice/remind the students of the attention signal and continue outside to the designated flying zone.
8. Before having students split off in their groups into their flying zones, demonstrate the Pre-Flight Checklist and then the beginning practice maneuvers (i.e. takeoff/land, move around).
9. Instruct students to change roles when their battery is drained.

10. Monitor students as they complete safety checks and their pre-flight checklist.
11. Monitor the groups and have the roles switch each time a battery dies.
12. At the end of the lesson, have the groups clean up their designated fly zones. Continue back to the classroom
13. Instruct each group's engineer to disassemble the drones and return them, the project manager to gather their group's batteries and charge it at the designated charging station, and the pilot to fill out any flight log information needed

Discussion Questions: How did the custom-made arms function? Was it any different from the PCB or cardboard arms? Did the custom arms work the first time you turned on the drone? If not, how did you fix the arms to make your drone work?

Quick Step-by-Step Overview of Lesson

Day 1

1. Assign roles for each group member.
2. Have the engineer assemble their drones with the custom arms.
3. Go over safety again. More information can be found in the 'Safety' section.
4. Go over the Drone Connection and Controls section.
    a.) Remind students that turning on the drone in the classroom will result in a penalty.
5. Go over beginning practice maneuvers (i.e. takeoff/land, move around).
6. Make sure everyone meets the requirements in the checklist:
    a.) Students must have a permit to fly.
    b.) There must be designated fly zones set up outside; one for each group. More information on setting up a designated fly drone can be found in the 'Designated Fly Zone' section.
    c.) Students must fill in the Pre-Flight Checks in their flight logs before flying the drones.
7. Monitor the groups and have the roles switch each time a battery dies.
8. At the end of the lesson, clean up the designated fly zones.
9. Each group needs to disassemble the drones, and the engineers need to gather their group's batteries and charge it at the designated charging station.

Lesson 7: Programming Your Drone 1

Key Concepts:

- Logical Thinking
- Programming.

Objectives:

- Cadets will learn the basics of programming a Drone.

Instructor Background: Grades 5 -12+

Time: 1 hour

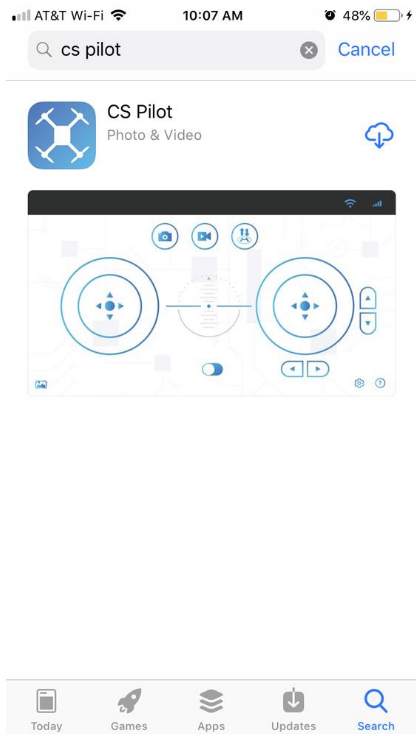
Supplies:

1. Circuit Scribe Drone Builder Kit or Drone Builder Classroom Kit
2. iOS or Android-enabled device
3. CS Pilot App

Instructions:

Where to Start

Open the iOS App Store or Android Play Store and search for the "**CS Pilot App"**. If you already have the app, then you can move on to the next step. If you have an older version of the app, we suggest you *delete it* and download it again.

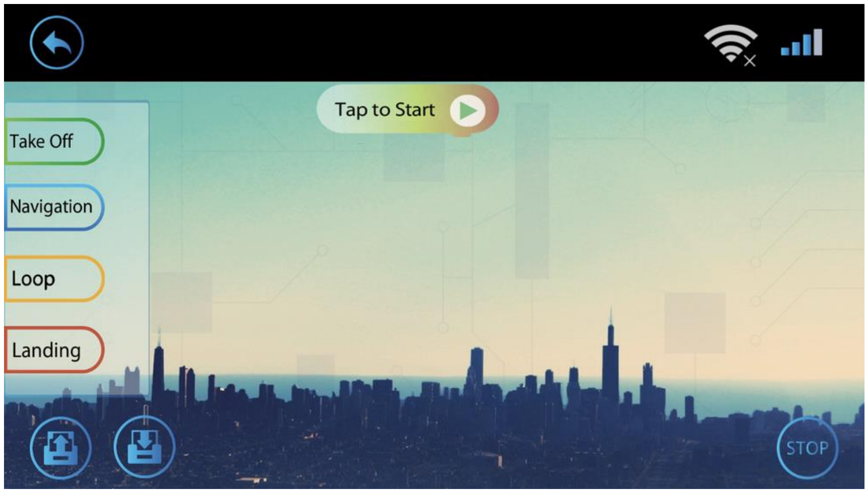


Using the App

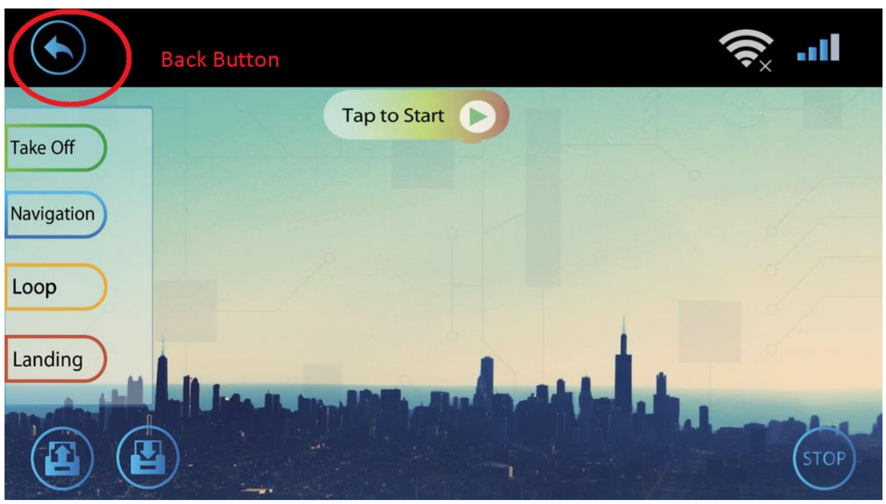
When you open the app, there are two modes: "pilot" and "programming". The "pilot" mode is how you manually fly the Drone. That is what we used for the previous Drone lessons. The "program" mode lets you control the Drone using instruction blocks.

