# UAS Aerodynamics and Performance

**Session Time:** Three, 50-minute sessions



## DESIRED RESULTS

### ESSENTIAL UNDERSTANDINGS

Remote pilots must have a firm understanding of aerodynamic principles, as well as the ways in which atmospheric conditions can impact UAS performance, in order to ensure successful operations.

Safe and efficient aviation operations require that pilots use math, science, and technology.

### ESSENTIAL QUESTIONS

1. How can a remote PIC use knowledge of atmospheric conditions and aerodynamics to anticipate a UAS's likely performance, even in the absence of detailed manufacturer information?
2. What methods can remote PICs use to ease the workload of flying a UAS, and to ensure that they stay within speed and altitude limits set by the FAA?

### LEARNING GOALS

**Students Will Know**

- How atmospheric factors such as density altitude and wind can impact the performance of a UAS.
- Aerodynamic principles that can affect the flight of fixed-wing and multicopter UAS.
- Methods for ensuring that UAS operations remain within regulatory parameters set by the FAA.

**Students Will Be Able To**

- *Identify* different ways that atmospheric conditions and aerodynamic principles might impact UAS performance. [DOK-L1]
- *Draw conclusions* about how atmospheric conditions will affect UAS performance on a given day. [DOK-L3]
- *Assess* real-world scenarios to determine risks posed by factors such as density altitude, wind, or vortex ring state, and identify ways to mitigate them. [DOK-L3].

## ASSESSMENT EVIDENCE

**Warm-up**
Students will refresh their knowledge of the concepts of altitude, pressure, and vortex ring state in rotorcraft.

**Formative Assessment**
Students will complete a short quiz to check knowledge of basic aerodynamic factors.

**Summative Assessment**

Concepts from the lesson will be applied during a pair of scenarios set in different conditions.

## LESSON PREPARATION

### MATERIALS/RESOURCES

- UAS Aerodynamics and Performance Presentation
- UAS Aerodynamics and Performance Student Activity 1
- UAS Aerodynamics and Performance Student Activity 2
- UAS Aerodynamics and Performance Student Activity 3
- UAS Aerodynamics and Performance Teacher Notes 1
- UAS Aerodynamics and Performance Teacher Notes 2
- UAS Aerodynamics and Performance Teacher Notes 3
- **Ruler or straight edge**

### LESSON SUMMARY

Lesson 1: Practical Weather for UAS Pilots
Lesson 2: Small UAS Loading
**Lesson 3: UAS Aerodynamics and Performance**

The lesson will begin with a warm-up, refreshing the concepts of altitude, pressure, and vortex ring state in rotorcraft.

During the next part of the lesson, reasoning is tied to these concepts, along with practical exercises that serve to contextualize them. Students are also presented with UAS-specific factors that affect operations.

Finally, FAA Knowledge Test questions are followed by a scenario-based assessment that asks students to make operational decisions to reduce risk, based upon given atmospheric conditions and aerodynamic principles.

### BACKGROUND

Atmospheric conditions (e.g. temperature, humidity) can present unique challenges to aircraft operators. It is important to be aware of these factors when conducting flights in both manned and unmanned aircraft, because aircraft performance limits can be exceeded if appropriate caution is not exercised. For example, as students discovered in the previous lesson on weight and balance, density altitude can have a significant effect on a UAV's ability to carry the same load on different days.

Students will see familiar concepts within this lesson, and will be reminded of the role that factors like density and pressure altitude, humidity, and temperature can have on a flight. They have learned about the impact atmospheric conditions can have on manned flight, and this lesson will focus on the ways these same factors can influence the flight of both fixed-wing and multirotor UAVs. They will also be asked to recall vortex ring state from the grade 10 lesson on rotorcraft; this phenomenon can affect multirotor UAVs in much the same way it affects manned helicopters.

By now, a common theme in UAS (particularly sUAS) that you will have noticed is that there is far less documentation available from drone manufacturers than there is from manufacturers of manned aircraft. As a result, UAS pilots are often test pilots; the only way to know whether an alteration made to a particular unmanned vehicle is acceptable may be to fly it under controlled conditions and make observations. Even so, the more knowledge that a remote pilot has about aerodynamics, atmospheric conditions, and the interplay between the two, the less likely it is that they will attempt a potentially unsafe flight that exceeds the performance envelope of their vehicle.

