Classifying UAS

Session Time: One, 50-minute session

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

The intended purpose and use of an aircraft drives aircraft design considerations and construction techniques, materials, and components. (EU1)

ESSENTIAL QUESTIONS

1. How are UAS classified?
2. Why does the FAA care so much about weight in its classification of UAS?

LEARNING GOALS

Students Will Know

- Several different types of UAS and their characteristics
- How the FAA classifies UAS
- How the FAA's classification of a UAS affects operating rules and privileges
- The levels of autonomy UAS operate under

Students Will Be Able To

- *Describe* the different classifications and physical characteristics of UAS. (DOK-L2)
- *Select* UAS with appropriate design characteristics and autonomy levels for specific missions. (DOK-L2)
- *Identify* the autonomy level capability of different UAS and explain how the autonomous UAS can be used for a particular mission. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Students watch a video of an unmanned aircraft system (UAS) making a delivery, then work in small groups to answer questions.

Formative Assessment
Students select design characteristics and an autonomy level for several missions that require UAS.

Summative Assessment
Students read two scenarios and answer questions about the UAS described.

LESSON PREPARATION

MATERIALS/RESOURCES

- Classifying UAS Presentation
- Classifying UAS Student Activity 1
- Classifying UAS Student Activity 2
- Classifying UAS Teacher Notes 1
- Classifying UAS Teacher Notes 2

LESSON SUMMARY

Lesson 1: Classifying Aircraft
Lesson 2: Classifying UAS

The lesson begins with students watching a video of a UAS making a delivery. They will respond to several questions about the physical characteristics of the UAS and be asked to predict whether the same classifications of manned aircraft also apply to UAS. The lesson then explores the classification systems that exist for UAS and how these classifications are made.

During the next part of the lesson, students will be introduced to characteristics of different types of UAS. This discussion will focus on fixed-wing, single-rotor, and multirotor UAS. Then, students will complete the formative assessment in which they select a design characteristic and an autonomy level for several missions that require UAS. Students will then extend their understanding of lesson concepts by choosing a UAS that would best be suited to accomplish the tasks listed in the formative assessment.

The lesson concludes with students completing the summative assessment by responding to questions about scenarios that describe details about a UAS.

BACKGROUND

Students may have some familiarity with unmanned aircraft systems (UAS) and/or drones, but it is unlikely that they will appreciate the difference between the terms UAS and drone. The term UAS refers to an unmanned aircraft and the associated elements that are required for its safe and efficient operation. These elements include, but are not limited to, the unmanned vehicle, communication datalinks, controllers, sensors, and the human operator. In other words, this aircraft does not have a human pilot onboard, but it is piloted either by an operator from a remote location such as a ground station, or autonomously through an onboard computer. The term drone refers only to the flying vehicle. It is worthwhile to mention that historically, this term has been used to connote military UAS. With the evolution of technology and better understanding in the UAS field, drone has been replaced several times with terms such as UA, UAV, or remotely piloted vehicle/aircraft (RPV/A).

Unmanned systems are categorized in a similar fashion to manned aircraft. The categories of UAS are fixed-wing, single-rotor, and multi-rotor systems. These systems range in size from small to large, filling different roles and missions.

In recent years, the popularity and mission capability of UAS have been rapidly increasing, and the FAA created a solution to permit commercial use. By creating Part 107 in 14 Code of Federal Regulation (CFR), the FAA developed a set of regulatory guidelines that would safely and gradually allow the operational integration of small UAS (sUAS), those weighing less than 55 pounds, in the national air space (NAS). Prior to 14 CFR Part 107, the requirements to operate UAS commercially were very strict, requiring a manned pilot certificate as well as an exemption from section 333 of the FAA Modernization and Reform Act of 2012 and a Certificate of Waiver or Authorization (COA).

With few exceptions, the manner in which UAS are operated recreationally has not changed much, except for the requirement that the drone be registered with the FAA. UAS flown recreationally are still viewed as model aircraft and may be operated under section 336 of the Special Rule for Model Aircraft.