Programming Mode

The programming canvas will open and have different buttons you can interact with.

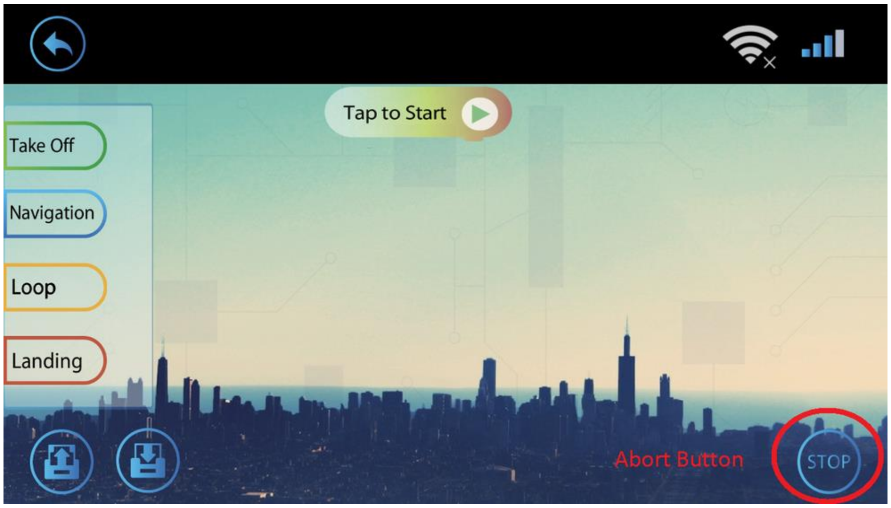


Back Button
Start from the top right. The button circled in red will take you back to the main menu where you can select the “Piloting” or “Programming” mode.



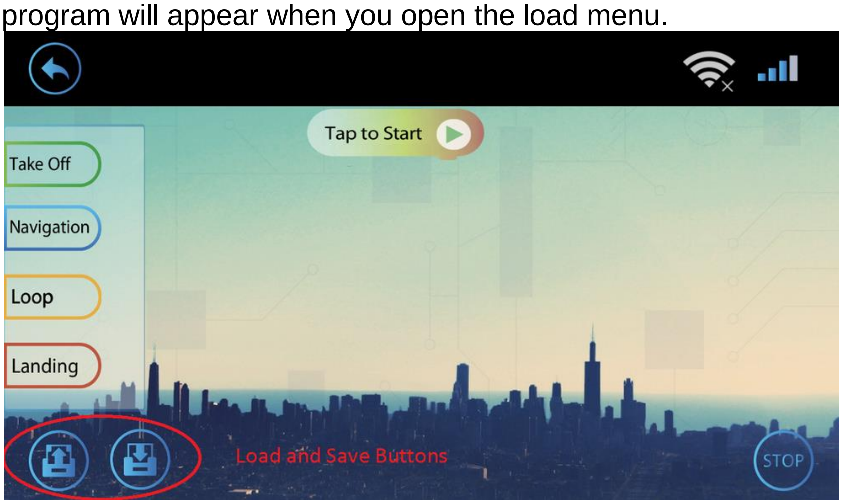
The icons on the top left are the signal strength and battery life indicators. These will show you the strength of the Wi-Fi signal that you are getting from the Drone and the amount of battery life left.

Abort Button
The button in the bottom right of the screen is the Abort button. This button can only be pressed once a program has started. It will turn red while a program is active and, if pressed, will cause the Drone to halt its program and land immediately.



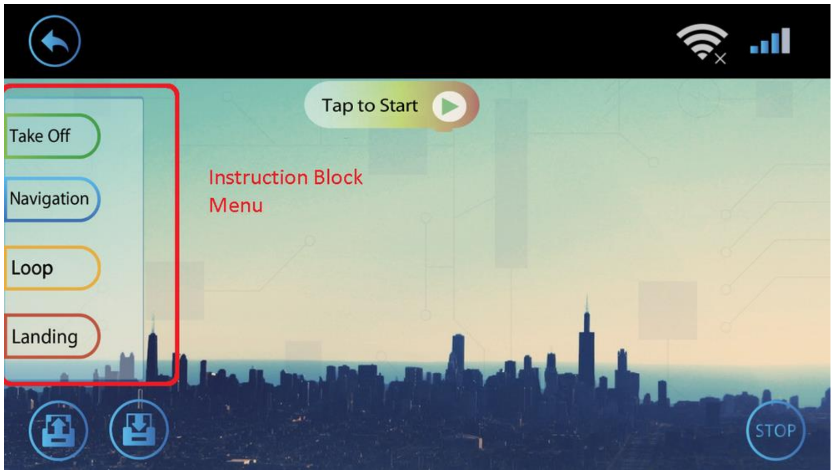
Saving and Loading

The buttons on the bottom right are for saving and loading programs that you have built. The button with the down arrow allows you to **Save** while the button with the up arrow lets you **Load** programs that have been saved. You can name your programs whatever you like. The name and date of the program will appear when you open the load menu.



