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UNIT 7 | SECTION A | LESSON 3 | PRESENTATION

UAS AERODYNAMICS AND PERFORMANCE

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LEARNING OBJECTIVES

At the end of this lesson, you will be able to:

- ***Identify*** **different ways that atmospheric conditions and aerodynamic principles might impact UAS performance.**
- ***Draw conclusions*** **about how atmospheric conditions will affect UAS performance on a given day.**
- ***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.**

WARM-UP

With your instructor, review the following key terms. Explain how and why each is an important factor for pilots.

- **Density Altitude**
- **Pressure Altitude**
- **Vortex Ring State**

CRASH INVESTIGATION ACTIVITY: PART I

Complete Student Activity 1.

- **As teams, you will investigate drone incidents using the included eyewitness accounts, weather information, and flight data.**
- **Then, list any likely contributing factors based on the information available.**
- **You will retain this activity sheet for use later in this lesson.**

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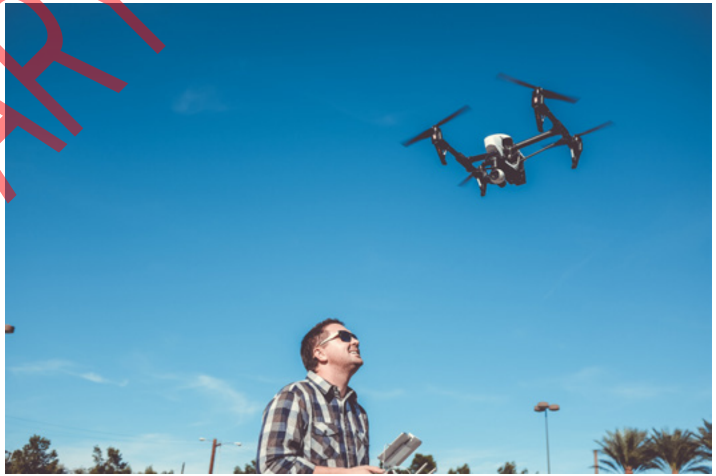
UAS PERFORMANCE & DATA AVAILABILITY

- **Manned aircraft have extensive information available gathered from test flights and have charts and graphs generated to show performance in many conditions.**
- **While this data regarding weight and balance, flight limitations, and performance information is plentiful for manned aircraft, it can be difficult or impossible to obtain for UAS.**

ALTERATIONS TO UAS

UAS operators are, in essence, test pilots.

- Without performance data readily available, PICs must find their own ways to obtain performance data for their aircraft in different conditions.
- Regardless, an understanding of factors such as density and pressure altitude is crucial for safety.
- Data may be found online at the manufacturer website, in a Pilot's Operating Handbook, or in the Owner's Manual.



Editorial credit: NeONBRAND via Unsplash

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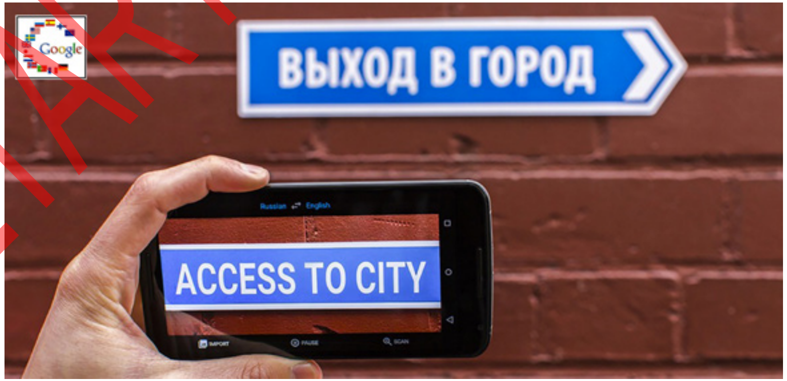
INFORMATION IN OTHER LANGUAGES

UAS information printed in other languages may need to be translated.