### MISCONCEPTIONS

From the last lesson, which focused on UAS weight and balance, students will recall that sUAS manufacturers typically provide far less data to remote pilots than manned aircraft manufacturers provide to pilots. This is true not only of weight and balance information, but also of performance data. Students familiar with manned operations might assume that sUAS PICs are provided with detailed charts and graphs depicting expected performance on a given day, like those that are supplied by manned aircraft manufacturers. This, however, is not the case. Small UAS pilots are often test pilots, and must apply a general knowledge of aerodynamics and atmospheric conditions to their specific flight to anticipate how their vehicle might react in prevailing conditions.

Students will likely also recall that in manned flight, pilots are able to adhere to regulatory restrictions on airspeed and altitude simply by monitoring their instruments (their airspeed indicator and altimeter, respectively). While some sUAS provide this information to the remote pilot, many do not. Therefore, crews must use other techniques to ensure that they remain within regulatory boundaries.

## DIFFERENTIATION

To support student comprehension in the **EXPLORE** and **EXPLAIN** sections, have students swap papers for peer review and critique. Encourage students to examine the other group's probable causes for the crash to offer input and alternate theories (if applicable).

To support student comprehension in the **EVALUATE** section, perform demonstrations using the interactive Koch Chart for a given scenario. Have students compare their answers to the interactive Koch Chart.



# LEARNING PLAN

## ENGAGE

**Teacher Material:** UAS Aerodynamics and Performance Presentation

**Session 1**

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

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

**Warm-Up**

This lesson will explore topics that students have learned about in grade 10 (e.g. aerodynamics, performance), but with a UAS focus.

- As a warm-up, ask students what they remember about these terms that will appear in the lesson and how each one affects a manned aircraft's performance.

- **Density Altitude**
  ***Definition***: *Density altitude is pressure altitude corrected for nonstandard temperature. As temperature and altitude increase, air density decreases. In a sense, it's the altitude at which the airplane "feels" its flying.*
  ***Explanation***: *On a hot and humid day, an aircraft will accelerate more slowly down a runway, will need greater airspeed attain the same lift, and will climb more slowly. This is because as air becomes less dense, it provides less lift. As a result, aircraft taking off and landing at high density altitudes require greater runway distance. Fewer air molecules in a given volume of air also result in reduced propeller and engine efficiency and therefore reduced net thrust. All of these factors can lead to an accident if degraded performance has not been anticipated and compensated for.*

- **Pressure Altitude**
  ***Definition***: *Pressure altitude is a standard baseline altitude that is obtained when an altimeter is set to 29.92.*
  ***Explanation***: *29.92 inches of mercury is sea level pressure in the standard atmosphere. When the altimeter is set to this value, the reading on the dial is the pressure altitude.*

- **Vortex Ring State**
  ***Definition***: *Vortex ring state (VRS) describes vibration in an aircraft's rotors, followed by a rapid uncontrolled descent.*
  ***Explanation***: *VRS usually results from upward-moving air through the inner portion of the rotors. When a rotorcraft descends near-vertically or vertically at slower speeds, vortices are created that become stronger as power is added to the craft. The best way to escape these vortices is to move in a forward or sideward direction or reduce power if altitude allows.*

The purpose of this exercise is to generate discussion, and to refresh students on some of the basics prior to delving into UAS flight specifically.



## EXPLORE

**Teacher Materials:** UAS Aerodynamics and Performance Presentation, UAS Aerodynamics and Performance Teacher Notes 1
**Student Material:** UAS Aerodynamics and Performance Student Activity 1

**Slide 5:** Conduct **UAS Aerodynamics and Performance Student Activity 1**, in which students will assume the role of a crash investigator using mock eyewitness accounts to surmise contributing factors. Have students split into teams and use provided eyewitness data to list likely contributing factors in drone crash scenarios. **UAS Aerodynamics and Performance Teacher Notes 1** provides sample answers. After completing the activity at the team level, feel free to discuss as a class if time warrants. After the activity, have students retain their activity sheet for use later in the lesson.