Instruction Blocks

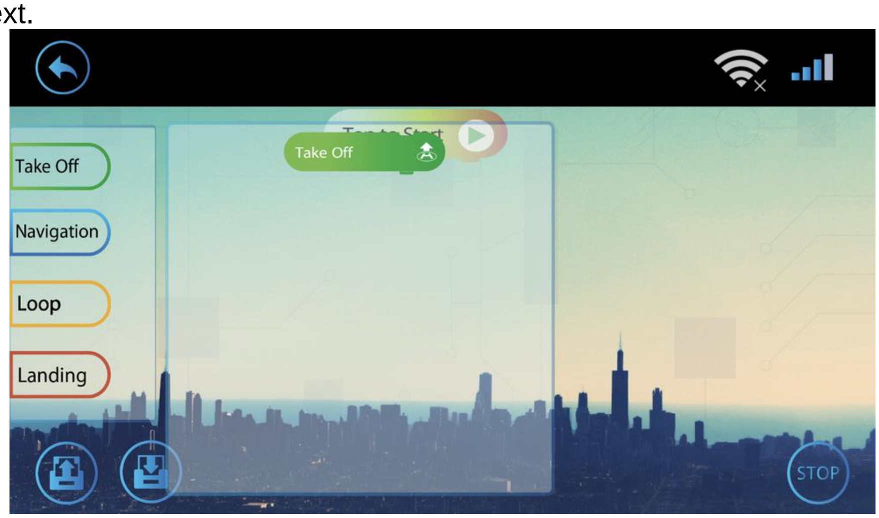
The buttons on the right are the instruction blocks that we use to give the drones commands. There are four categories of instructions: Takeoff, Navigation, Loop and Landing. Once you tap on a category, it will open and let you drag instruction blocks into the program. Navigation and Loop will be covered in Lesson 2 and 3 (Lesson 7, 8 and 9 of the Drone Curriculum Guide).



INSTRUCTOR TIP:
Just tapping on an instruction block won't add it to the program you must tap and drag the block to get it.

Takeoff

Drag the Takeoff instruction block to the “Tap to Start” Button. The Takeoff block will snap onto the start button. The Takeoff block must always be the first block after the “Tap to Start” Button. If you hit “Tap to Start”, you'll notice that the program won't work. It needs one more block that we will add next.

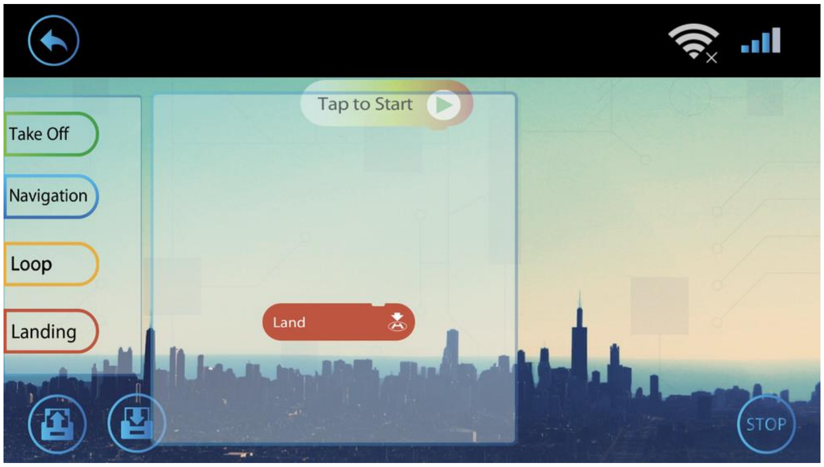


INSTRUCTOR TIP:
All programs must start with Takeoff.

Landing Block

The Landing window lets you add the "Land" block. Drag the Land block to just under the Takeoff block and it will snap in place. The Land block must always be the last block, or the program won't start.

Congratulations! You've created your first program.



INSTRUCTOR TIP:
Every set of instructions that you give the Drone must start with Takeoff and end with Land.

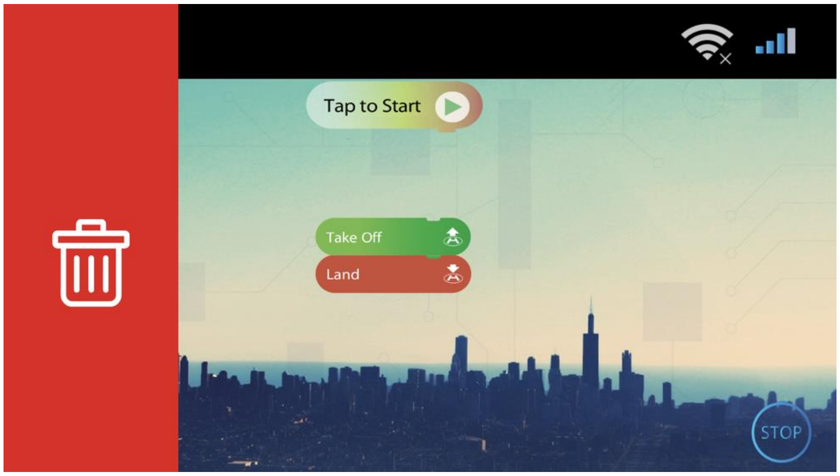
First Flight

Place your Drone in a clear area with at least a 5 foot radius of clear space around it. Once the Drone is on and connected to your phone, hit the Tap to Start button. The Drone will take off to a few feet off of the ground and hover for a second before landing .

INSTRUCTOR TIP:
Ensure that the Drone hub is flat. The sensors inside the Drone will try to automatically level out the Drone, if it is crooked or tilted.

Deleting Instruction Blocks

Whenever you drag an instruction block around on the screen, a red bar with a picture of a trash can on it will appear on the left side of the screen. If you drag instruction blocks over to the trash can, they will be deleted.



INSTRUCTOR TIP:
You cannot delete the Tap to Start Button since it is where the instruction blocks have to start.

Class Discussion
Offer the cadets a question and answer session after the activity. Once all the cadets' questions are answered, begin to review the discussions with the whole class.

Lesson 8: Drone Programming 2 - Navigation

Key Concepts:

- Drone Programming
- Navigation

Objectives:

- Cadets will learn to program and autonomously navigate a drone.

Instructor Background: Grades 5-12+

Time: 1 hour

Supplies:

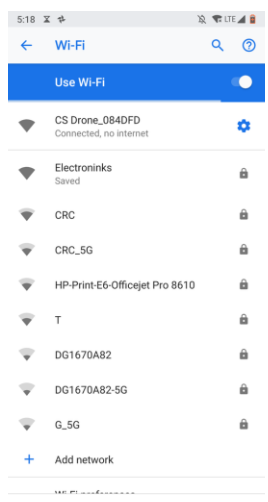
1. Circuit Scribe Drone Builder Kit
2. iOS or Android-enabled Device
3. CS Pilot App

Instructions:

Connect your Drone to your Phone

Power your Drone with the button on the bottom. Make sure the Drone's battery is fully charged.