Because UAS are still comparatively new, there is much work that needs to be done in the field of classifying systems. Many organizations use their own classifications to suit their individual needs. Until UAS are fully integrated into the NAS, it is reasonable to expect the classification system to continue to grow and evolve beyond simple classifications like weight.

Students who are interested in UAS careers will have exciting new opportunities. New markets will emerge as UAS become more autonomous. These autonomous systems provide multiple advantages, including the ability to handle missions where human limitations, such as rest, food, water, compensation, and workload, are limiting factors.

MISCONCEPTIONS

Common misconceptions about the topics covered in this lesson include assumptions that UAS or drones are only used for military purposes, that all UAS are governed by the same rules, and that certifications are not required to pilot drones for commercial purposes. These misconceptions should be dispelled at the conclusion of this lesson.

DIFFERENTIATION

To deepen student understanding in the **ENGAGE** section, encourage students to compare the execution of the package delivery by a UAS to the same delivery by a manned aircraft. Let students identify the pros and cons of one over the other to help students understand the roles of different aviation platforms.

To aid retention of material previously introduced and foster assimilation of the new material, have students identify different categories of UAS in the **EXPLORE** section of this lesson plan. Help students contrast the categories of UAS adopted by the FAA to those used by other organizations—most notably, the U.S. Department of Defense (DoD).

To promote reflective thinking and guided inquiry in the **EXTEND** section, have students consider their dream jobs and careers identify ways that UAS could be used to improve efficiency at work.

LEARNING PLAN

ENGAGE

Teacher Material: Classifying UAS Presentation

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

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

Warm-Up

Show students the video of Amazon's first customer drone delivery.

- "Amazon Prime Air's First Customer Delivery" (Length: 2:05)

  http://video.link/w/3nVd

Divide the class into small groups of three to four students and ask them to write and discuss their answers to the following questions:

- What type of UAS do you think this is?
- What size do you think this aircraft is?
- Do you think this UAS would be classified in the same way that manned aircraft are classified?

After students discuss these questions in their small groups, allow a few minutes for the groups to share their thoughts with the entire class. [DOK-L2; *infer; predict*]

Questions

Possible answers:

- What type of UAS do you think this is?

This is a small UAS

It is a quadcopter

- What size do you think this aircraft is?

It will be a "small" UAS. The amount of payload Amazon is transporting in this video can be used to infer this. In this video, it is carrying payloads of up to 5 pounds.

- Do you think this UAS would be classified in the same way that manned aircraft are classified?

As students will recall, manned aircraft classes include airplane, rotorcraft, glider, etc. It is possible to classify this UAS in similar ways. UAS can be fixed-wing airplanes or rotorcraft; however, some differences will still exist in the classification of both. The UAS in the video is a rotorcraft (similar) but also a quadcopter (different).

EXPLORE

Teacher Material: Classifying UAS Presentation

Slide 5: Be sure that students understand that the acronym UAS stands for "unmanned aircraft system." In other words, an unmanned aircraft (UA) does not have a human pilot onboard the aircraft; it is piloted by an operator from the ground or autonomously through a computer. The term UAS involves all of the components that are involved in the flight of an unmanned aircraft, including the aircraft itself and its control system. The control system includes communication datalinks, controllers, sensors, and the human operator. The term drone, or unmanned aerial vehicle (UAV), refers to the unmanned aircraft itself. Emphasize that a UAV is part of a UAS.

Slide 6: Clarify that government organizations have different purposes and different standards for classifying unmanned aircraft systems.

For the FAA, these classifications ensure the public is protected by properly regulating UAS so they do not cause accidents in flight. One of the largest challenges facing UAS is their integration into the National Airspace System (NAS). The NAS is all of the airspace in the country, with operations in aircraft ranging from balloons and gliders, to small private airplanes, to airliners and military jets. The dominant principal of all of these operations is to "see and avoid" other aircraft, a directive that is more complex for unmanned UAS. To avoid collisions, methods must be developed for UAS and manned aircraft to operate in the same area safely.

