Anti-Icing Systems

Session Time: Three, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

The intended purpose and use of an aircraft drives aircraft design considerations and construction techniques, materials, and components. (EU 1)

Innovations in aviation are driven by the desire to make aircraft safer, more capable, and more efficient. (EU 3)

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. (EU 5)

ESSENTIAL QUESTIONS

1. How does icing affect aircraft and how they fly?
2. How does icing equipment affect the way we fly?

LEARNING GOALS

Students Will Know

- What aircraft icing is
- How it affects flight
- What can be done to prevent, address, or avoid it

Students Will Be Able To

- *Describe* the circumstances in which icing forms. (DOK-L2)
- *Compare* icing solutions. (DOK-L3)
- *Analyze* an icing accident in light of what they've learned. (DOK-L4)

ASSESSMENT EVIDENCE

Warm-up
Students will begin by stating what they already know or assume to know about ice and how it could negatively impact flight operations, both on the ground and in the air. The teacher should write the students' correct responses on a board where everyone can see in order to keep track and potentially address them as they come up in the lesson.

Formative Assessment
Students will complete a worksheet that challenges them to recall what they've learned regarding the causes of icing, the reasons it is problematic, and the technologies available to deal with it.

Summative Assessment
Students will combine into teams to assess a fatal icing accident in light of what they've learned. Each team will draw conclusions about the causes of the accident, then make a presentation to the class which includes information about

the conditions in which the ice was formed, the actions of the pilot, and what could have been done to prevent the accident.

LESSON PREPARATION

MATERIALS/RESOURCES

- Anti-Icing Systems Presentation
- Anti-Icing Systems Student Activity 1
- Anti-Icing Systems Student Activity 2
- Anti-Icing Systems Student Activity 3
- Anti-Icing Systems Student Activity 4
- Anti-Icing Systems Teacher Notes 1
- Anti-Icing Systems Teacher Notes 2
- Anti-Icing Systems Teacher Notes 3
- Anti-Icing Systems Teacher Notes 4

Ice in Flight (per group)

- 2 small, inexpensive model gliders, foam or balsa wood will work
- water
- sink sprayer or water bottle
- access to a freezer
- a scale

Deice, Ice Baby (per group)

- 4 large ice cubes
- 3 bowls
- water
- glycol or antifreeze
- plate
- moderately heated surface, such as coffee warmer, candle warmer, or crockpot

Recommended Student Reading

- **Pilot's Handbook of Aeronautical Knowledge**
  Chapter Seven, Aircraft Systems, pages 7-40 to 7-41 https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/09_phak_ch7.pdf

LESSON SUMMARY

Lesson 1: Pressurization and Oxygen Systems
Lesson 2: Anti-Icing Systems

This two-session lesson will begin by allowing students to share their existing knowledge about icing to create a shared mental model and engage them before jumping into the presentation.

Throughout this lesson, students will explore the basic principles of icing as they relate to aircraft operations. This includes the theory behind why/how airframe ice forms, why it is so dangerous, the weather phenomena that cause it, how pilots should plan, anti-icing and deicing equipment, as well stories of accidents and how they could have been prevented.

An activity in which students weigh and attempt to fly model gliders coated in ice will help illustrate the two key dangers associated with icing—added weight, and airflow disruption that reduces lift and increases drag.

As a formative assessment, students will recall what they have learned regarding the causes of icing, the reasons it is problematic, and the technologies available to deal with it by completing a worksheet. Students will then use ice cubes to model the ways in which different anti-icing solutions work.

At the conclusion of the lesson, students will answer private pilot knowledge test questions. As the summative assessment, students will take on the role of safety investigators following an actual fatal aircraft accident relating to icing. Students will give presentations that give both contributing and causal factors.

BACKGROUND

Ice forms on aircraft surfaces when there is visible moisture present (i.e. clouds, fog, drizzle, mist, etc.) and air and/or aircraft surface temperatures are below freezing. Ice can begin to form layer upon layer, and the thicker the ice, the greater the likelihood that the air passing over the surfaces will become disrupted. Even a very thin coating of ice can disrupt airflow over the airfoils, decreasing lift and increasing drag. Thicker coatings of ice can also add significant weight, potentially making an aircraft too heavy to fly.