## EXPLAIN

**Teacher Materials:** UAS Aerodynamics and Performance Presentation, UAS Aerodynamics and Performance Teacher Notes 1, UAS Aerodynamics and Performance Teacher Notes 2
**Student Materials:** UAS Aerodynamics and Performance Student Activity 1, UAS Aerodynamics and Performance Student Activity 2

**Slide 6:** Students will remember in the previous lesson that, while detailed weight and balance information is plentiful for manned aircraft, far less information is typically available for sUAS. This is also true for performance information. For manned aircraft, extensive information gathered from test flights is compiled and used to create charts and graphs to predict performance for flights under a wide variety of conditions.

**Slide 7:** By contrast, remote pilots are often acting as test pilots. Because there are few performance details provided by sUAS manufacturers, the PICs themselves must find ways to obtain knowledge about how their system flies in different conditions. Also, it is important for remote pilots to have a fundamental understanding of drone performance and aerodynamic factors in order to make alterations to their aircraft. Performance information, if available, may be provided in a Pilot's Operating Handbook, a UAS Owner's Manual, or a manufacturer's website.

Students will have learned about manned aircraft aerodynamics, including those that affect airplanes and helicopters. UAS operations are influenced by these same factors, which also affect unmanned aircraft. Because aerodynamic factors can have a dramatic impact on the safety of drone operations, it is imperative that remote pilots research their aircraft thoroughly, using both manufacturer data and information from other pilots.

**Slide 8:** If a UAS is manufactured in a country outside of the United States, documentation may need to be translated. Physical print can be translated via apps such as Google Translate, Google Lens, and others. To do this, one needs to simply point a smartphone camera at the document, and it will be translated.

While some translations may not be precise, seamless, or complete, it is better than having no guide at all. In any case, to ensure flight safety, an effort should be made to obtain needed documentation directly from the manufacturer through a website or other means.

**Slide 9:** In any event, the PIC should know the operating environment, including conditions that could affect performance or handling, and any other information that could potentially affect flight safety.

Typically, a remote PIC will want a minimum of a 2:1 thrust-to-weight ratio in order to ensure performance required under normal conditions, along with a safety margin.

**Slide 10:** As an exercise in finding this thrust value, present the following two scenarios.



**Questions**

These problems can be figured out using the following formula: **(W  2) / E = L**
- W = Total Weight
- E = # of Engines/Motors
- L = Lift/thrust needed per engine or motor
- Note: For increased safety, round up to the nearest pound.

- If a quadcopter weighs 20 lbs., how much thrust would a single engine or motor need to support?
  **10 lbs.**
  *In this example, (20  2)/4 = 10; therefore, each motor would need to provide at least 10 lbs of lifting force to achieve the 2:1 lift-to-weight ratio.*
- If a hexacopter weighs 34.5 lbs, would motors providing 11 lbs of lift (per motor) be sufficient for a safe flight?
  **No.**
  *In this example, (34.5  2)/6 = 11.5; therefore, each motor would need to provide at least 12 lbs of lifting force to achieve the 2:1 lift-to-weight ratio. Rounding up from 11.5 lbs to 12 lbs provides extra safety.*

**Slide 11:** It is important that remote pilots have a firm understanding of how an aircraft's performance is likely to be reduced by changes in atmospheric conditions. Remind students that aircraft are supported by air, which consists mainly of molecules of nitrogen and oxygen. Nitrogen and oxygen molecules weigh more than water vapor molecules. Because the same amount of space is occupied by both forms of matter (air and water vapor), wet air weighs less than dry air and therefore has less mass for a given volume. Heating the air causes the air molecules to move farther apart, which also decreases the mass of a given volume of air. These processes are key to understanding density altitude.

**Teaching Tips**

**Density Altitude**

**Definition:** Density altitude is pressure altitude corrected for nonstandard temperature. As temperature and altitude increase, air density decreases. In a sense, density altitude is the altitude at which the airplane "feels" it is flying.

**Slide 12:** Altitude is a factor because as you climb, the temperature decreases about 2° Celsius per 1000 feet (Thermal Lapse Rate). Pressure altitude is a baseline altitude that is obtained when an altimeter is set to 29.92. When the altimeter is set to this value, the reading on the dial is the pressure altitude. It is also obtainable using the following formula: Pressure altitude = (standard pressure – current pressure)  1,000 + field elevation

**Slide 13:** Density altitude can be thought of as the altitude an aircraft would be at on a day with standard conditions (15° C, 29.92 in Hg). Performance charts are usually based on standard conditions. Low density altitudes are conducive to good performance, while high density altitudes will degrade performance.