UAS technology is progressing faster than the integration technology can be implemented. As an example, NextGen and automatic dependent surveillance-broadcast (ADS-B) upgrades to the NAS have been years in the making and are still slowly being implemented.

Teaching Tips

Students learned about NextGen and ADS-B in ninth grade, but they will likely need to be reminded of what these are. See the summaries below for more information.

NextGen

A new airspace system called the Next Generation Air Transportation System (dubbed NextGen) will convert our current radar-based air traffic system to a satellite-based one. GPS technology will be used to shorten flight routes, save time and fuel, reduce traffic delays, increase airspace capacity, and permit controllers to monitor and manage aircraft with greater safety margins. Data exchange will eventually replace radio communications. This means pilots will receive air traffic control clearances and instructions via something like a text message rather than voice communications over a radio.

ADS-B

Automatic Dependent Surveillance-Broadcast (ADS-B) is the GPS-equipped hardware that will be installed on aircraft in order to give air traffic controllers more precise aircraft positions. Nearly all aircraft will be required to have ADS-B equipment installed by 2020. ADS-B equipment receives high-fidelity GPS data from aircraft and distributes that data to air traffic control facilities. ADS-B equipped aircraft also will be able to communicate with each other and anticipate any potential issues to adjust flight paths as necessary to avoid collisions.

To aid the safe integration of UAS into the NAS as well as promote public support for UAS, the FAA has classified these aircraft into small (sUAS) and large UAS. This is important because 14 CFR Part 107 spells out the regulations for people operating sUAS. It also allows close monitoring of these systems and their characteristics as they continue to evolve. Consequently, data can be gathered for subsequent integration efforts of larger, more complex systems.

- Students who are looking to enter UAS-related careers may well end up as FAA Part 107 pilots, operating for themselves or as pilots for a company. Students looking to operate UAS in the NAS commercially are required to obtain a Remote Pilot Certificate in accordance with the provisions of 14 CFR Part 107.

Military and Department of Defense (DOD) classifications provide a way to organize UAS by group according to their size, speed, and other capabilities and functions, so that the proper type of UAS will be selected for a specific role or mission.

Because UAS are relatively new, there may be other ways to classify them in the future. Just as manned pilots need more advanced certifications for larger and more advanced aircraft, the same may be true for the future of UAS. As the integration into the NAS continues, there will be a need for more detailed classifications and differentiation between systems. Currently, FAA Part 107 only encompases sUAS up to 55 pounds, but as larger more advanced systems are developed, the classifications will develop too.

Slide 7: The FAA classifies UAS according to weight.

- Small UAS (sUAS) are under 55 pounds. These UAS can be flown for recreational or commercial purposes. Both uses require registration with the FAA. Commercial uses require the operator to obtain a Part 107 Remote Pilot Certificate.
- Large UAS are 55 pounds or more. Operators must obtain an exemption from FAA regulations that require aircraft to be registered and approved for use and pilots to be licensed. The U.S. Secretary of Transportation has the

authority to determine if a certificate of airworthiness (CofA) is required for UAS to operate in the National Airspace System (NAS). The application and approval process for this exemption, known as a 333 Exemption, and CofA can be arduous. The Part 107 regulations were created to allow for a faster integration into the NAS. Part 107 allowed many types of commercial operations that had previously required individual 333 Exemptions to continue under Part 107, without the need to go through the difficult, expensive, and time consuming 333 Exemption process. By making it easier to conduct many types of commercial UAS operations, Part 107 created an opportunity for new markets to develop.

This classification system seeks to ensure safety and UAS integration into the NAS.