Icing has been a problem since the earliest days of aviation, and it has been the cause of many fatal accidents through the years. Over time aircraft manufacturers have developed solutions to help remove ice (deicing) on the ground and in the air, and inhibit the formation and accumulation of ice (anti-icing). Today, many aircraft are equipped with deice or anti-ice measures. Prediction and avoidance capabilities have also significantly improved, however icing still remains a significant threat to the aviation community.

In addition to the problems with lift and weight associated with ice, it can also block the windscreen, preventing pilots from seeing, clog ports and tubes, causing instrument failures, break antennas and probes, and even be ingested into engines, causing engine failure.

MISCONCEPTIONS

Although students have learned the details of how ice affects the carburetor and fuel systems in previous lessons, they likely do not understand the intricacies of how ice affects flight and how dangerous it can be. The warm-up for this lesson is meant to establish a baseline for what the students think they know about ice formation and how it affects flight. Any misconceptions they may have should be addressed at the beginning of the lesson so as to not carry these wrong assumptions through the entire lesson. However, the proper concepts that students have should be written down on the board and built upon as the lesson progresses.

Ice may be somewhat of a nuisance on the ground in the day-to-day lives of those not in the aviation business, but it can be deadly for aviators and their passengers if not properly understood and avoided/mitigated. There is a significant difference between driving on icy roads with residual ice on your car and flying with ice on your aircraft. While a car may slip and slide, an aircraft may be incapable of continued flight.

DIFFERENTIATION

To support struggling students during the Formative Assessment, create a word bank by writing the answer options on the board. To assist students in developing ideas regarding accident causes for the Summative Assessment, quickly review the key dangers associated with icing and revisit the slide on ground deicing and its limitations.

LEARNING PLAN

ENGAGE

Teacher Material: Anti-Icing Systems Presentation

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

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

Warm-Up

Ask students to state what they know about ice as it relates to flying. This discussion can include weather phenomena, physics, aircraft operation, and ways to prevent and eliminate ice. Write the students' correct responses on a board where everyone can see in order to keep track and potentially address them as they come up in the lesson.

Possible correct statements/assumptions:

- *Ice disrupts airflow over aircraft surfaces.*
- *Ice increases weight and drag while decreasing lift.*
- *Ice is one of the most dangerous threats to an aircraft.*
- *Ice can be clear, rime, or mixed.*
- *There are countermeasures, but the best course of action is avoidance.*
- *Deicing removes ice that has formed, while anti-icing keeps ice from forming.*
- *For ice to form on aircraft surfaces, there must be visible moisture and temperatures at or below freezing.*
- *Ice can form over tubes and ports, causing significant instrument errors.*
- *Of all the weather phenomena that can causing aircraft icing, freezing rain is the most dangerous.*

[DOK-L2; *Predict*]

EXPLORE

Teacher Materials: Anti-Icing Systems Presentation, Anti-Icing Systems Teacher Notes 1
Student Material: Anti-Icing Systems Student Activity 1

Slide 5: Ice forms on aircraft surfaces when there is visible moisture present (e.g., clouds, fog, or rain) and when temperatures are at or below freezing. Temperatures refers to either the ambient air temperature or the temperature of the surface to which the moisture binds, such as the aircraft skin. Ice disrupts the flow of air over aircraft surfaces, decreasing lift. Ice can also form layer upon layer, and the thicker the ice, the greater the weight.

Since the early days of aviation, icing has cost many their lives and aircraft. Over time, as understanding increased, aircraft manufacturers and engineers introduced both deice (ice removal) and anti-ice (ice prevention) systems to combat icing and increase safety. Prediction and avoidance capabilities have also significantly improved; however, icing still remains a significant threat to the aviation community.