- **This can be done using a smartphone and web apps, such as:**
  - Google Translate
  - Google Lens
- **Simply point your phone at the document, and the app will translate to your native language.**



Editorial credit: Technotification

THRUST-TO-WEIGHT RATIO

- **Ensure that you have the following information:**
  - All available UAS flight performance data
  - Current conditions/weather data
- **You will then need to ensure your thrust-to-weight ratio is <u>2:1 or better</u> to ensure reliable performance and allow for a safety margin.**

The next slide will present two practice scenarios.

THRUST-TO-WEIGHT RATIO: APPLIED

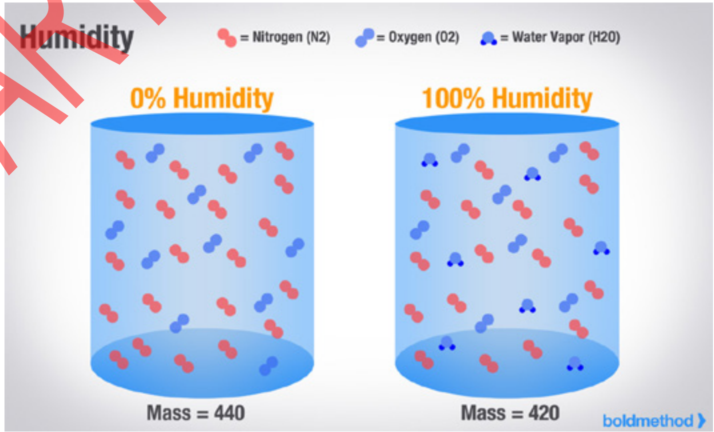
Solve the following problems.

- **Use the following formula: (W x 2) / E = L**
  - W = Total weight
  - E = # of engines/motors
  - L = Lift/thrust needed per engine or motor
  - Note: For 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?***
- ***If a hexacopter weighs 34.5 lbs, would motors providing 11 lbs of lift (per motor) be sufficient for a safe flight?***

FACTORS THAT AFFECT THE AIR

Water vapor weighs less than the nitrogen or oxygen in the air, but takes up about the same amount of space. Therefore:

- When there is more water vapor, the air has less mass.
- Less mass means the air is less dense.
- Temperature further affects the density of the air.
- All of these factors affect the density altitude.



Editorial credit: Boldmethod

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THERMAL LAPSE RATE & PRESSURE ALTITUDE

As you climb, temperature drops roughly 2°C per 1,000 feet. This is the thermal lapse rate.

- **Pressure Altitude**
  - The indicated altitude on the altimeter when it is set to an agreed upon standard pressure.
  - Standard conditions: 29.92" Hg (Inches of Mercury) & 15°C
  - Pressure altitude formula
    - (standard press. – current press. setting) x 1,000 + field elevation

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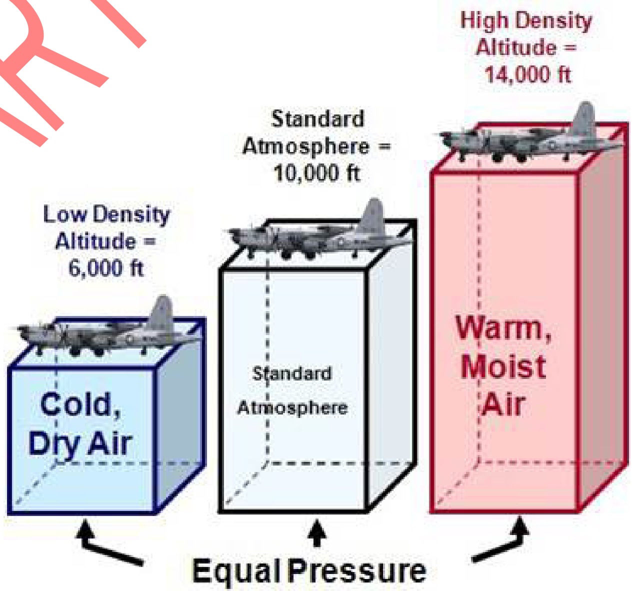
WHAT IS DENSITY ALTITUDE?