Slide 8: This slide explains the five groups in the DOD's classification of UAS. Review the characteristics of each group:

- Group 1: Gross takeoff weight is between 0 and 20 pounds, the normal operating altitude is less than 1,200 ft above ground level, and the maximum airspeed is 100 knots.
- Group 2: Gross takeoff weight is between 21 and 55 pounds, the normal operating altitude is less than 3,500 ft above ground level, and the maximum airspeed is 250 knots.
- Group 3: Gross takeoff weight is less than 1,320 pounds, the normal operating altitude is less than 18,000 ft mean sea level, and the maximum airspeed is 250 knots.
- Group 4: Gross takeoff weight is greater than 1,320 pounds, the normal operating altitude is less than 18,000 ft mean sea level, and it can have any airspeed.
- Group 5: Gross takeoff weight is greater than 1,320 pounds, the normal operating altitude is above 18,000 ft mean seal level, and it can have any airspeed.

Each representative UAS is hyperlinked to a corresponding photograph of the aircraft in the Classifying UAS Presentation.

Slide 9: UAS can be described based on their design characteristics.

Fixed-Wing - like an airplane, the wings are attached to the aircraft's body or the aircraft has a flying wing design.

Single-Rotor - similar to a helicopter, it has one rotor with several blades.

Multirotor - several rotors are affixed; within this type, there are several names for the aircraft based on the number of rotors.

- 3 rotors = tricopter
- 4 rotors = quadcopter
- 6 rotors = hexacopter
- 8 rotors = octocopter

Slide 10: This slide shows a fixed-wing UAS. Explain the design and components of this type, as well as the advantages and disadvantages, as follows.

Fixed-wing systems operate in a variety of roles commercially, in the military, or recreationally. They generally have these characteristics:

- Design - fixed-wing or flying wing
- Size - may range from very light (1 pound or less) to 9 tons or more
- Launch System - can be thrown, propelled by rockets, launched with a bungee cord and rail system, launched with a hydraulic or pneumatic launcher; or released from a parasail. They can also take off like a standard aircraft.

- Landing System - conventional landing gear (wheels or skids), or they can be recovered by a net, arresting line, skyhook, windsock, or parachute.
- Powerplant - electric, piston, or turbine

Depending on the role in which a fixed-wing UAS is employed, it offers a variety of advantages, which include:

- Longer range - Generally, fixed-wing UAS can carry more fuel or energy, and use it more efficiently than other types of similar sized UAS. This enables a fixed-wing UAS to travel farther.
- Better payload capabilities - Fixed-wing UAS are generally able to carry much larger payloads over greater distances using less power. Bigger payload capabilities allow fixed-wing UAS to carry larger, heavier sensors and cameras, providing improved data collection and image quality.
- Better aerodynamic qualities -Designs of fixed-wing UAS incorporate more aerodynamically efficient structures that enable the vehicle to fly longer, smoother, and faster; consequently, these designs offer better handling qualities.
- Increased speed - The improved aerodynamic design of a fixed-wing UAS means it can travel faster through the air and with reduced drag on the vehicle.
- Longer autonomous capability - The increased endurance and ranges offered by fixed-wing UAS translate into increased autonomous flight times.
- High altitude capabilities - Fixed-wing UAS are generally able to fly higher due to their improved aerodynamic qualities as well as more efficient power plants. This is beneficial in large survey areas where high altitudes translate to greater surface coverage by the UAS cameras or sensors.
- Reduced acoustic signature - The high altitude capability, better aerodynamic qualities, and increased speed of fixed-wing UAS also enable them to have reduced audible noise over a given area.

Disadvantages of fixed-wing UAS compared to other UAS include:

- Inability to hover - Fixed-wing UAS must continue to generate forward thrust and lift to be able to sustain their flight. Consequently, they cannot provide extended coverage over a particular object of interest.
- Need an open area to takeoff/land - This is perhaps the single biggest disadvantage of fixed-wing UAS because it limits the locations where they can operate. It also increases the overall cost of operations.
- Reduced image resolution at higher altitudes - The higher a camera, the less detailed the surface images it captures. Consequently, UAS flying at high altitudes usually produce poorer quality images.

