



# UAS Engines and Fuel



Session Time: Two, 50-minute sessions

## DESIRED RESULTS

### ESSENTIAL UNDERSTANDINGS

Innovations in aviation are driven by the desire to make aircraft safer, more capable, and more efficient. (EU2)

A deep understanding of how an aircraft operates enables a pilot to fly the aircraft to its maximum capabilities in both normal and abnormal situations. (EU5)

### ESSENTIAL QUESTIONS

1. What makes a drone fly?
2. How are drone propulsion systems similar to and different from those of manned aircraft?

### LEARNING GOALS

#### Students Will Know

- The types of propulsion systems commonly used in small unmanned aircraft systems (sUAS)
- The types of power storage and fuel used in sUAS
- The advantages and disadvantages of each

#### Students Will Be Able To

- *Explain* the differences between brushed and brushless electric motors. (DOK-L2)
- *Create* a simple working model of a direct current electric motor. (DOK-L4)
- *Assess* the best powerplant and battery combination for different types of drones flying specific missions. (DOK-L3)

## ASSESSMENT EVIDENCE

#### Warm-up

Students watch a brief video about the earliest batteries and electric motors and then discuss how these technologies have evolved and become essential to the operation of many modern machines, including drones.

#### Formative Assessment

Students will answer a series of questions to demonstrate their understanding of the basic components of electric motors and the differences between brushed and brushless motors. They will then be asked to make an argument for the type of motor they would choose if they were designing a drone.

#### Summative Assessment

Students will pretend to work for a drone design company that develops custom drones for clients. The company has received orders for a variety of drone projects and it's up to each student to determine what type of motor and fuel system to use.

## LESSON PREPARATION

### MATERIALS/RESOURCES

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- [UAS Engines and Fuel Presentation](#)
- [UAS Engines and Fuel Student Activity 1](#)
- [UAS Engines and Fuel Student Activity 2](#)
- [UAS Engines and Fuel Student Activity 3](#)
- [UAS Engines and Fuel Teacher Notes 1](#)
- [UAS Engines and Fuel Teacher Notes 2](#)
- [UAS Engines and Fuel Teacher Notes 3](#)

#### Build a DC Motor Activity (Per Group)

- Sandpaper
- Magnet
- Two (2) alligator clip electrical connections
- Wire cutters
- Drill with a 1/16 drill bit
- Two (2) paper clips
- Screwdriver with a thin shaft
- One (1) 12-inch piece of 20 gauge magnet wire
- One (1) AA battery (larger batteries such as C or D cells also work)
- Block of wood (recommend a 6-inch length of 2 x 4)

### LESSON SUMMARY

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#### Lesson 1 - UAS Engines and Fuel

The lesson will begin with a warm-up activity that introduces the concept of electromagnetism and examines some of the earliest discoveries and applications in a short video. The information provided in the video will be used to generate a class discussion of how these technologies have evolved and become essential to the operation of many modern machines, including drones.

In the next part of the lesson, students will take a closer look at the most common types of powerplants used in drones--direct current electric motors. They will consider the features, advantages, and disadvantages of both brushed and brushless electric motors, and will learn how the combination of permanent magnets and electromagnets can be used to produce rotational motion. In the formative assessment, students will answer a series of questions to demonstrate their understanding of the basic components of electric motors and the differences between brushed and brushless motors. They will then be asked to make an argument for the type of motor they would choose if they were designing a drone.

Next, students will see the principles they've learned in action by building a simple direct current electric motor. This activity is likely to bridge the first and second sessions.

Students will next examine the types of fuel sources used by small UAS, with an emphasis on common battery types used to power electric motors. Students will learn the advantages and disadvantages of various battery types as well as safe handling recommendations for more volatile batteries.

To conclude the lesson, students will synthesize the information they've learned about sUAS powerplants and fuel in an exercise in which they pretend to work for a drone design company that develops custom drones for clients. They will

be given specifications for several drone projects and must determine what type of motor and fuel system to use, explaining their reasoning to the clients.

## BACKGROUND

At the most fundamental level, key technologies used to power drones have been around for almost 200 years. Batteries and electric motors were invented in the 19th century, and the technologies have been refined and put to new uses ever since. Today electric motors and batteries are ubiquitous in modern life.