AOPA's website explains this process in practical terms: "On a hot and humid day, the aircraft will accelerate more slowly down the runway, will need to move faster to attain the same lift, and will climb more slowly. The less dense the air, the less lift, the more lackluster the climb, and the longer the distance needed for takeoff and landing. Fewer air molecules in a given volume of air also result in reduced propeller efficiency and therefore reduced net thrust. All of these factors can lead to an accident if the poor performance has not been anticipated."

Air density can be thought of as a ratio: air that is half as dense will require double the volume of air to achieve the same level of performance. As an analogy, if an automobile has wet tires, its stopping distance is increased due to less available friction. A multicopter operating at a high density altitude would require extra power to arrest a descent for the same reason. Both density altitude and wind must be taken into account when planning aircraft recovery and landings.

**Teaching Tips**

- Density Altitude Formula:

Density altitude = pressure altitude + [120  (current temperature – ISA temperature for your elevation)]

(ISA temperature means International Standard Atmosphere temperature, found on an ISA chart)

**Slide 14:** A runway in Colorado and a runway in New Orleans have different elevations, humidity levels, and temperatures. Such factors affect sUAS flight. On a hot day, a UAS will generate less lift because the air is less dense, raising the density altitude (the level the aircraft "thinks" it's flying), causing the aircraft to work harder to make up for fewer air molecules. As motors and engines have an upper limit of RPM, this means the UAS will reach a critical limit altitude sooner on a hot day than on a day where the air is denser.

**Slide 15:** To further review these concepts, present students with the following problems.

**Questions**

Takeoff Field Elevation: 1500 MSL
Current Pressure: 30.00 Hg
Temperature: 19°C

- What is the pressure altitude?
  **Pressure altitude = (standard pressure – current pressure)  1,000 + field elevation**

(29.92 – 30)  1,000 + 1500 ft

(–0.08  1,000) + 1,500 ft
–80 + 1,500 ft = **1,420 ft pressure altitude**

- What is the density altitude?
  **Density altitude = pressure altitude + [120  (current temperature – ISA temperature for your elevation)]**

(ISA is 15°C, and –2° per 1,000 ft; therefore, ISA at 1,500 ft is 15°C – 3°C, or "ISA – 3")
1,420 ft + [120  (19°C – 12°C)
1,420 ft + [120  7°C]
1,420 ft + 840 = **2,260 ft density altitude**

Therefore, at takeoff, a UAS in these conditions is performing as if it were at 2,260 ft in standard conditions.

**Session 2**

**Slide 16:** Takeoff and climb are directly impacted by air density. Colder air is more dense, allowing more propulsion to take place. For every action, there is an equal and opposite reaction per Newton's Third Law. For example, as a single air molecule is pushed backwards by the propulsion device (i.e., propeller), it propels that device forward.

Because a propulsion device only passes through or interacts with a certain amount of air at a time, having more or fewer molecules to push in that given volume of air has a large impact on the efficiency of that propulsion device. This is exemplified during takeoff and landing, where the slower speeds and warmer temperatures mean propellers have fewer air molecules to use for propulsion.

**Slide 17:** The Koch (Pronounced "coke") Chart is a nomogram that quickly estimates the increase in takeoff distance and the decrease in rate of climb that an aircraft will experience due to pressure altitude and temperature. Shown in this slide is an example chart with instructions. An interactive version is available here: https://www.takeofflanding.com.

**Slide 18:** Like takeoff, landing is a phase of flight greatly influenced by atmospheric conditions, including density altitude and wind. Fixed-wing aircraft and multicopters should be landed into the wind when possible. This reduces the amount of crosswind correction that is necessary and—for multicopters—reduces the chances of vortex ring state developing (this will be discussed soon). Relative air movement toward the propeller increases the amount of air the propeller can interact with, simulating a higher density of air. Therefore, when flying a fixed-wing drone, a pilot should conduct takeoffs, climbs, and landings into a headwind. The more air passing through the propeller, the better.