Slide 11: This slide shows a single-rotor UAS. Explain the design and components of this type, as well as the advantages and disadvantages, as follows.

- Design - single-rotor (single main rotor, plus a tail rotor for stability)
- Size - may range from very light (less than 1 pound) to 2 tons or more
- Launch System - vertical takeoff and landing (VTOL)
- Landing System - VTOL
- Powerplant - electric, piston, or turbine

Single-rotor UAS have these advantages as compared to other UAS:

- Higher speeds compared to multirotors - By design, single-rotor UAS are able to operate at increased forward speeds. This enables them to travel over greater distances in a given time period.

- Ability to hover in flight - Rotor UAS (both single and multi) have the ability to hover in flight. This means they can be used to observe single objects of interest over an extended period of time—even at low altitudes.
- Less space needed for landing - The major benefit of rotor UAS over fixed-wing UAS is their reduced dependence on prepared landing sites or large landing sites. This reduces the overall costs associated with their operation.

Single-rotor UAS have these disadvantages as compared to other UAS:

- More expensive to maintain than multirotor UAS
- Noisy
- More maintenance - With more complex parts such as rotors and connectors for such rotors, the single-rotor UAS typically requires more maintenance than the fixed-wing UAS.
- Range restricted - The range of most single-rotor UAS is limited due to design constraints and weight limitations.
- Reduced altitude capabilities -These systems cannot be operated at high altitudes due to their aerodynamic designs and power plants. They cannot generate the required lift to sustain flight at high altitudes.
- Lower endurance -Single-rotor UAS do not carry enough fuel to remain aloft for extended periods.

Slide 12: This slide shows a multirotor UAS, specifically a hexacopter (six rotors). Explain the design and components of this type, as well as the advantages and disadvantages, as follows.

- Design - Multirotor UAS have more than one rotor. The most common designs include 3 rotors (tricopter), 4 rotors (quadcopter), 6 rotors (hexacopter), 8 rotors (octacopter) and—in rare cases—12 and 16 rotor configurations.
- Size - may range from very light (less than 1 pound) to hundreds of pounds
- Launch System - vertical takeoff and landing (VTOL)
- Landing System - VTOL
- Powerplant - electric

Then, review the advantages and disadvantages of multi-rotor UAS.

Multi-rotor UAS have these advantages as compared to other UAS:

- Reduced dependence on prepared runways or landing sites - Due to vertical launch and recovery (VTOL), they need little to no prepared surface to be launched or recovered. This is beneficial to the overall cost of operation of these systems.
- Highly maneuverable - The variation in torque and thrust from the rotor blades of a multirotor allows control over the vehicle. This ability makes it possible to maneuver the vehicle in many dimensions even while hovering over a single location, giving it more agility than a single-rotor or fixed-wing UAS.
- Stable - Due the number of blades a multirotor has in operation, the airflow around the vehicle is better distributed; this contributes to the stability of the vehicle. This also protects the vehicle should one of the blades fail in flight.
- Capacity for better image resolution -The ability to hover in fixed locations, as well as the need to operate at lower altitudes, means that the sensors can provide users with better image resolution. On the other hand, the payload weight is significantly less than of fixed-wing UAS. This may translate into less-capable sensor payloads, and thus lower quality images than are possible with fixed-wing UAS.

Multi-rotor UAS have these disadvantages as compared to other UAS:

- Reduced range - The range of multirotor UAS is limited due to high energy demand and weight constraints.