Density altitude is the altitude at which the aircraft would "feel" it is on a standard day.

- **Aircraft performance charts are usually based on standard day conditions.**
- **Density altitude formula**
  - Pressure altitude + [120 x (current temp. – ISA temp. for your elevation)]
  - ISA temperature: International Standard Atmosphere temperature, found on an ISA chart

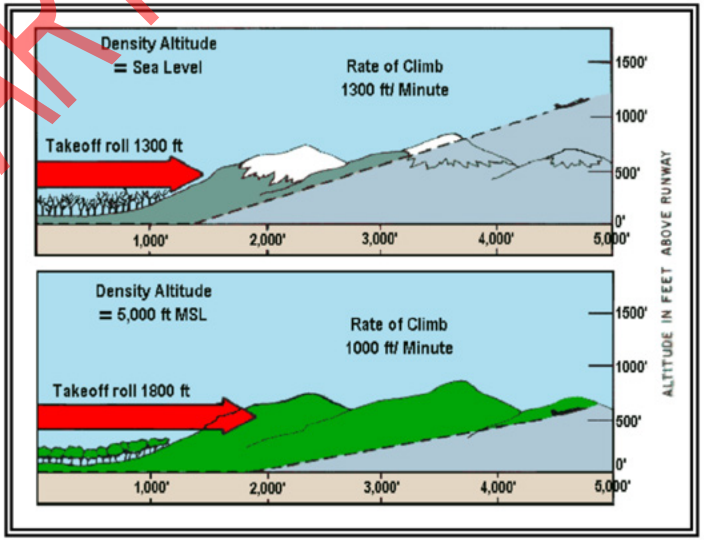


Editorial credit: National Weather Service

WHY DENSITY ALTITUDE MATTERS

A runway in Colorado and a runway in New Orleans have different elevations, humidities, and temperatures. Such factors affect air density and overall flight.

- A UAS will generate less lift when air is less dense (density altitude is higher).
- As density altitude increases, an aircraft must work harder to make up for fewer air molecules.



Editorial credit: AOPA

DENSITY ALTITUDE: APPLIED

Using the following conditions, figure out the pressure and density altitudes.

- **Takeoff Field Elevation: 1,500 MSL**
- **Current Pressure: 30.00” Hg**
- **Temperature: 19°C**
  - *What is the pressure altitude?*
  - *What is the density altitude?*

Pressure altitude = (standard pressure – current pressure setting) x 1,000 + field elevation

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

(ISA temperature is 15°C, and –2° per 1,000 ft)
Therefore, ISA at 7,000 ft would be 1°C.

DENSITY AND NEWTON'S THIRD LAW

For every action, there is an equal and opposite reaction, per Newton's Third Law. Therefore:

- **As each air molecule is pushed *backward* by the propeller, it pushes the propeller equally *forward.***
- **Having more or fewer molecules to push in a given volume of air has a large impact on the efficiency of the propeller.**
- **During takeoff and landing, this effect is magnified because ground-level temperatures are warmer and ground speeds are lower.**