Pull up your device's Wi-Fi settings. Connect to the "CS Drone" Wi-Fi network that your powered Drone is using. When your Wi-Fi app says you are connected, switch out of the settings and open the CS Pilot App.



INSTRUCTOR TIP:

If you are having trouble connecting to your Drone try the following troubleshooting steps:

Try these steps if your Drone's Wi-Fi is not showing up:

- Make sure your Drone's battery is fully charged and plugged in correctly (the charger will have a lit red LED when the Drone battery is charging. It will turn off when the battery is fully charged ~20m).
- Make sure the Drone is powered correctly (the red light will flash).
- Turn off auto-connect in your Wi-Fi preferences.
- Close the CS Pilot app.
- Turn Wi-Fi off and back on.
- If your Wi-Fi hasn't shown up, try power cycling the Drone (turn off, unplug the battery, wait 15 seconds, plug it back in and turn the battery back on).
- Open the CS Pilot app.

Launch the Pilot App and select "Program Mode"

Once you are connected over Wi-Fi, launch the app and select "Program Mode", the red LED on the Drone should flash rapidly and then turn solid. Now your Drone is connected and ready to be programmed!

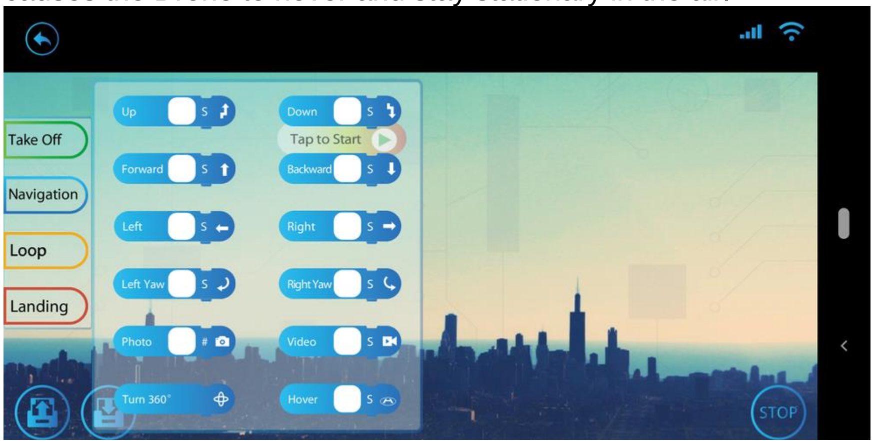
INSTRUCTOR TIP:
If your Drone disconnects during programming (i.e. your Drone's LED is flashing red, but your Wi-Fi on your device says it is still connected), try switching to "Pilot" mode. Once the LED stops flashing red and turns solid, you are connected and can switch back to programming mode.

Explore the Navigation Window

By using the building blocks in the navigation menu, you can program the Drone to autonomously navigate! Programs are limited to 30 seconds of flight time. Navigation blocks are very simple to use.

- Up/Down/Forward/Backward/Left/Right: moves the Drone in the corresponding direction for however many seconds are input. 1 second/ ~60cm.
- Left Yaw/Right Yaw: turns the Drone for however many seconds are input. 1 second/ ~90°.
- Photo: takes a specified number of photos using the Drone's forward facing camera and save them to the app's photo roll.
- Video: takes a video for a specified number of seconds using the Drone's forward-facing camera and save them to the apps photo roll.

- Turn: turns the Drone a complete 360°. 1 second/ ~360°.
- Hover: causes the Drone to hover and stay stationary in the air.



Write your First Autonomous Program

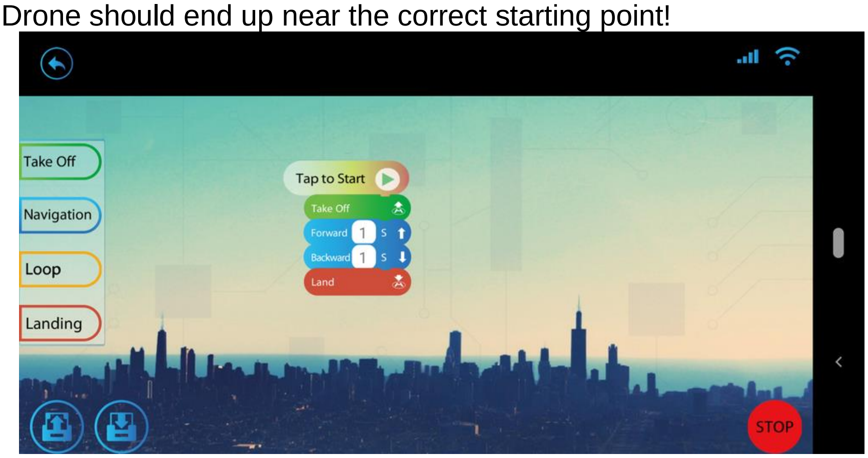
Now that we understand what each navigation command does, let's write our first simple autonomous Drone program!

1. First, open the "Take Off" menu and drag a Take Off block onto the screen.
2. Next, open the "Navigation" menu and drag a forward and backward block onto the screen.
3. Finally, open the "Landing" menu and drag a Land block on screen.

Now connect your blocks.

1. First, we will connect the "Take Off" block to the "Tap to Start" block.
2. Then, we will connect the "Forward" and the "Backward" blocks.
3. Finally, the "Land" block.

Once all your blocks are connected change the inputs for the "Forward" and "Backward" blocks to 1 second each. This code will cause your Drone to fly forward ~60 cm and then fly backwards ~60 cm. Your Drone should end up near the correct starting point!



INSTRUCTOR TIP:
Be sure and review the instructor lesson about setting up a safe classroom flying experience before allowing students to fly the Drone in the classroom.