Slide 6: Ice poses a number of aerodynamic hazards. On aerodynamic surfaces such as the wings and stabilizers, ice disrupts airflow, reducing lift and increasing drag. It also increases stall speed. Accumulations of ice may cause some lifting surfaces, such as the tail, to stall unexpectedly. Even with a light frost, lift can be significantly reduced. With enough accumulation, aircraft control may be lost. Wind tunnel and flight tests have found that accumulations of ice (to include frost and snow) on a wing's leading edge/upper surface that are no thicker or rougher than a piece of coarse sandpaper can reduce lift as much as 30 percent and increase drag by 40 percent!

Slide 7: Ice causes lots of other problems, too.

- Ice adds to the aircraft's overall weight, increasing fuel consumption, required angles of attack (AOA), and approach /landing speeds. It can make the aircraft too heavy to keep flying.

- On the windscreen, it restricts the pilot's ability to see.
- It can clog sensors, including pitot tubes, static ports, vents, and other critical openings, which could cause instrument errors or failures and degrade necessary venting.
- Ice increases the surface area of antennas and probes, increasing their weight and drag, and could potentially cause them to break off at higher indicated airspeeds.
- Ice can potentially lock up an engine by blocking the air supply or even sending ice chunks into the engine itself.

Slide 8: Three different types of ice commonly form on aircraft structures—rime ice, clear ice, and mixed ice.

- Rime ice has a milky, white appearance, and a rough texture. Most of it can usually be removed or prevented by deicing and anti-icing systems.
- Clear ice, sometimes also called "glaze ice," tends to be translucent. It may be smooth, but often contains air pockets that make the surface bumpy or rough. It is more dense and harder than rime ice, and can be difficult to break or remove.
- Mixed ice is a combination of clear and rime ice.

Slide 9: A variety of phenomena affect icing formation.

- Not all clouds are alike. Some are more wet than others. Geography plays a large part in this, as clouds forming over large bodies of water tend to pose a more significant threat because they contain more moisture.
- Stratus clouds tend to contain more rime ice, and cumulus clouds tend to contain the more dangerous clear ice.
- Clouds behind cold fronts and some warm fronts tend to produce the most ice.
- Freezing rain causes the most rapid accumulation of ice, making it the most dangerous.

Slide 10: Show this video to explain how and why pilots need to pay attention and respond to icing.

- "Flying the Weather: Picking Up Ice" (Length 4:29)
  https://video.link/w/u1Xg

Questions

After watching the video, ask students to jot down their response to the following question. Then, ask for a few student volunteers to share what they learned from the video.

- What do you think are some of the most important tips from this video?
  Possible response: how subtle icing accumulation may be, notice it on small surfaces first, next notice vibrations, do everything you can to escape icing conditions. Be prepared to recognize instrument failures and fly without use of those instruments.

Slide 11: Prior to beginning Student Activity 1, be sure to prepare the frozen model airplane.

Distribute a copy of **Anti-Icing Systems Student Activity 1** to each student. In this activity, students will use model airplanes to explore how ice affects aircraft performance and aerodynamics. Students should record their observations and answers to the questions.

Additional directions and possible responses are provided in **Anti-Icing Systems Teacher Notes 1**.

EXPLAIN

Teacher Materials: Anti-Icing Systems Presentation, Anti-Icing Systems Teacher Notes 2
Student Material: Anti-Icing Systems Student Activity 2

Slide 12: Some aircraft are better equipped to handle icing conditions than others. The best equipped aircraft are certified for "flight into known icing" conditions, or FIKI.

- **FIKI:** This type of aircraft is legal to fly in icing conditions. Most airliners and large cargo aircraft fall into this category. They must meet strict requirements and be equipped with both deice and anti-ice systems, although avoiding icing is still the best course.
- **Non-FIKI:** Most small and general aviation aircraft are not certified for flight into known icing conditions. This does not necessarily mean that the aircraft is not equipped with deice or anti-ice systems designed to be used in the event of unexpected encounters with ice. It simply means that the aircraft cannot be deliberately flown in known icing conditions.

FIKI aircraft are more expensive and complex. If a particular airplane will never be flown in icing conditions, then it would make sense to cut down on cost and complexity by not having deicing and anti-icing systems.

Slide 13: Anti-icing systems inhibit the formation of ice. Deicing systems remove ice that has already formed.