All electric motors depend on the principle of electromagnetism to work. A combination of permanent magnets and electromagnets allows the motor to take advantage of the fact that opposing magnetic poles attract while like poles repel. In the simplest instance, a magnet that is allowed to rotate around an axis and is placed near a magnet held in a fixed position will rotate until the opposing poles are aligned. Without further input, the two magnets would remain in this position. But if one of the magnets is an electromagnet and the flow of electricity through it is reversed, its polarity will switch. This causes the rotating magnet to turn again so that the opposing poles are once again aligned. By repeatedly switching the direction of electricity, and therefore the poles in the electromagnet, the rotating magnet will keep turning as it tries to align with the opposing poles. This generates the sustained rotation needed to produce useful work, such as turning a propeller.

While electric motors may operate on either direct current or alternating current, those used in drones operate on direct current supplied by batteries. Different types of electric motors and batteries are commonly used in drones. Each has advantages and disadvantages, which students will learn about in this lesson.

## MISCONCEPTIONS

Students may believe that because drones are a relatively new product, the technology that powers them is also new. In fact, they will learn that the first batteries and electric motors were developed almost 200 years ago. Students also may be familiar with small recreational drones and as a result may believe that all drones are powered by simple battery-powered electric motors. While these are the most common fuel and propulsion sources in small drones, larger drones use a wide variety of fuel and propulsion systems.

## DIFFERENTIATION

To help students who may struggle to integrate the information in the lesson or retain what they've learned from one session to the next, allow students to complete the formative assessment in groups, encouraging discussion of the concepts presented. When they've completed their work, review the answers to the questions as a class. Allow students to keep their corrected student activity sheets to help them review the previous session's content before conducting the summative assessment.

## LEARNING PLAN

### ENGAGE

**Teacher Material:** [UAS Engines and Fuel Presentation](#)

**Slides 1-3:** Introduce the topic and learning objectives of the lesson.

**Slide 4:** Conduct the **Warm-Up**.

#### Warm-Up

Show students a short video about the earliest batteries and electric motors.

- “The First Electric Motor” (Length 4:08)

<http://video.link/w/jfVg>

After watching the video, lead a class discussion in which students propose answers to the questions below. Student answers will depend on their level of experience with drones. During the course of the lesson they will learn much more about the uses, limitations, and variety in the batteries and electric motors used in drones.

Where are batteries and electric motors used today?

*Possible answers include: toys, electric toothbrushes, cordless vacuums, and cars.*

How are these technologies--batteries and electric motors--relevant to drones?

*Possible answers might include: Most small drones, both recreational and professional, depend on battery-powered electric motors for propulsion.*

How did the technology used in batteries and electric motors have to change to make their use in modern drone applications possible?

*Possible answers might include: Batteries became more portable (sealed containers), longer lasting, smaller, and more powerful. In addition, other kinds of batteries were developed that did not depend on a simple metal-acid chemical reaction. And rechargeable batteries were developed, making them more practical for repeated use. Electric motors also became more portable, smaller, and more powerful.*

What kinds of changes in these technologies would make them even more valuable for drone applications in the future?

*Possible answers include: A continuation of the trend toward smaller, more portable, longer lasting, and more powerful would increase the value of both electric motors and batteries. Students who are familiar with drones may also mention issues like how many times batteries can be recharged and battery volatility.*

[DOK 2; relate]

## EXPLORE

**Teacher Material:** [UAS Engines and Fuel Presentation](#)

**Slide 5:** Although the focus of this lesson is on small unmanned aircraft systems (sUAS), it's important for students to recognize that unmanned aircraft come in a wide range of shapes and sizes. A manned aircraft must account for the needs of a human pilot, including room for the pilot to sit, the capacity to lift the weight of the pilot, and the need for oxygen at high altitudes. It also must incorporate all the controls for the aircraft, such as the yoke, throttle, and rudder pedals. Unmanned aircraft do not face these same limitations, so they come in a much wider variety of configurations and sizes.