Box Challenge!

Now that you have gotten acquainted with programming your Drone to autonomously navigate, let's try and complete a challenge! The challenge is simple, have your Drone fly in a box pattern. The Drone should remain in your class' flying area and should end up roughly where you began. There are multiple ways to complete the challenge; can you code more than one?

Class Discussion

Offer the cadets a question and answer session after the activities. Once all of the cadets' questions are answered, begin to review the discussions as a whole class.

Lesson 9: Drone Programming 3 - Loops

.

Key Concepts:

- Logical Thinking
- Programming Loops

Objectives:

- Students learn how to shrink their Circuit Scribe Drone programs with the Loop block!

Instructor Background: Grades 5 -12+

Time: 1 hour

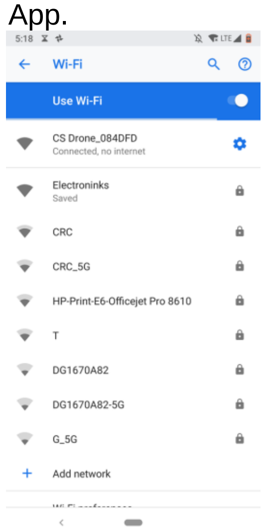
Supplies:

1. Circuit Scribe Drone Builder Kit or Drone Builder Classroom Kit
2. iOS or Android-enabled device.
3. CS Pilot App

Instructions:

Connect your Drone to your Phone

- Power your Drone with the button on the bottom. Make sure the Drone's battery is fully charged.
- Pull up your device's Wi-Fi settings. Connect to the "CS Drone" Wi-Fi network that your powered Drone is using. When your Wi-Fi app says you are connected, switch out of the settings and open the CS Pilot App.

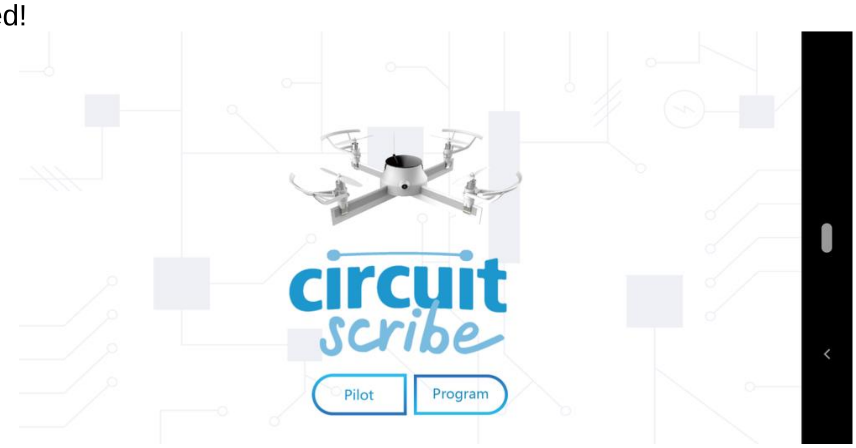


INSTRUCTOR TIP:
Try these steps if your Drone's Wi-Fi is not showing up:

- Make sure your Drone's battery is fully charged and plugged in correctly (the charger will have a lit red LED when the Drone battery is charging. It will turn off when the battery is fully charged ~20m).
- Make sure the Drone is powered correctly (the red light will flash).
- Turn off auto-connect in your Wi-Fi preferences.
- Close the CS Pilot app.
- Turn Wi-Fi off and back on.
  If your Wi-Fi hasn't shown up, try power cycling the Drone (turn off, unplug the battery, wait 15 seconds, plug it back in and turn the battery back on).
- Open the CS Pilot app.

Launch the Pilot App and select "Program Mode"

Once you are connected over Wi-Fi, launch the app and select "Program Mode”, the red LED on the Drone should flash rapidly and then turn solid. Now your Drone is connected and ready to be programmed!



INSTRUCTOR TIP:
If your Drone disconnects during programming (i.e. your Drone's LED is flashing red, but your Wi-Fi on your device says it is still connected), try switching to "Pilot" mode. Once the LED stops flashing red and turns solid, you are connected and can switch back to programming mode.

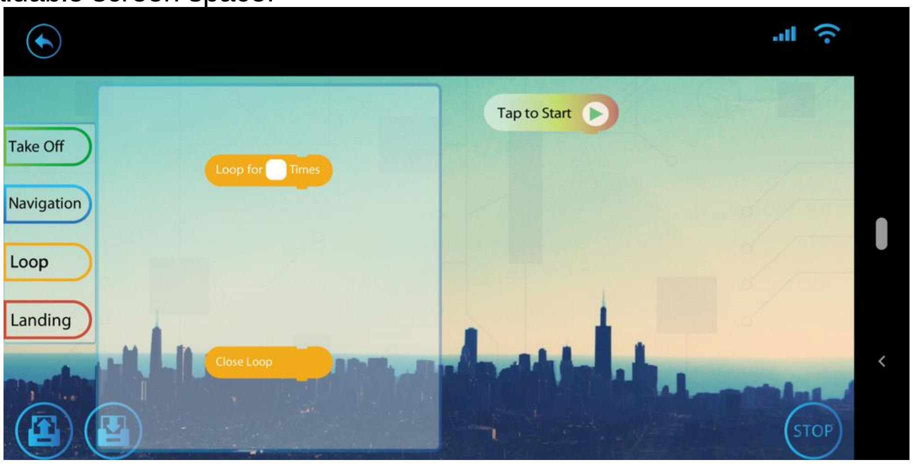
Explore the Loop Menu

The loop menu has two coding blocks in it: the Loop block and the Loop Close block.

- The Loop block has an input field where you can write a number from 1 to 99, which specifies how many times the code inside the loop will run. The Close loop block specifies the end of the code that is run in the loop.

Using the blocks is easy: drop the Loop block into your program anywhere below the Take Off block and before the Land block and add the code blocks you would like to run multiple times afterwards. Finally, use the Close Loop block to specify that the code you want to loop over is done.

When the Drone runs your code, it will run the code inside the loop as many times as you specify in the Loop block input field! This makes long repetitive code easier to read and conserves valuable screen space!