- Limited altitude - The blades of a rotor UAS (both single and multi) are in constant motion and provide the lift necessary for flight. However, at higher altitudes, the air is less dense and the rotors cannot provide sufficient lift to maintain flight. Consequently, rotor UAS are limited to flights at lower altitudes.
- Noisy - Advances in technology have given rise to much quieter rotor blades. However, since they have to operate at lower, closer, altitudes, multirotor UAS are louder than fixed-wing UAS.
- More maintenance - With more complex parts such as rotors and connectors for such rotors, the multirotor UAS typically requires more maintenance and repairs than the fixed-wing UAS.
- Low payload capacity - Most multirotor UAS are designed to be able to carry very limited payloads. When the payload takes the form of sensors or cameras, this can mean less capability and lower image resolution.
- Lower endurance - Multirotor UAS are not designed to carry sufficient power to remain aloft for extended periods of time.

Slide 13: This slide explains the level of autonomy in UAS, based on the role of the operator. UAS with no autonomy generally require direct control for successful flight and stabilization. The standard "toy" drone has no autonomy, as it requires consistent human input to remain in flight.

Partially autonomous UAS often have gyro stabilization, GPS, and can be pre-programmed with geographic coordinates from a ground control station (GCS).

Fully autonomous UAS do not require GCS and require zero human interaction. The Navy X-47B has conducted an autonomous refueling as a demonstration of the system's abilities. Full autonomy is still very much in development, relying on the expertise of professionals from a broad range of fields to incorporate computer learning and decision making into the systems.

EXPLAIN

Teacher Materials: Classifying UAS Presentation, Classifying UAS Teacher Notes 1
Student Material: Classifying UAS Student Activity 1 **(Part 1)**

Slide 14: Conduct the **Formative Assessment**.

Formative Assessment

In this activity, students will complete Part 1 of **Classifying UAS Student Activity 1**. Have students work in small groups (23 students/group) to select UAS design characteristics and an autonomy level required for certain missions. Students should use what they learned so far in this lesson and conduct additional Internet research if they do not know the answers. Ask volunteers to share their work with the class and allow for a brief discussion.

Answers to this assessment are found in **Classifying UAS Teacher Notes 1**.

[DOK-L2; *classify,* DOK-L1; *identify]*

EXTEND

Teacher Materials: Classifying UAS Presentation, Classifying UAS Teacher Notes 1
Student Material: Classifying UAS Student Activity 1 **(Part 2)**

Slide 15: Conduct the following activity.

In this activity, students will complete Part 2 of **Classifying UAS Student Activity 1**. Working in the same groups as in Part 1, students should choose from the list of available types a UAS that will best complete each of the four missions from Part 1 of the activity. Students will then discuss their choices as a class.

Answers to this activity are found in **Classifying UAS Teacher Notes 1**.

EVALUATE

Teacher Materials: Classifying UAS Presentation, Classifying UAS Teacher Notes 2
Student Material: Classifying UAS Student Activity 2

Slide 16: Conduct the **Summative Assessment**.

Summative Assessment

Students will be given two scenarios about people who are considering buying a UAS. Students will then answer questions about each person's need.

Provide each student with **Classifying UAS Student Activity 2**. The activity contains two scenarios and five questions about each scenario.

The correct answers are provided in the **Classifying UAS Teacher Notes 2**. [DOK-L2; *interpret*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Student work shows evidence of one or more of the following:
  - An understanding of the classifications and characteristics of UAS
  - An ability to classify UAS based on its characteristics
  - Knowledge of levels of autonomy of a UAS
- Contributions show understanding of course of the concepts covered in the lesson
- Contributions show in-depth thinking, including analysis or synthesis of lesson objectives

Points	Performance Levels
9-10	Consistently demonstrates criteria
7-8	Usually demonstrates criteria
5-6	Sometimes demonstrates criteria
0-4	Rarely to never demonstrates criteria

GOING FURTHER

If time allows, have students draw a diagram of a UAS they saw in class. Have the students classify characteristics, such as its speed, size, and lift systems. Finally, students should indicate which category the UAS would fall under based on what they have learned in this lesson.

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.9-10.9** - Draw evidence from informational texts to support analysis, reflection, and research.

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