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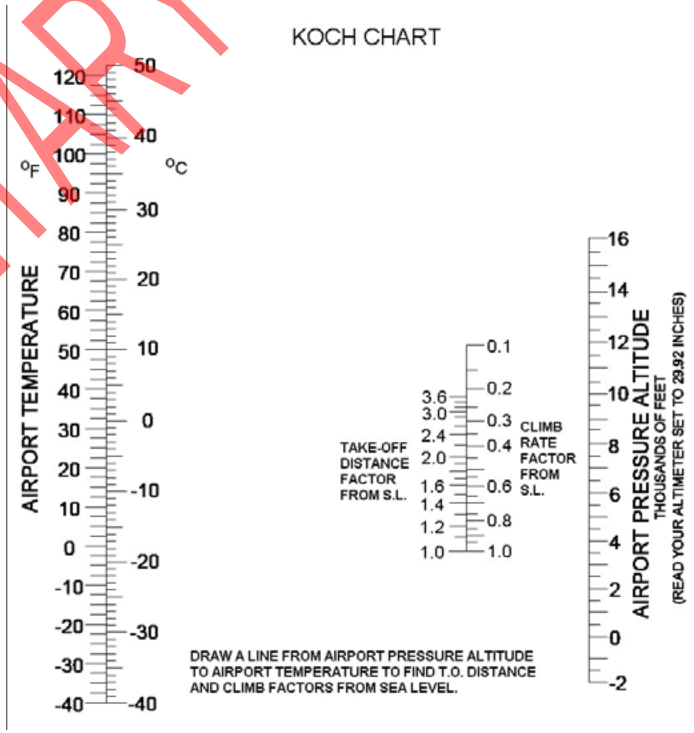
THE KOCH CHART

The Koch (pronounced “coke”) Chart is a tool that allows for quick estimation of takeoff distances and rate of climb.

- An interactive version is available here: www.takeofflanding.com

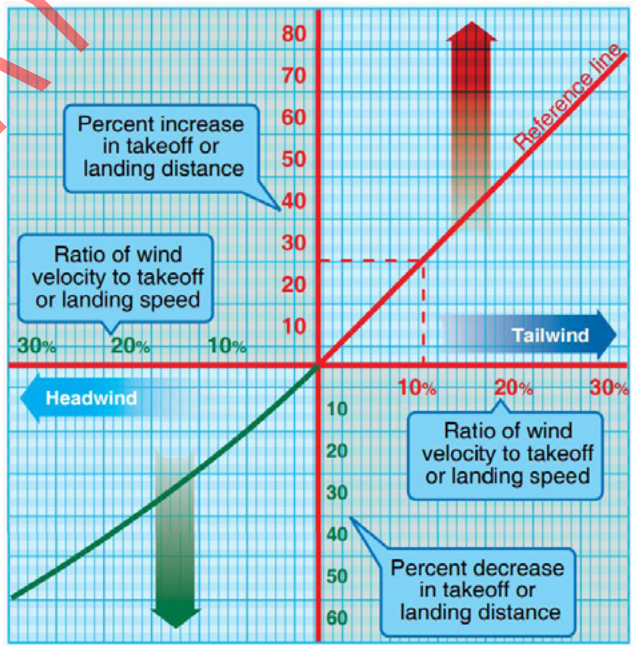


Editorial credit: AerodynamicAviation.com

AERODYNAMICS OF LANDING

Landing, takeoff, and climbs are greatly influenced by atmospheric conditions.

- **Landing, takeoff, and climbs should be done into a headwind when possible.**
  - This increases the amount of air passing through the propeller.
  - This, in turn, reduces the effect of cross-winds, and in multicopters, the likelihood of a Vortex Ring State developing, which will be covered soon.



Editorial credit: Pilot's Handbook of Aeronautical Knowledge

AERODYNAMICS: KNOWLEDGE CHECK

What direction relative to the wind should takeoffs, climbs, and landings be made? Why?

What is a Koch Chart for?

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RECONNAISSANCE OF HAZARDS

The values and information obtained during preflight regarding density altitude, the Koch Chart, and prevailing weather conditions should all be taken into account when choosing takeoff and landing locations.

- **This ensures enough room for takeoff, landing, and any emergency maneuvers like aborted landings, takeoffs, or wind shear recovery.**
- **Obstacles can change airflow drastically by obstructing the flow of prevailing winds, and turbulence can result from areas where heating and/or cooling of the earth's surface is uneven.**

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ICE AND WINTRY WEATHER

Ice degrades airflow and can accumulate rapidly due to fast moving surfaces in cold temperatures. The most common areas for this to occur are:

- Wing leading edges on fixed-wing aircraft
- Propeller leading edges on both rotorcraft and fixed-wing aircraft
- Carburetors of reciprocating engine fixed-wing aircraft

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GROUND EFFECT

Ground effect—which occurs at altitudes less than one-half the wingspan of an aircraft above the ground—causes aircraft to experience a reduction in drag.