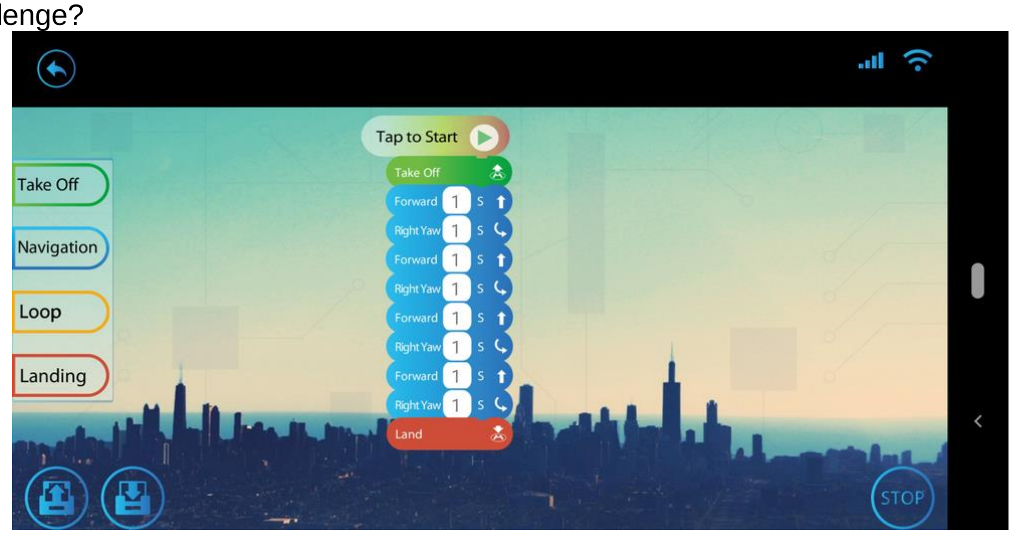


Write your First Loop Program

Now that you understand loops and how to use them with your CS Drone, let's write our first loop program! In the program we would like to solve the box challenge put forth in the last lesson, but by using loops.

If you remember from the Box Challenge, you were to write a program to autonomously fly in a box pattern. There are many different ways to complete the challenge, in this step we are going to explore one such way. By using the power of loops, we are going to shrink a 10-block program into a 6-block program, which means less dragging and more blocks that can fit on your screen.

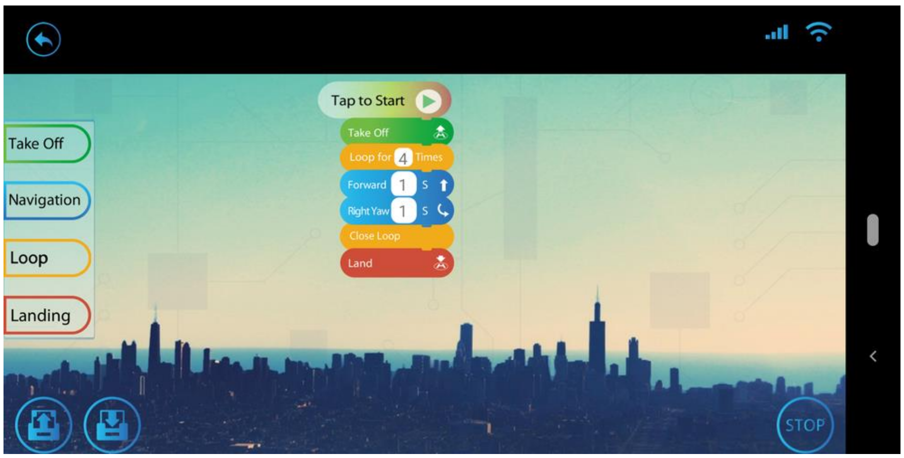
The program is fairly straight forward, the Drone takes off, flies forward for 1 second, turns right for 1 second (~90°) and repeats these steps four times before landing. The Drone flies around the perimeter of an invisible box in the same way that you would walk around the box, walking forward first, turning once you reached a corner and then repeating for all other sides of the box! Can you think of another program you could you write, using the loop blocks, to complete the box challenge?



Loop Challenge

Try to write the challenge programs below using the loop blocks to simplify them!

- BOX COUNTERCLOCKWISE - Move in a box formation counterclockwise using loops.
- ROCK AND ROLL- Back and forth 4 times and then a 360° spin.
- SURVEILLANCE - Complete the box challenge, but take a photo at every corner of the box.
- HOVER DRONE - Move back and forth with hover commands after each navigation command 5 times.
- MANUAL 1080 - Turn 3 full rotations without using the Turn command block.



Class Discussion

Offer the cadets a question and answer session after the activities. Once all of the cadets' questions are answered, begin to review the discussions as a whole class.

Lesson 10: Drone Mastery

Key Concepts:
- Drone Programming
- Navigation
- Spatial Perception and Orientation
- Problem Solving

Objectives:
- Students reinforce the standards learned in the previous lessons through activities

Instructor Background: Grades 5 – 12+

Time: 1 – 2 hours

Supplies:
1. Circuit Scribe Drone Builder Kit
2. Cardboard arms from lesson 3
3. iOS or Android-enabled Device
4. CS Pilot App
5. Extra Cardboard
6. Materials to make a drone course (cones, hula-hoop, table, etc.)

Roles:
- Engineer – responsible for turning off the drone, which must be done before conducting any maintenance, fixing the drone and putting the drone back together, in case the pilot crashes their drone.
- Project Manager – responsible for safety. They advise the pilot if they are getting too close to anyone or if the group breaks any safety rules. They are also responsible for carrying the drone and necessary materials to the designated flying zone.
- Pilot - responsible for flying the drone and recording flight info into the flight log. They also complete a secondary safety check after being approved by the project manager and the pre-flight checklist.

Safety and FAA Guidelines:
Review these safety procedures to the students again.
- Always keep a flying drone in sight. Don't lose track of the drone.
- Keep the drones off the ground when not in use (to prevent them from being stepped on).
- Always keep a clear flying zone.
  - Try to keep a 10 ft radius clear of people and objects while flying the drone
- Do not fly in adverse weather conditions, such as in high winds or reduced visibility.