Because they come in so many sizes and fulfill such a wide range of missions, unmanned aircraft have an equally wide range of powerplants and fuel types. They use all the same types of engines and fuel found in manned aircraft, including jet engines, four-stroke internal combustion engines, and rotary engines. In addition, they commonly use electric motors--something not often found in manned aircraft.

As with all design considerations for aircraft, manned and unmanned, weight is a key consideration in selecting the right kind of powerplant and fuel. Other factors that go into choosing a powerplant and fuel system for an unmanned aircraft include the type of mission being flown, the size of the aircraft needed, the payload to be carried, the duration of flight required, and the distances to be traveled.

**Slide 6:** The FAA considers small UAS to be those weighing less than 55 pounds. Typically, these aircraft use electric motors powered by batteries to provide propulsion. Because these aircraft are small and light, they need propulsion systems that are also small and light. Compared to combustion engines, electric motors are lighter, have fewer moving parts, and are easier to maintain. Because they are powered by batteries, they also tend to have less range (can't fly as far) and have less endurance (can't fly as long).



### Questions

Ask students: Why might sUAS manufacturers be willing to sacrifice range and endurance for simplicity and low weight?

*Student responses will vary but in general students should recognize that most of the missions flown by sUAS don't require extended range and endurance. Students may or may not be familiar with FAA requirements regarding line-of-sight. These rules require sUAS operators to keep their aircraft within sight at all times. This inherently limits the distances they may travel. Using light motors means less power is required to get the sUAS into the air and keep it flying. In addition, simple motors can be more easily repaired and are generally less expensive than more complex powerplants. This is important because sUAS aren't always flown with the same level of precision and care as a manned aircraft and are more likely to experience crashes. And both hobbyists and commercial operators want to keep costs down.*

**Slide 7:** All electric motors are electromagnetic—that is they depend on the interaction between electricity and magnets to generate rotational energy. Although electric motors can be designed to run on either direct current (DC) or alternating current (AC), those typically used in sUAS are DC motors. Varying the amount of current moving through the system changes the RPM in a DC electric motor.

All DC motors have two key components—a stator and a rotor. The stator is the portion of the motor that remains stationary during operation. The rotor is the portion of the motor that spins in response to the electromagnetic field being generated. The components will be explained in greater detail in upcoming slides.

Most sUAS use one of two types of DC motor—a brushed motor or a brushless motor. Brushed motors are also sometimes called “canned” motors because they look like they are contained in a can. The “can” is in fact the stator for this type of motor. Both types of motors will be examined in more detail in upcoming slides.



### Teaching Tips

Students may not be entirely familiar with the differences between DC and AC. DC is an electric current that flows at a constant level in one direction. This is the type of electricity provided by batteries, so it's what's used in everything from toys to tablet computers to electric cars. Alternating current reverses direction at regular intervals—60 times per second in the United States—and is the type of current being used when something is plugged into a wall outlet. This is the type of current being used in electric motors that power refrigerators and other household appliances.

**Slide 8:** DC motors depend on the fact that opposing magnetic forces attract while like forces repel. They use a combination of electromagnets and permanent magnets to create rotation. In sUAS, this rotational force is used to turn the propellers that provide lift and thrust to aircraft like quadcopters.

Ask students to think back to the warm-up video and recall that an electromagnet is a magnet created by electricity flowing through metal, which generates a magnetic field. Increasing the amount of electricity flowing through the metal increases the strength of that field. Reversing the direction of the flow of electricity reverses the polarity of the magnetic field.

DC motors use one or more permanent magnets and an electromagnet that switches poles. As the electromagnet is energized, its north pole is attracted to the permanent magnet's south pole, causing the electromagnet to turn. The flow of electricity is then reversed, reversing the electromagnet's poles, and causing it to turn again as it aligns its new north pole with the permanent magnet's south pole. This repeated shifting of poles keeps the rotation going.

Show students a video that describes how DC motors work.

- “How DC Motors Work” (Length 5:30)  
<http://video.link/w/Oelg>

**Slide 9:** As mentioned previously, DC motors have two key parts—the stator and the rotor. The stator is the portion of the motor that remains stationary, while the rotor is the portion that turns.