**Teaching Tips**

The graph on this slide shows the relationship between the relative wind velocity (plotted on the x-axis as a headwind or tailwind) and the takeoff and landing distance (plotted on the y-axis as an increase or decrease in distance).

To use the chart, find the ratio of relative wind to the speed for takeoff or landing on the x-axis, then follow that point vertically to the reference line. Then, follow that meeting point horizontally to the vertical centerline of the chart.

For example, a takeoff of 50 mph with a 5-mph tailwind (10% ratio tailwind) would result in a 25% increase in takeoffand landing distance, as shown by the dotted line on the chart.

**Slide 19:** To verify conceptual understanding of the importance of a headwind, ask students the following questions.

**Questions**

- What direction relative to the wind should takeoffs, climbs, and landings be made? Why?
  *Into/against the wind to increase the amount of air passing through the propeller*
- What is a Koch Chart for?
  *The chart is for quickly estimating the increase in takeoff distance and the decrease in the rate of climb due to pressure altitude and temperature.*

**Slide 20:** Pilots should reconnoiter a launch area for hazards and obstacles such as power lines, trees, or buildings before a flight. The values and information obtained in preflight regarding density altitude, the Koch Chart, and prevailing weather conditions should all be taken into account.

This process helps to ensure an aircraft has ample room to take off, land, and maneuver for any emergency situations that arise, such as an aborted landing or takeoff, wind shear, etc. Wind is caused by the uneven heating of Earth's surface; on a smaller scale, destabilizing airflow can come from wind as it blows around obstacles. Turbulence can also occur over surfaces that are hotter or colder than the surrounding area.

**Slide 21:** Wintry conditions can cause ice accumulation on fast-moving surfaces because they cool rapidly. This usually happens around leading edges of wings or propellers—and especially in reciprocating engine carburetors of large fixed-wing UAS—because air is forced through a venturi (hourglass shaped passage) which causes it to cool. It is then mixed with fuel vapor, which cools it even further. Ice accumulation can generally be managed with heating devices and/or flying at a lower altitude.

**Slide 22:** Students will recall that ground effect—which occurs when an aircraft is flying at an altitude less than one-half of its wingspan above the ground—causes aircraft to experience a reduction in drag due to interaction between the ground and the aircraft's wingtip vortices. Like manned aircraft, UAS experience ground effect. This is true for both fixed-wing and multicopter drones. Ground effect can allow aircraft to become airborne even though they are not generating enough power for sustained flight. If this is the case, upon departing the area of ground effect, will lose the additional lift it provided.

The following video illustrates the "cushion" of air that aircraft experience as they near the ground:

- "Ground Effect Visualization" (Length 1:05)
  https://safeYouTube.net/w/LB5z

For teachers unable to access Safe YouTube links, the video is also available here: https://youtu.be/TdEWqWOokFU

**Slide 23:** Students will recall that manned helicopters can enter into a condition known as vortex ring state (VRS), or settling with power. This condition can also affect UAVs that have rotor systems, whether they are helicopters or multicopters. In normal conditions, airflow through the blades of a UAS is directed downward through the blades of the aircraft.

Vertical or near-vertical descents, the most problematic descent angles being 45–90°, can cause VRS to develop when they are performed at a moderate rate. A descent rate of 300 ft per minute is required for manned rotorcraft to enter VRS. This value is based on the behavior of air and can be thought of as a component of the fluid physics as a sort of "Goldilocks speed" that allows air vortices to form and curl inward and upward into the rotating bodies. During VRS, vortices of air begin to move upward through the rotors instead of downward. this will result in rapid descent of the aircraft.

**Slide 24:** Recovery from VRS is somewhat counterintuitive; a pilot's instinct might be to add more power to the rotors and create lift. However, this will only exacerbate the problem by making the upward vortices stronger. Recovery from VRS is obtained by moving horizontally at a higher rate to "cut through and away" from the vortices, or to descend faster still. The chosen method will typically depend on distance to the ground or other objects.