    - Your Circuit Scribe Drone weighs 3.3 oz., making it light enough for wind to blow them away. A strong enough gust of wind can even blow your drone right at you or your cadets.
- Do not touch the motors after the drone has been in flight, as they may be hot to the touch.
- Never leave the battery plugged in for extended periods of time or overnight.
- The cadet in the “engineer” role must always turn off the drone before fixing or putting anything back together.

The Federal Aviation Administration requires the following:

- Fly your drone at or below 400 feet when in uncontrolled or "Class G" airspace. (Your Circuit Scribe Drone flies up to 150 ft. in the air, so no need to worry about this one!)
- Do NOT fly in controlled airspace (around and above many airports).
- Never fly near other aircraft, especially near airports.
- Never fly over groups of people, public events, or stadiums full of people.
- Never fly near emergencies, such as any type of accident response, law enforcement activities, firefighting or hurricane recovery efforts.
- Never fly under the influence of drugs or alcohol.
- Do not fly near or over sensitive infrastructure or property, such as power stations, water treatment facilities, correctional facilities, heavily traveled roadways, government facilities, etc.
- Do not intentionally fly over unprotected persons or moving vehicles.
- Check and follow all local laws and ordinances before flying over private property.

Designating a Fly Zone:

For the most optimal flying conditions, find a flat, open field away from any cars, streets or obstacles. Using cones or indicating markers, place a cone at each corner of a 20x20 foot square. Make as many fly zones as there are groups and be sure to number them for each group. Be sure to keep the fly zones at a safe distance from any hazardous obstacles.

Avoid flying near any cars or a populated playground. The fly zones should be spaced out enough to prevent any rogue drone from crashing into other cadets.

Activity 1: Drone Safety Review

Time: 10 min.

Description: Cadets review the drone safety procedures with a few questions in class.

Step-By-Step:

1. Pass out a worksheet with three to five questions on it/ask students three to five questions orally (true or false + explanation):
    a. Possible worksheet questions can be:
        i. You can fly your drone in adverse weather conditions or conditions with reduced visibility. (Answer: False, drones should only be flown in clear weather conditions.)
        ii. You should not touch the drone's motors immediately after it has been in flight. (Answer: True, the drone's motors will be hot and shouldn't be touched.)
        iii. The pilot disassembles the drone. (Answer: False, the engineer disassembles the drone.)
        iv. You should fly over private property at any time. (Answer: False, you should check the local laws before attempting to fly over private property.)
        v. You should keep your drone at or below 400 feet in the air at all times. (Answer: True, you should always keep your drone under 400 feet.)
        vi. You should remove the batteries from the drone if you are leaving it overnight. (Answer: True, never leave the batteries in the drone overnight.)
        vii. You should not fly under the influence of drugs or alcohol. (Answer: True, always fly with full awareness.)
        viii. You should fly over moving vehicles. (Answer: False, it is dangerous for both your drone and a driver to fly near a moving vehicle.)
2. According to how the students do, review the above safety rules.

Activity 2: Drone Programming Obstacle Course

Materials:

- Drone
  - PCB Arms
  - Cardboard Arms
- Timer/Stopwatch
- Drone Permit
- Cones

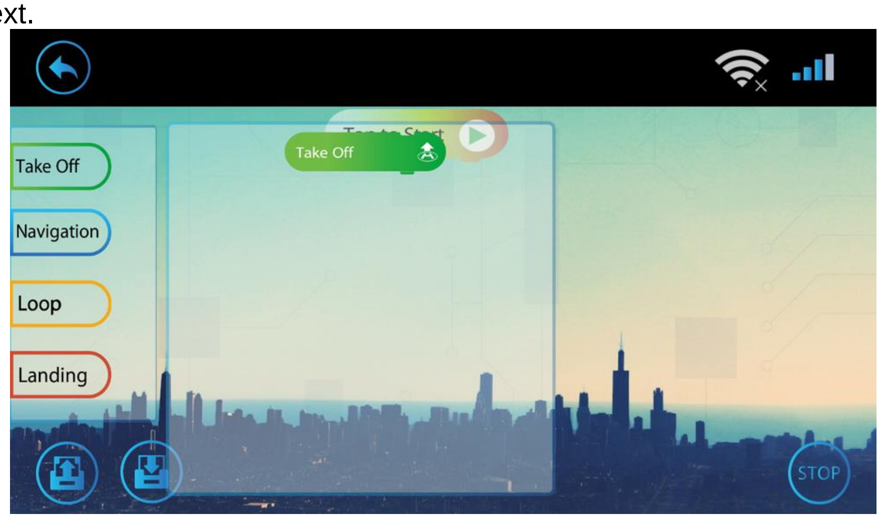
Time: 1 hour

Description: Cadets will program their drone in order to navigate certain obstacles.

Guide:

Takeoff

Drag the Takeoff instruction block to the “Tap to Start” Button. The Takeoff block will snap onto the start button. The Takeoff block must always be the first block after the “Tap to Start” Button. If you hit “Tap to Start”, you'll notice that the program won't work. It needs one more block that we will add next.



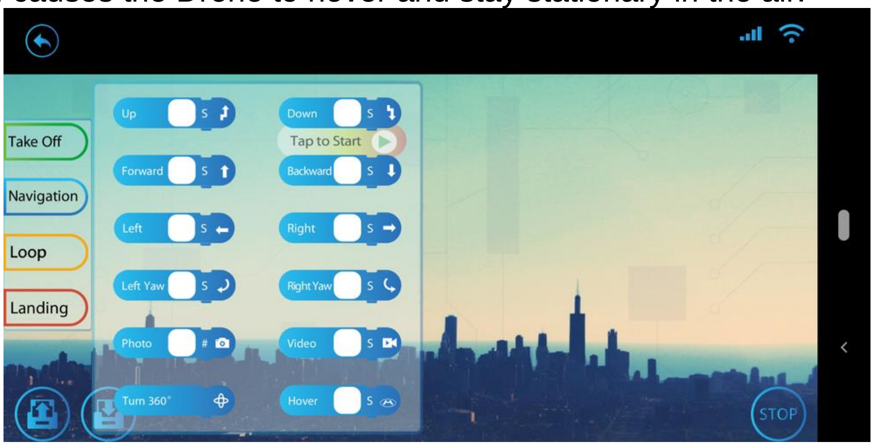
All programs must begin with the takeoff block.