- **Aircraft can become airborne even though they are not generating enough power, and upon departing the area of ground effect, the aircraft will lose the additional lift it provided.**

VIDEO

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VORTEX RING STATE

Vortex Ring State, also known as "settling with power," affects rotor systems.

- Normally, air flows downward through the blades of rotorcraft. When certain descent rates are reached, vortices can develop that push air upward through the inner sections of the rotor blades.
- What results is the rapid, uncontrolled descent of the aircraft.
- The most problematic descent angles that can cause VRS are between 45 and 90 degrees.

Editorial credit: Pilot's Handbook of Aeronautical Knowledge

VORTEX RING STATE: RECOVERY

A pilot's instinct might be to add more power to the rotors and create lift—however, this will only make the upward vortices stronger.

- **Recovery is generally accomplished by one of two methods:**
  - Moving horizontally
  - Descending faster still
- **The chosen method will typically depend on distance to the ground or other objects.**

This video illustrates the effects of VRS on a drone.

VIDEO

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VORTEX RING STATE: BEST PRACTICES

Vortex Ring State can be avoided with awareness of the conditions it develops with, and proper precautionary flight techniques.

- **It usually occurs during landing when slow, vertical descent is typically being used.**
  - Keep in mind this allows for less vertical recovery space because of ground proximity.
  - It is good practice to maintain forward airspeed during an approach to land.
- **VRS can also develop during a hover if altitude is not closely monitored by the PIC.**

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VORTEX RING STATE: KNOWLEDGE CHECK

At what point(s) do you think that VRS would be most likely to develop?

How can the risk of VRS be reduced when landing a multicopter?

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ENDURANCE

Endurance, or the duration of the ability to maintain powered flight, is affected by many factors:

- Weight and balance
- Wind
- Temperature
- Humidity
- Density altitude
- … and more

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CRASH INVESTIGATION ACTIVITY: PART II

Break into the same groups from earlier in the lesson, when you completed Student Activity 1.

- **Revisit and revise your answers as necessary, in light of what you have learned to this point.**
- **As a class, discuss your conclusions; be prepared to support your ideas using the topics discussed in the lesson.**

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AERODYNAMICS AND PERFORMANCE QUIZ

WORK INDIVIDUALLY TO DEMONSTRATE YOUR UNDERSTANDING OF THE LESSON SO FAR BY ANSWERING THE QUESTIONS FOR STUDENT ACTIVITY 2.

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INSTABILITY MANAGEMENT: PART I

Multicopters are inherently unstable.

- **GPS positioning systems keep the aircraft oriented in 3D space and help the PIC maintain more hands-off control of the aircraft.**
- **Without such a system, flying in a stable manner can prove difficult.**
  - CG could shift from a camera installation, changing the flight characteristics.
  - Wind conditions may change in-flight.
  - Icing conditions could alter the thrust power of one of more propellers.

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INSTABILITY MANAGEMENT: PART II

Another system to help maintain stability is the trim system.

- **Trim can be manipulated using the GCS, and offers the ability to fine tune the pitch and bank of the aircraft.**
  - On some models, this can include yaw and throttle trim.
  - This allows the pilot to fly more hands-off.
- **Paired with a GPS positioning system, a UAS can remain stable even in non-ideal conditions.**