Both anti-icing and deicing systems protect the:

- wing leading edge and tail surfaces
- pitot and static port openings
- fuel tank vents
- stall warning devices
- windshield
- propeller blades

More advanced aircraft may also be equipped with ice detection caution/warning lights as well as lights on the control surfaces themselves so the pilots can see the extent of icing during night flights.

The majority of light general aviation aircraft only have a heated pitot tube, so they are not equipped for flying in ice. Any aircraft that is not FIKI certified must exit icing conditions immediately under federal regulations.

Slide 14: One example of a system that acts as a deicer for the aircraft's airfoil is the inflatable boot. This is a rubber sheet that's been bonded to the airfoil's leading edge. The pneumatic pump that inflates the boot to crack and break away ice is engine-driven, and many turboprop aircraft divert bleed air to the wing to do this. The inflatable boot is controlled by a switch on the flight deck and can be activated one time or set to cycle automatically at certain time intervals.

In older versions of boots, if they were inflated too early while still in icing conditions, the ice layer would actually expand rather than break off, leading to ice bridging. This would cause the following boot inflations to be ineffective and fail to remove the ice. With modern boots, some residual ice will remain, but bridging should not occur. Therefore, pilots can now cycle the boots immediately when they notice ice accumulation. Each aircraft/boot has its own manufacturer specifications and recommendations, which the pilot should know and follow.

Use this short video to show deicing boots in action.

- "Boots Deicing in Severe Icing Conditions" (Length 0:42)
  https://video.link/w/3EXg

Slide 15: Heating the leading edges of wings and other leading edges is an effective way to prevent ice formation. These are called thermal anti-ice systems. High performance aircraft often have hot air to spare from the engine. In turbine aircraft, hot air from the compressor is directed to the leading edges. The surfaces then become hot enough to melt ice or prevent its formation.

Some newer aircraft use an electrically-heated graphite foil laminate, which is applied to the wing and horizontal stabilizer leading edges. These typically have both a forward zone and an aft zone:

- The forward zone receives continuous heat to prevent ice from forming (anti-icing).
- The aft zone receives heat on/off in cycles to dislodge existing ice (deicing).

As with other anti-ice systems, these should be engaged prior to entering icing conditions.

Slide 16: A less-common ice protection system that is capable of both anti-ice and deice is known as the weeping wing. This system utilizes small holes located wings' leading edges to pump out antifreeze, usually glycol based. The liquid is blown back across the wing surfaces, which both breaks down built-up ice and prevents further ice from accumulating.

Slide 17: Windscreens may use two different types of anti-ice systems.

- Like the weeping wing, one system pumps glycol out of windshield nozzles to the windscreen to chemically break down ice and prevent further accumulation. The flow rate is controlled from the flight deck.
- The electric heating method uses small wires or conductive materials which are embedded in between the layers of the windscreen, similar to the rear window defrosters on many cars. A switch on the flight deck activates an electrical current that heats the conductive materials enough to prevent ice formation. However, this system should only be activated during flight so that the passing air may cool the windscreen. If left on while on the ground, it could potentially overheat and crack or otherwise damage the windscreen. Additionally, it may cause the magnetic compass to deviate as much as 40° due to the magnetic field produced by the electrical current.

Slide 18: Even though propellers move at high rates of speed, they are subject to in-flight icing and require anti-ice system protection. Like the wing and windscreen protection systems, propellers may use glycol or electrically-heated elements to prevent or remove ice.

Like the weeping wing, some propellers are equipped with discharge nozzles aimed at the blades' roots. Because this system is made to operate while the propeller is spinning, centrifugal force moves the glycol across blades' leading edges. As with the wings, the leading edges are the most critical for maintaining lift and ensuring that the flow of air remains undisrupted.

Slide 19: Other parts of the aircraft are also equipped with anti-ice and deice systems. Some of the most critical components on the aircraft are the pitot and static ports, fuel vents, and stall-warning sensors. Electrical heat is supplied to them to ensure the pilots' instruments are accurate even in icing conditions. Depending on the aircraft, other ports, antennae, and equipment may also be electrically heated.

Proper preflight of all these systems is critical to ensure a safe operating aircraft. None of this equipment, however important, is intended to allow for sustained long-term flight in icing conditions.