In a brushed motor, the stator has two opposing permanent magnets, while the rotor or armature is an electromagnet. As students saw in the video, the magnets attract and repel one another creating rotation as the fields of the electromagnet switch. As the rotor turns, the brushes also turn, contacting first one terminal and then the other. It is these changing contacts that reverse the flow of electricity through the electromagnet, reversing the poles, and causing the rotation to continue.

**Slide 10:** A brushless motor reverses the roles of the stator and rotor. In these motors, the electromagnet remains stationary while the permanent magnets rotate. Instead of using brushes to reverse the flow of electricity, brushless motors use an electronic circuit, called a controller, and a rotational sensor to change the direction of the flow of electricity, causing rotation.

## EXPLAIN

**Teacher Materials:** [UAS Engines and Fuels Presentation](#), [UAS Engines and Fuels Teacher Notes 1](#)

**Student Material:** [UAS Engines and Fuels Student Activity 1](#)

**Slide 11:** There are advantages and disadvantages to each type of motor. Brushed motors are inexpensive and easy to repair. However, they require regular maintenance to replace the brushes, which wear down as they turn and scrape against the terminals. Brushed motors are less efficient and have a lower power-to-weight ratio than other types of electric motors. They also generate electromagnetic interference (EMI), which can disrupt the function of avionics or other electronic components of the aircraft or interfere with communications between the aircraft and the ground-based control unit. In addition, brushed motors do not shed heat well. High temperatures can damage the motor or other aircraft components.

Brushless motors are more expensive and require more complex controllers, which are also more expensive. However, they have a better power-to-weight ratio, are small, and do not produce EMI.

**Slide 12:** Conduct the **Formative Assessment**.

### Formative Assessment

Students will answer a series of questions to demonstrate their understanding of the basic components of electric motors and the differences between brushed and brushless motors. They will then be asked to make an argument for the type of motor they would choose if they were designing a drone.

Provide students with **UAS Engines and Fuels Student Activity 1** and have them answer the questions. Answers to this assessment are found in **UAS Engines and Fuels Teacher Notes 1**.

[DOK 2, *compare*; DOK 3, *develop a logical argument*]

## EXTEND

**Teacher Materials:** [UAS Engines and Fuels Presentation](#), [UAS Engines and Fuels Teacher Notes 2](#)

**Student Material:** [UAS Engines and Fuels Student Activity 2](#)

**Slide 13:** Students will see the principles governing electric motors in action as they build a simple direct current electric motor. Divide students into groups of two or three and provide each group with a copy of **UAS Engines and Fuels Student Activity 2** and the necessary materials.

This activity is likely to conclude the first session and may continue into the second session. If appropriate, use the question below as a way to refresh student's memories at the start of the second session.

When students have completed the activity, initiate a class discussion to answer the following question: How is the motor you built similar to and different from the brushed and brushless motors used in sUAS?



### Questions

How is the motor you built similar to and different from the brushed and brushless motors used in sUAS?

*Student answers will vary, but the following points may be made as part of the discussion: This design is brushless. It is similar to both brushed and brushless motors in that it consists of a stator and a rotor. The stator includes a fixed magnet as it would on a brushed motor. But this design has only one permanent magnet, instead of two, and it does not have a mechanism for switching the polarity of the electromagnet. It has much lower power than a motor used in an sUAS. Like the motors used in sUAS, this one relies on battery power, relies on electromagnetics, and uses direct current as a power source.*

**Slide 14:** All aircraft, whether manned or unmanned, must be able to carry enough fuel to complete the flight or mission for which they were designed. The type of fuel used to power the aircraft depends on the type of powerplant selected. Fuels used in UAS include batteries of various types, liquid fuels like gasoline or diesel, and fuel cells. Each type of fuel will be explored in greater detail in upcoming slides. Some UAS also use solar panels to help recharge batteries and provide supplemental energy while in flight. However, this system is not efficient enough to provide all the power needed for most UAS operations.