Navigation

By using the building blocks in the navigation menu, you can program the Drone to autonomously navigate! Programs are limited to 30 seconds of flight time. Navigation blocks are very simple to use.

- Up/Down/Forward/Backward/Left/Right: moves the Drone in the corresponding direction for however many seconds are input. 1 second/ ~60cm.
- Left Yaw/Right Yaw: turns the Drone for however many seconds are input. 1 second/ ~90°.

- Photo: takes a specified number of photos using the Drone's forward-facing camera and save them to the app's photo roll.
- Video: takes a video for a specified number of seconds using the Drone's forward-facing camera and save them to the apps photo roll.
- Turn: turns the Drone a complete 360°. 1 second/ ~360°.
- Hover: causes the Drone to hover and stay stationary in the air.



Loops

The Loop menu has two coding blocks in it: The Loop block and the Loop Close block.

- The Loop block has an input field where you can write a number from 1 to 99, which specifies how many times the code inside the loop will run. The Close loop block specifies the end of the code that is run in the loop.

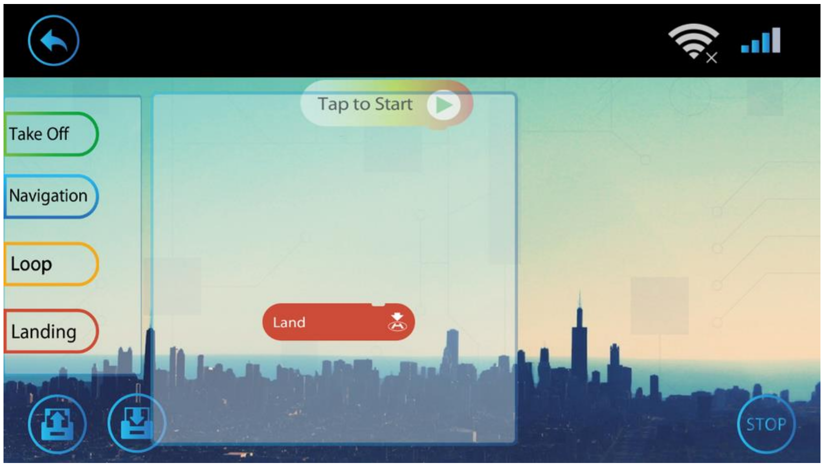
Using the blocks is easy: drop the Loop block into your program anywhere below the Take Off block and before the Land block and add the code blocks you would like to run multiple times afterwards. Finally, use the Close Loop block to specify that the code you want to loop over is done.

When the Drone runs your code, it will run the code inside the loop as many times as you specify in the Loop block input field!

Landing Block

The Landing window lets you add the "Land" block. Drag the Land block to just under the Takeoff block and it will snap in place. The Land block must always be the last block, or the program won't start.

Congratulations! You've created your first program.



All programs end with the land block.

Step-by-Step:

1. Go over practice maneuvers with the class to get them re-acquainted with the programs (take off/navigation/loops/land).
2. Afterwards, create groups, assigning roles for each group member. Allow the cadet with the Pilot role, in each group, to study the obstacle course and report to their team with ideas for programs.
    a. Students can decide whether to use the PCB arms or the cardboard arms – each come with strengths and weaknesses. Have the Engineer disassemble and reassemble the drone.
3. Give the teams time (15-20 minutes) to design a program that will get them through or around the obstacles in the drone's path.
4. Use the attention signal and bring the students to the obstacle course outside.
5. Have the Pilots use the program and attempt to clear the obstacle course. If they can't clear the course, give them the opportunity to bring their drone back to their team to make edits.
6. If a battery dies or a Pilot clears the obstacle course, have the cadets switch roles.
7. Before the next cadet that takes the Pilot role begins, give the cadets an opportunity to edit their code to make it better.
8. After each student has piloted the drone, instruct each group's engineer to disassemble the drones and the project manager to gather the drone's batteries to charge them.

Scoring Rubric:

- Cadets that clear the obstacle course gain 10 points for each member of a group that clears.
- The group that clear the obstacle course the fastest gains 10 points.

Class Discussion:

Have the most successful teams explain their strategies. Offer the cadets a chance to ask questions. Once the cadets' questions are answered, begin to review the discussions as a whole class.

Activity 3: Drone Race!

Materials:
- Drone
  - PCB Arms
  - Cardboard Arms
- Timer/Stopwatch
- Drone Permit
- Materials for obstacle course (cones, hula-hoop, table, etc.)

Time: 30 – 60 mins.

Description: Groups of cadets will compete to navigate around obstacles in a race.

Step-By-Step:
1. Create groups, assigning roles for each group member. Allow the cadet with the Pilot role, in each group, to study the obstacle course and report to their team.
   a. Students can decide whether to use the PCB arms or the cardboard arms – each come with strengths and weaknesses. Have the Engineer disassemble and reassemble the drone.
2. Have the Pilots attempt to clear the obstacle course. If they can't clear the course, give them the opportunity to bring their drone back to their team to create a new strategy or let the project manager ask the instructor questions.
3. If a battery dies or a Pilot clears the obstacle course, have the cadets switch roles.
4. After each student has piloted the drone, instruct each group's engineer to disassemble the drones and the project manager to gather the drone's batteries to charge them.

Scoring Rubric:
- Cadets that clear the obstacle course gain 10 points for each member of a group that clears.
- The group that clear the obstacle course the fastest gains 10 points.

Class Discussion:
Have the most successful teams explain their strategies. Offer the cadets a chance to ask questions. Once the cadets' questions are answered, begin to review the discussions as a whole class.