The following video offers a summary of VRS, as well as footage illustrating its effects on a drone:

- "Vortex Ring State and your DJI Phantom" (Length 3:59)
  https://safeYouTube.net/w/0F5z

For teachers unable to access Safe YouTube links, the video is also available here: https://www.youtube.com/watch?v=q3jhYhBn_NQ

**Slide 25**: VRS usually occurs during landing when a slow, vertical descent is used to bring a multicopter to a landing. The helicopter is in close proximity to the ground during this phase of flight, which means that there is often little room for recovery. VRS can also develop during a hover when altitude is not closely monitored and a descent develops. It is good practice to maintain forward airspeed during an approach to land, as this will keep an aircraft from beginning to settle into its own vortices.

**Slide 26:** To check retention, ask the following:

**Questions**

- At what point(s) do you think that VRS would be most likely to develop?
  *VRS is most likely to occur during the landing phase, when near-vertical, slow descents are used to land.*
- How can the risk of VRS be reduced when landing a multicopter?
  *Pilots should maintain forward airspeed on an approach to land.*

**Slide 27:** As was discussed in the last lesson, endurance is affected by variables that include weight and balance. Weather conditions also affect endurance; a simple rule is that anything that requires more maneuvering or control inputs will reduce endurance due to the drain on the drone's power source.

If a UAS is slowed by wind, it will not travel as far in a given period and will require more fuel or battery power to complete a mission. Likewise, greater weight will require more power to remain aloft and will slow the UAS. Remote pilots should thoroughly review manufacturer information and plan ahead so as not to run out of battery life and risk the drone or the safety of others.

**Slide 28:** The following activity is a continuation of the one conducted earlier in the **EXPLORE** section. Have students get into the groups they were in for the **EXPLORE** activity, and revisit and revise their answers for **UAS Aerodynamics and Performance Student Activity 1** in light of what they learned during the lesson. Then, discuss students' conclusions as a class, using the sample responses in **UAS Aerodynamics and Performance Teacher Notes 1** as a guide.

**Slide 29:** Complete the **Formative Assessment**.

**Formative Assessment**

Provide students with **UAS Aerodynamics and Performance Student Activity 2**, which contains a short quiz covering the topics discussed. Answers are provided in **UAS Aerodynamics and Performance Teacher Notes 2**.

[DOK-L1; *identify*]

## EXTEND

**Teacher Material:** UAS Aerodynamics and Performance Presentation

**Session 3**

**Slides 30-31:** Flying unmanned aircraft without GPS or sophisticated stabilization systems can be difficult, given the instability of multicopters. Sometimes, conditions such as wind will increase the difficulty even further. Also, if the center of gravity (CG) shifts as a result of a redistributed load (as students learned in the previous lesson), the change in balance can affect the flight characteristics. An example of such a change might be the installation of a new camera, which might make a drone that once hovered in place develop a backward, forward, or side-to-side motion.

While such conditions might make flight difficult, UAS come with a feature that reduces the workload of the remote pilot: trim. Trim, which can be manipulated using a ground control station, offers a fine tuning of pitch and bank (and, on some models, yaw and throttle). The result is that remote pilots can be more hands-off and don't need to worry that their aircraft could suddenly change course in an unwanted direction.

The following video illustrates the usefulness of trim on a quadcopter:

- "Drone How To: Trimming Your Quadcopter" (Length 2:24)
  https://safeYouTube.net/w/dH5z

For teachers unable to access Safe YouTube links, the video is also available here: https://youtu.be/NXNS-7iIT4U

**Slide 32:** Regulation 107.51 states that sUAS cannot be flown faster than a ground speed of 87 knots (100 miles per hour) or higher than 400 feet above ground level (AGL) unless flown within a 400 foot radius of a structure and not higher than 400 feet above the structure's immediate uppermost limit. VFR sectional charts are imperative for obtaining information about the locations and height of terrain and surrounding structures.

**Slide 33:** As a class, ask students the following two questions. Sample answers are not all-inclusive, but cover most practical solutions.