**Slide 15:** The type of fuel used to power a UAS affects the weight, range, endurance, and speed of the aircraft. For small UAS, batteries are by far the most common source of fuel. They may provide power to the electric motors that make

the UAS fly. They may also be used to power other onboard equipment such as avionics, cameras, and communications equipment. The majority of sUAS depend on either nickel-based or lithium-based batteries for power. Each type has advantages and disadvantages.

**Slide 16:** Nickel batteries come in two main types: nickel-metal hydride, commonly abbreviated as NiMH and nickel-cadmium, abbreviated as NiCd. Students should be familiar with these types of batteries, which are commonly used in toys, remote controls, and other common household items.

Each cell of these types of batteries is rated at 1.2 volts. To achieve greater voltage, the batteries can be connected in series. To achieve greater amperage, they can be connected in parallel.

Nickel-based batteries are common in older sUAS, but are falling out of favor in newer aircraft. Even in these aircraft, however, they may be used to power avionics but not motors.



#### Teaching Tips

Students may not be familiar with the differences between wiring in series and in parallel. When batteries are wired in series, they are connected along a single path and the voltage of the batteries is additive so that three 1.2 volt batteries wired in series produce a total of 3.6 volts, but their amperage remains unchanged. When batteries are wired in parallel, the amperage is additive, but the voltage remains unchanged.

**Slide 17:** The other common type of battery used in sUAS is the lithium-based battery. Like nickel-based batteries, they come in two main types: lithium-ion, abbreviated as Li-ion, and lithium-polymer (LiPo). Li-ion batteries may be used to power motors, but are more often used to power avionics on board sUAS. LiPo batteries are typically used to power motors. Lithium-based batteries have a higher voltage rating than nickel-based batteries, with each cell rated at 3.7 volts.

In addition to the voltage rating, lithium-based batteries have two other ratings. The C rating shows how quickly energy can be continuously discharged from the battery. The S number shows how many cells are in the battery, and therefore how much voltage the battery produces. These ratings are important to ensure the batteries can meet the energy demands of the motor(s) without causing damage or injury.

**Slide 18:** All batteries should be treated with care, but LiPo batteries require special care and handling to ensure safe operation. Show students a video about how to care for drone batteries.

- “How to take care of your drone batteries” (Length 1:02)

<https://video.link/w/8Uah>

UAS pilots should always inspect batteries before using or charging them to make sure there are no visible signs of damage such as leaking, swelling, or cracks. It is important not to leave LiPo batteries unattended during charging as they have been known to catch fire, and are best charged inside a fire-resistant case or pouch designed for that task. To help minimize the risk of fire, batteries should only be charged at room temperature, never when temperatures are too cold or right after flying when the batteries may be hot. Overcharging batteries, or discharging them too quickly, can cause permanent damage, as can using the wrong type of charger.

Under FAA regulations, UAS operators are also required to replace batteries regularly. Regulations require that they be replaced following the guidelines of the UAS manufacturer or the battery manufacturer, whichever is more restrictive.

**Slide 19:** Each type of battery has advantages and disadvantages, and sUAS designers must select the right battery for the aircraft, motor, and mission.



Nickel-based batteries are inexpensive, readily available, and charge quickly. They are stable and unlikely to start a fire. However, they have a comparatively low power-to-weight ratio, low endurance, and their performance tends to degrade noticeably over time or with repeated charging.

Lithium-based batteries have a relatively higher power-to-weight ratio and longer endurance. But they are also more costly, require special charging equipment, and have a shorter lifespan. And, as mentioned earlier, they can be volatile, sometimes catching fire if not handled and charged correctly.

**Slide 20:** While batteries are the most common fuel source for sUAS, other types of fuel are used in UAS of various sizes and types. Liquid fuels include gasoline, diesel, and jet fuel. Smaller drones with internal combustion engines commonly use glow fuel, which is a blend of methanol (usually 58%-88%) and oil (12%-28%). Nitro fuel adds up to 30% nitromethane to the blend. Typically, liquid fuels are used only in relatively large UAS because they are heavy and take up a large volume of space.

Fuel cells are a promising form of energy storage, but are not yet in widespread use. They contain solid or gaseous hydrogen. This form of fuel is growing in popularity because of its promise of greater endurance and less volatility (for cells using solid hydrogen).