VIDEO

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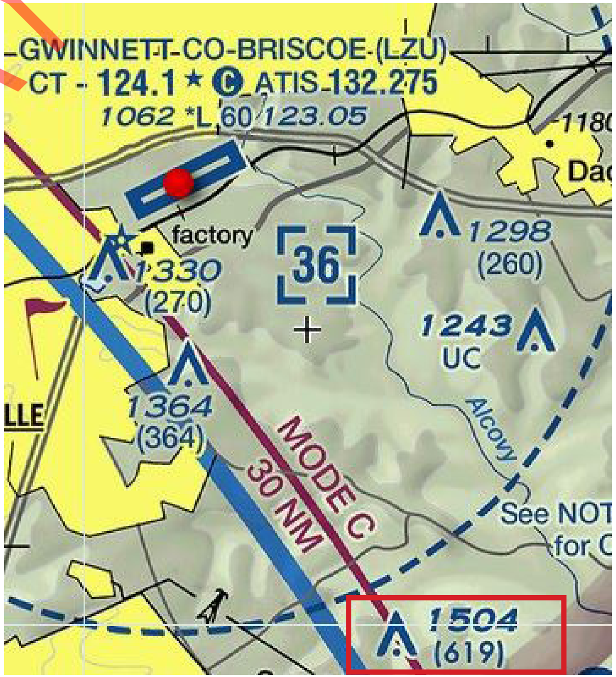
FLYING WITHIN LIMITS

Regulation 107.51 mandates the following:

- **An sUAS cannot be flown faster than a ground speed of 87 knots (100 miles per hour).**
- **An sUAS cannot be flown 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 height of nearby structures and objects.**



Editorial credit: SkyVector

FLYING WITHIN LIMITS: KNOWLEDGE CHECK

As a class, answer the following two questions:

- ***How could remote pilots ensure that ground speed limits are not surpassed?***
- ***How could remote pilots ensure that altitude limits are not surpassed?***

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REMOTE PILOT KNOWLEDGE TEST QUESTION

ACCORDING TO 14 CFR PART 107, WHO IS RESPONSIBLE FOR DETERMINING THE PERFORMANCE OF AN sUAS?

A. Remote pilot-in-command.

B. Owner or operator.

C. The manufacturer.

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REMOTE PILOT KNOWLEDGE TEST ANSWER

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REMOTE PILOT KNOWLEDGE TEST QUESTION

THE MOST CRITICAL CONDITIONS OF LAUNCH PERFORMANCE ARE THE RESULT OF SOME COMBINATION OF TEMPERATURE, ALTITUDE, HIGH GROSS WEIGHT, AND

A. obstacles surrounding the launch site.

B. unfavorable wind.

C. available battery.

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REMOTE PILOT KNOWLEDGE TEST ANSWER

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REMOTE PILOT KNOWLEDGE TEST QUESTION

MAXIMUM ENDURANCE IS OBTAINED AT THE POINT OF MINIMUM POWER TO MAINTAIN THE AIRCRAFT

A. in steady, level flight.

B. at the slowest airspeed possible.

C. in a long gradual descent.

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REMOTE PILOT KNOWLEDGE TEST ANSWER

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REMOTE PILOT KNOWLEDGE TEST QUESTION

WHAT IS THE BEST SOURCE FOR SUAS PERFORMANCE DATA AND INFORMATION?

A. Manufacturer publications.

B. Estimates based upon similar systems.

C. Aeronautical Information Manual (AIM).

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REMOTE PILOT KNOWLEDGE TEST QUESTION

HOW CAN A REMOTE PILOT DETERMINE THE ALTITUDE OF THE TERRAIN AND STRUCTURES WHERE AN sUAS OPERATION WILL TAKE PLACE?

A. Sectional chart.

B. Road maps.

C. Google Earth.

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REMOTE PILOT KNOWLEDGE TEST ANSWER

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REMOTE PILOT KNOWLEDGE TEST QUESTION

A REMOTE PILOT IS OPERATING AN SUAS THAT DOES NOT HAVE GPS OR AN INSTALLED ALTIMETER. HOW CAN THEY DETERMINE THE ALTITUDE AT WHICH THEY ARE OPERATING?