**Questions**

- How can remote pilots ensure that ground speed limits are not surpassed?
  - *Ground control station telemetry monitoring (real-time visual)*
  - *Setting speed limits in software*
  - *GPS monitoring*
  - *A radar gun*
  - *Installing internal or external sensors*

- How can remote pilots ensure that altitude limits are not surpassed?
  - *Ground control station telemetry monitoring (real-time visual)*
  - *Setting altitude limits in software*
  - *Visual references of known heights such as buildings or VFR landmarks depicted on a sectional chart,*
  - *Altitude-enabled GPS monitoring*

- *Using triangulation of ground distance and distance to GCS telemetry (if available)*
- *Have crewmembers pace off 400 feet from the UAS when it is on the ground to get a visual perspective of the distance the aircraft may appear in flight*

## EVALUATE

**Teacher Materials:** UAS Aerodynamics and Performance Presentation, UAS Aerodynamics and Performance Teacher Notes 3
**Student Material:** UAS Aerodynamics and Performance Student Activity 3

**Slides 34-61:** These lessons are building the knowledge to pass the FAA Remote Pilot Knowledge test. The following questions resemble actual questions on the FAA exam. Review the questions and answers with students.

**Slide 62:** Conduct the **Summative Assessment**.

**Summative Assessment**

Provide students with **UAS Aerodynamics and Performance Student Activity 3**. This scenario-based individual assessment will ask students to make operational decisions to reduce risk based upon given atmospheric conditions and aerodynamic principles (e.g. knowledge of vortex ring state). Sample responses are in **UAS Aerodynamics and Performance Teacher Notes 3**.

[DOK-L3; *assess*; DOK-1; *calculate*]

**Summative Assessment Scoring Rubric**

- Follows assignment instructions
- Postings show evidence of one or more of the following:
  - Demonstrates knowledge of how air conditions affect flight
  - Demonstrates knowledge of flight factors unique to multicopter and rotorcraft
  - Provides explanation of actions pilots can take to account for nonstandard conditions
- Contributions show understanding of the concepts covered in the lesson
- Contributions show in-depth thinking including analysis or synthesis of lesson objectives

| Points | Performance Levels |
|---|---|
| 9-10 | Plans two accurate flight models around various conditions using accurate calculations and a thorough understanding of weather factors |
| 7-8 | Plans two flight models around various conditions using mostly accurate calculations and a sufficient understanding of weather factors |
| 5-6 | Plans two flight models around various conditions. Calculations are mostly inaccurate and shows an insufficient understanding of weather factors |
| 0-4 | Flight models are incomplete and inaccurate. A lack of understanding of lesson objectives is evident |

## GOING FURTHER

- The site https://www.takeofflanding.com has an interactive Koch Chart. This can be loaded with a local airport and gives real time conditions.
- At https://www.weather.gov/epz/wxcalc_densityaltitude, the National Weather Service provides a calculator for ease of use in solving density altitude.
- Another version of a pressure calculator can be found here: http://imageserver.fltplan.com/PressureAndDensityAltitudeCalc.htm.

# STANDARDS ALIGNMENT

## COMMON CORE STATE STANDARDS

- **RST.11-12.2** - Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
- **RST.11-12.4** - 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 11-12 texts and topics*.
- **WHST.11-12.6** - Use technology, including the Internet, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information.
- **WHST.11-12.8** - Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
- **WHST.11-12.9** - Draw evidence from informational texts to support analysis, reflection, and research

### FAA AIRMAN COMPLETION STANDARDS

### REMOTE PILOT

**III. Weather, Task B. Effects of Weather on Performance**

- Knowledge The applicant demonstrates understanding of:
  - **UA.III.B.K1** Weather factors and their effects of performance:
    - **UA.III.B.K1a** a. Density altitude
    - **UA.III.B.K1b** b. Wind and currents
    - **UA.III.B.K1c** c. Atmospheric stability, pressure, and temperature

**IV. Loading and Performance, Task A. Loading and Performance**

- Knowledge The applicant demonstrates understanding of:
  - **UA.IV.A.K1** General loading and performance:
    - **UA.IV.A.K1a** a. Effects of loading changes
    - **UA.IV.A.K1b** b. Balance, stability, and center of gravity

- **UA.IV.A.K2** Importance and use of performance data to calculate the effect on the aircraft's performance of an sUAS.

## REFERENCES


https://www.aopa.org/training-and-safety/active-pilots/safety-and-technique/weather/density-altitude#WIDA
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"Vortex Ring State and your DJI Phantom" (Length 3:59) https://www.youtube.com/watch?v=q3jhYhBn_NQ
"Drone How To: Trimming Your Quadcopter" (Length 2:24) https://youtu.be/NXNS-7iIT4U