## EVALUATE

**Teacher Materials:** [UAS Engines and Fuel Presentation](#), [UAS Engines and Fuel Teacher Notes 3](#)

**Student Material:** [UAS Engines and Fuel Student Activity 3](#)

**Slide 21:** Conduct the **Summative Assessment**.

### Summative Assessment

Provide each student with a copy of **UAS Engines and Fuel Student Activity 3**. Students will pretend to work for a drone design company that develops custom drones for clients. The company has received orders for a variety of drone projects and it's up to each student to determine what type of motor and fuel system to use. Students should be able to justify their decisions to the clients. Sample answers can be found in **UAS Engines and Fuel Teacher Notes 3**.

[DOK 4, *apply concepts*]

### Summative Assessment Scoring Rubric

- Follows assignment instructions
- Student work shows evidence of understanding regarding:
  - The advantages and disadvantages of brushed and brushless motors
  - The advantages and disadvantages of different types of batteries
  - How mission and aircraft design affect decisions about powerplants and fuel sources
- Contributions show understanding of the concepts presented in the lesson
- Contributions show in-depth thinking including analysis or synthesis of lesson objectives

**Points      Performance Levels**

9-10 For each example, the student selects a combination of battery and motor that will best fulfill the mission and makes a well-reasoned argument for why this is the best combination, taking into account issues such as weight, endurance, range, complexity, and cost. The student's explanation makes a clear connection between aircraft mission, design, and propulsion.

7-8 For the majority of the examples, the student selects a combination of battery and motor that will best fulfill the mission and makes a well-reasoned argument for why this is the best combination, taking into account issues such as weight, endurance, range, complexity, and cost. The student's explanation makes a clear connection between aircraft mission, design, and propulsion.

5-6 For the majority of the examples, the student selects a combination of battery and motor that will reasonably fulfill the mission and makes a logical argument for the selection, taking into account some of the factors discussed in the lesson, such as cost and weight. The student's explanation does not make a clear connection between aircraft mission, design, and propulsion.

0-4 For the majority of the examples, the student selects a combination of battery and motor that will not reasonably fulfill the mission and fails to make a logical argument for the selection. The student's explanation does not make a clear connection between aircraft mission, design, and propulsion.

## GOING FURTHER

Have students research one category of drone they find interesting, such as racing drones, military drones, or package delivery drones. They should collect information about the types of powerplants and fuel used in these drones, looking for commonalities and differences across the category. Students will use the information they collect to make a brief slide presentation explaining their findings and their hypothesis as to why drone designers in the category they researched made the design choices they did.

Alternatively, students can research new forms of propulsion being studied for use in drones such as electroaerodynamic thrust, also called ion wind propulsion. Students should use their research to create a brief slide presentation outlining the current state of the technology, the hopes for its performance, and the barriers between its current state and widespread adoption.

## STANDARDS ALIGNMENT

### NGSS STANDARDS

#### Three-dimensional Learning

- **HS-ETS1-2** - Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering
  - Science and Engineering Practices
    - Asking Questions and Defining Problems
    - Constructing Explanations and Designing Solutions
  - Disciplinary Core Ideas
    - ETS1.A: Defining and Delimiting Engineering Problems
  - Crosscutting Concepts

- None
- **HS-ETS1-3** - Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
  - Science and Engineering Practices
    - Constructing Explanations and Designing Solutions
  - Disciplinary Core Ideas
    - ETS1.B: Developing Possible Solutions
  - Crosscutting Concepts
    - None

## COMMON CORE STATE STANDARDS

- **RST.9-10.2** - Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- **RST.9-10.4** - Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.
- **WHST.9-10.6** - Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.
- **WHST.9-10.8** - Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- **WHST.9-10.9** - Draw evidence from informational texts to support analysis, reflection, and research.

## REFERENCES

Terwilliger, Brian, et.al., *Small Unmanned Aircraft Systems Guide: Exploring Designs, Operations, Regulations, & Economics* (2017) Aviation Supplies & Academics, Inc.

Jenkins, Kevin. *The Droner's Manual: A Guide to the Responsible Operation of Small unmanned Aircraft* (2017) Aviation Supplies & Academics, Inc.