A. Gaining a visual perspective of what 400 feet looks like on the ground before the flight.

B. Operating a second sUAS that has an altimeter to gain a visual perspective of 400 feet from the air.

C. Operating the sUAS in close proximity to a structure known to be 400 feet tall.

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REMOTE PILOT KNOWLEDGE TEST QUESTION

THE TERM "ANGLE OF ATTACK" IS DEFINED AS THE ANGLE

A. between the wing chord line and the relative wind.
B. between the angle of incidence and the horizon.
C. formed by the longitudinal axis of the aircraft and the chord line of the airfoil.

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REMOTE PILOT KNOWLEDGE TEST QUESTION

THE ANGLE OF ATTACK AT WHICH AN AIRFOIL STALLS WILL

A. increase if the CG is moved forward.

B. remain the same regardless of gross weight.

C. change if gross weight is increased.

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REMOTE PILOT KNOWLEDGE TEST QUESTION

AN INCREASE IN LOAD FACTOR WILL CAUSE AN UNMANNED AIRCRAFT TO

A. stall at a higher airspeed.
B. enter an uncontrolled state.
C. pitch up.

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REMOTE PILOT KNOWLEDGE TEST ANSWER

AN INCREASE IN LOAD FACTOR WILL CAUSE AN UNMANNED AIRCRAFT TO

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C. pitch up.

REMOTE PILOT KNOWLEDGE TEST QUESTION

AS ALTITUDE INCREASES, THE ANGLE OF ATTACK AT WHICH A GIVEN sUAS STALLS WILL

A. decrease as the true airspeed decreases.

B. decrease as the true airspeed increases.

C. remain the same as at low altitude.

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REMOTE PILOT KNOWLEDGE TEST ANSWER

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REMOTE PILOT KNOWLEDGE TEST QUESTION

WHAT IS THE MOST EFFECTIVE WAY TO RECOVER IF YOU FIND YOUR SUAS IN VORTEX RING STATE?

A. Increase forward speed.

B. Increase power.

C. Initiate a climb.

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REMOTE PILOT KNOWLEDGE TEST QUESTION

WHAT EFFECT DOES HIGHER DENSITY ALTITUDE HAVE ON PROPELLER EFFICIENCY?

A. Increased efficiency due to less friction on the propeller blades.

B. Reduced efficiency because the propeller exerts less force than at lower density altitudes.

C. Increased efficiency because the propeller exerts less force on the thinner air.

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REMOTE PILOT KNOWLEDGE TEST QUESTION

WHICH OF THE FOLLOWING DOES NOT OCCUR WHEN A UAS ENTERS GROUND EFFECT?

A. Reduced drag.

B. Reduced lift.

C. Increased performance.

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REMOTE PILOT KNOWLEDGE TEST ANSWER

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A. Reduced drag.

B. Reduced lift.

C. Increased performance.

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REMOTE PILOT KNOWLEDGE TEST QUESTION

WHAT COMBINATION OF ATMOSPHERIC CONDITIONS WILL REDUCE AIRCRAFT TAKEOFF AND CLIMB PERFORMANCE?

A. Low temperature, low relative humidity, and low density altitude.
B. High temperature, low relative humidity, and low density altitude.
C. High temperature, high relative humidity, and high density altitude.

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REMOTE PILOT KNOWLEDGE TEST ANSWER

WHAT COMBINATION OF ATMOSPHERIC CONDITIONS WILL REDUCE AIRCRAFT TAKEOFF AND CLIMB PERFORMANCE?

A. Low temperature, low relative humidity, and low density altitude.

B. High temperature, low relative humidity, and low density altitude.

C. High temperature, high relative humidity, and high density altitude.

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OPERATIONAL RISK MANAGEMENT ACTIVITY

INDIVIDUALLY, USE WHAT YOU HAVE LEARNED IN THE COURSE TO RESPOND TO SCENARIOS PRESENTED IN THE STUDENT ACTIVITY 3 WORKSHEET.

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