Slide 20: Prior to taxi and takeoff, ice and frost must be removed from the aircraft, especially the airfoils. Prevention is the best option. Where possible, aircraft may be placed in heated hangers to keep the surfaces clean and prevent frost and ice from forming in the first place. Sometimes planes that have accumulated ice are towed into heated hangars to allow the ice to melt. More often, the solution is to apply a deicing spray. This spray is typically a heated mixture of glycol and water and acts as an anti-icing agent as well by adhering to the aircraft surfaces. This is a short-term solution, however, and aircraft that remain in icing conditions while on the ground (to include freezing fog or frost-accumulating environments) have a limited amount of time before they must be deiced again. That's why it's critical to activate aircraft anti-icing as soon as possible after deicing has been accomplished.

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

Formative Assessment

Students will complete a worksheet that challenges them to recall key terms and features of icing and anti-icing systems. Provide a copy of **Anti-Icing Systems Student Activity 2** to each student and give them about 10 minutes to complete the questions.

Correct answers are provided in **Anti-Icing Systems Teacher Notes 2**.

[DOK-L1; *Recall*]

EXTEND

Teacher Materials: Anti-Icing Systems Presentation, Anti-Icing Systems Teacher Notes 3
Student Material: Anti-Icing Systems Student Activity 3

Slide 22: In this activity, students will test the effectiveness of aircraft deicing applications and write down their observations. Divide the class into small groups, depending on the materials available. Provide a copy of **Anti-Icing Systems Student Activity 3** to each student and give them about 10 minutes to complete this experiment. Additional instructions and possible student responses are provided in **Anti-Icing Systems Teacher Notes 3**.

Slide 23: Although weather will be addressed in detail in future lessons, students should understand that they are responsible for gathering "all available information" for a planned flight—and weather is a vital part of that. When it comes to known icing conditions, the rate of accumulation is important. Weather forecasts use standard terminology to help pilots understand how fast ice is likely to build up.

Point out the code and symbol for each icing intensity as you read the description.

- **Trace:** Ice becomes perceptible. Rate of accumulation is slightly greater than the rate of sublimation. It is not hazardous. Deicing/anti-icing equipment is not used unless encountered for an extended period of time (over 1 hour).
- **Light:** The rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour). Occasional use of deicing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used.
- **Moderate:** The rate of accumulation is such that even short encounters become potentially hazardous and use of deicing/anti-icing equipment or flight diversion is necessary.
- **Severe:** The rate of accumulation is such that deicing/ anti-icing equipment fails to reduce or control the hazard. Immediate flight diversion is necessary.

Slides 24-25: Pilots have several tactics when it comes to icing environments.

- **Fly in the clear.** Even though this should be obvious, many pilots fail to heed it, especially those that are equipped with anti-ice/deice systems. Pilots should avoid clouds by flying on top of or between cloud layers, which will help aircraft avoid the majority of icing situations. Pilots shouldn't shy away from requesting different altitudes from air traffic control. Pilots should also ask air traffic controllers for any pilot reports, called pireps. When available, these reports can provide information about a range of conditions, including icing, cloud altitudes, and turbulence.
- **Know the cloud bases, tops, and layers along the route of flight.** A solid deck (i.e., overcast) from 2,000 feet to 25,000 feet is significantly more dangerous—and much harder to escape—than scattered layers between the same altitudes.
- **Know your aircraft.** If you don't have proper deice/anti-ice equipment, then assess if your aircraft can handle the potential for icing along your route of flight. Additionally, know your service ceiling and performance ceiling. Some of the heaviest icing accumulations tend to occur near cloud-top height, so flying at an altitude that is in and out of the cloud tops is inadvisable.
- **Avoid using drag devices (flaps, gear, spoilers).** When approaching or within icing conditions, avoid using flaps and extending the landing gear until necessary. They increase the surface area of the aircraft and potential for ice accumulation.

- **Watch out for warm fronts.** The rain falling along the edge of the front may turn into supercooled droplets if it falls into the cold air that is being pushed back ahead of it. So even flying clear of clouds ahead of a warm front could put pilots in danger of encountering freezing rain, which produces the greatest accumulation rates of dangerous clear ice.

- **Have an escape plan.** Climb at best rate of climb speed for your aircraft and descend as expeditiously as possible through clouds to minimize time in icing conditions. If necessary, don't hesitate to tell air traffic control about what you require.
- **Don't get overconfident.** Even if your aircraft is approved for flight in icing conditions (FIKI certified), don't bank on it saving you in moderate to severe icing conditions. Some of the worst icing accidents have happened to very experienced pilots in high-powered, FIKI certified aircraft. The most severe icing conditions can cause any aircraft to go down, no matter its icing countermeasures.

Slide 26: Watch the following video together as a class and ask students to write down what they believe are the errors that the pilot makes throughout the video. Students will share their answers after the video ends.

- "Accident Case Study: Airframe Icing" (Length 13:22)
  https://video.link/w/OZXg

Questions

After watching the video, ask students to categorize the errors they listed.

- Which errors do you think were minor, and which errors do you think were critical?

Possible responses for critical errors:

- *Pilot attempting to fly higher to get out of the weather, but instead being hit with much worse icing*
- *Pilot not declaring the gravity of his situation (or declaring an emergency) to ATC sooner*
- *Pilot choosing to fly in icing conditions*

EVALUATE

Teacher Materials: Anti-Icing Systems Presentation, Anti-Icing Systems Teacher Notes 4
Student Material: Anti-Icing Systems Student Activity 4

Slides 27-34: Quiz students on these questions from the Private Pilot Knowledge Test.

Slides 35-36: Conduct the **Summative Assessment**.

Summative Assessment

In this activity, students will work together with a group as a safety investigation team, researching a fatal icing accident. Distribute a copy of **Anti-Icing Systems Student Activity 4** to each group, and direct students to watch the video, take notes, and prepare their presentations. Then, give each group a few minutes to share their presentations with the class.

For Part 2 of the activity, review the NTSB's assessment together as a class.

Additional instructions are provided in **Anti-Icing Systems Teacher Notes 4**.

[DOK-L3; *Draw conclusions*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Presentations show evidence of each of the following
  - Accurate and detailed description of icing incident and pilot actions
  - Thoughtful analysis of how these conditions caused the crash
  - Accurate and persuasive supporting evidence for assertions of causal factors

Points **Performance Levels**

9-10 Presentation gives an informed analysis about the conditions in which the ice was formed, the actions of the pilots, and what could have been done to prevent the accident.

7-8 Presentation adequately describes conditions in which the ice was formed, the actions of the pilots, and what could have been done to prevent the accident. Some descriptions aren't supported with evidence.

5-6 Presentation incorrectly describes conditions in which the ice was formed, the actions of the pilots, and what could have been done to prevent the accident. Many descriptions aren't supported with evidence.

0-4 Presentation is incomplete or incorrectly describes conditions in which the ice was formed, the actions of the pilots, and what could have been done to prevent the accident. Descriptions are uninformed or missing.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-PS1-4** - Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.
  - Science and Engineering Practices
    - Developing and Using Models
  - Disciplinary Core Ideas
    - PS1.B: Chemical Reactions
  - Crosscutting Concepts

        - Cause and Effect
        - Systems and System Models
        - Energy and Matter
- **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
        - Analyzing and Interpreting Data
        - Using Mathematics and Computational Thinking
        - Obtaining, Evaluating, and Communicating Information
    - Disciplinary Core Ideas
        - PS2.A: Forces and Motion
        - PS2.B: Types of Interactions
    - Crosscutting Concepts
        - Cause and Effect
- **HS-ETS1-3** - Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs 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
        - Asking Questions and Defining Problems
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.A: Defining and Delimiting Engineering Problems
        - ETS1.B: Developing Possible Solutions
    - Crosscutting Concepts
        - Systems and System Models

COMMON CORE STATE STANDARDS

- **W.9-10.1** - Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
- **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.9-10.2** - Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
- **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

https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/09_phak_ch7.pdf
https://www.aopa.org/news-and-media/all-news/1999/january/pilot/wx-watch-icing-rules-of-thumb
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