Supersonic Aircraft

Session Time: Three, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

Appreciate the rich, global history of aviation/aerospace and the historical factors that necessitated rapid industry development and expansion. (EU1)

Aspire to the highest level of technical proficiency as it relates to flight operations and engineering processes. (EU4)

Develop an uncompromising safety mindset, understanding that growth and development in the aviation/aerospace industry must always be accompanied by responsive safety initiatives. (EU5)

ESSENTIAL QUESTIONS

1. What limits how fast the aircraft of the future will travel?
2. What factors prevent supersonic aircraft from being widely used in commercial aviation today?
3. Can supersonic aircraft be made practicable?

LEARNING GOALS

Students Will Know

- Definitions related to high-speed flight
- Limitations and opportunities in supersonic flight
- Developments in technology that will make supersonic passenger travel possible in the future

Students Will Be Able To

- *Explain* challenges and opportunities related to supersonic commercial travel. (DOK-L2)
- *Summarize* ways in which regulation or aircraft design must evolve in order to make supersonic commercial travel a reality. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Students watch a short video of airplanes breaking the sound barrier and discuss the noise heard.

Formative Assessment
Students determine why the supersonic *Concorde* stopped flying.

Summative Assessment

Students write an opinion and give a short presentation on whether they think there should be supersonic commercial travel in the future.

LESSON PREPARATION

MATERIALS/RESOURCES

- Supersonic Aircraft Presentation
- Supersonic Aircraft Student Activity
- Supersonic Aircraft Teacher Notes
- Supersonic Aircraft Teaching Aid **(GOING FURTHER)**

Measuring the Speed of Sound Activity (per class) (GOING FURTHER)

- Two blocks of wood (recommend using two 20-inch pieces of 2x4 boards)
- Long tape measure
- Multiple stopwatches (can use the stopwatch function on smartphones)
- Clipboards
- Calculators
- Thermometer (to take outside temperature)
- An open space several hundred feet from a building from which to bounce the sound

LESSON SUMMARY

Lesson 1 – Supersonic Aircraft
Lesson 2 – Autonomous Aircraft
Lesson 3 – Electric Aircraft

To begin, show students a short video compilation of aircraft breaking the sound barrier. This may be students' first exposure to sonic booms. During the class discussion, students will learn the different regimes of flight, what a sonic boom is and how it develops, and more.

A watch-think exercise is linked to a video about why the world's first commercial supersonic aircraft, the *Concorde*, is no longer flying.

During the second session of this lesson, students will research what it will take to make supersonic commercial flight a reality once again and describe several pros and cons of supersonic air travel. Students will dig further into solving the issue of sonic booms by learning more about the creative work that NASA and industry partners are doing through the development of the X-59 QueSST aircraft.

In the third session, students will write an opinion and give a short presentation on whether they think there should be supersonic commercial travel in the future.

BACKGROUND

A supersonic aircraft is an aircraft capable of traveling faster than the speed of sound (Mach 1). A hypersonic aircraft flies at speeds exceeding Mach 5, or five times faster than the speed of sound. Rockets fly at hypersonic speeds.

When an aircraft flies faster than Mach 1, it creates a sonic boom. The sonic boom is a thunder-like noise heard on the ground. Early supersonic flights frequently caused sonic booms over inhabited areas, causing many complaints. Since 1973, supersonic flight over land has been forbidden in the United States because of the noise.

There have been only two aircraft built and operated in commercial supersonic passenger service. The Soviet *Tupolev Tu-144* conducted only 55 passenger-carrying flights. The British-French *Concorde* operated in passenger service between 1976 and 2003. While it was a technological success, it was noisy and required a lot of fuel. It had never been very profitable, so after a major crash in 2003 in which all the passengers and crew died, Air France retired the aircraft. The downturn in commercial aviation after the terror attacks of September 11, 2001, and the end of maintenance support for the aircraft by Airbus contributed to Air France's decision to retire the airplane.

Cost and noise are the two main reasons why supersonic commercial travel stopped when the *Concorde* was retired. The future of supersonic passenger travel will depend on engineers achieving two major goals:

- Designing a way to reduce the intensity of the sonic boom created when an airplane goes supersonic;
- Designing an aircraft that is much more economical and efficient to operate.

Many companies and NASA are researching how to overcome these hurdles.

LEARNING PLAN

ENGAGE

Teacher Material: Supersonic Aircraft Presentation

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

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

Warm-Up

Show students a very short video of a fighter jet breaking the sound barrier. Turn up the volume!

- "Supersonic Flight and Sonic Booms" (Length 00:22)
  http://video.link/w/0D2f

Ask students to respond to the following questions in a class discussion:

1.
What do you call the explosions heard in the video?

2.
Why does the cloud form around the airplane?

[DOK 2; *predict*, DOK 1; *what, why*]

Questions

What do you call the explosion heard in the video?
When an airplane or spacecraft breaks the sound barrier, it causes a sonic boom. A sonic boom is the sound heard when an aircraft or other type of aerospace vehicle flies faster than the speed of sound. An aircraft traveling faster than the speed of sound is going "supersonic."

Why does the cloud form around the airplane?
In supersonic flight, air molecules are pushed aside with great force, which forms a shock wave. If there is enough moisture in the air, the shock wave will be visible in the form of a cloud.

EXPLORE

Teacher Material: Supersonic Aircraft Presentation

Slide 5: Split the students into small groups and ask them to rank the four aircraft shown on the slide from slowest to fastest. They should be prepared to explain their reasoning. This will help students to start thinking about how aircraft are categorized based on their speed.

Questions

Slowest to Fastest

C. Citation CJ3 – maximum operating speed 320 mph, a straight-wing, mid-size business jet. Students may recall from the first semester that a jet with swept wings reduces drag and delays the onset of shock waves that are created near the speed of sound. Students should determine that a jet with straight wings will tend to fly slower.

A. Airbus A380 – maximum operating speed 391 mph, the world's largest passenger airliner, four very large engines, swept wings.

D. Bell X-1 – maximum operating speed 957 mph, the first airplane to break the speed of sound (1947), light aircraft with large rocket for an engine

B. Lockheed Martin F-35 Lightning – maximum operating speed 1,200 mph; multi-engine, state-of-the-art fighter jet

Slide 6: During the class discussion, students will learn the different regimes of flight, what a sonic boom is and how it develops, and more.

The speed of sound depends upon the medium and temperature through which the sound is traveling. For air (the medium) at a temperature of 15°C, the speed of sound is approximately 1,120 ft/s or 762 mph. This speed is referred to as Mach 1.

Slide 7: There are four speeds of flight, called the regimes of flight. The regimes of flight are subsonic, transonic, supersonic and hypersonic. The following slides will describe each regime.

Slide 8: Review the definition of "subsonic" with students. Anything going slower than the speed of sound is traveling at subsonic speed.

Slide 9: Explain the concept of "transonic" to students. When an aircraft is traveling very near the speed of sound, the aircraft is said to be transonic. While the aircraft itself may be traveling less than the speed of sound, the air going around the aircraft exceeds the speed of sound at some locations, such as over the top of a wing or at a rotor tip. For example, the Boeing B-2 Spirit bomber is a subsonic aircraft (travels slower than the speed of sound), but there are points on the airfoil where the velocity of the air is traveling at speeds faster than that of sound. In the photo on the slide, the transonic airflow is indicated by the moisture vapor on the body of the aircraft.

It will be helpful to refer back to the lesson regarding the forces of flight, particularly lift. Airflow is split above and below the airfoil or wing. The air on top of the wing is accelerated. If the wing itself is traveling at a speed near the speed of sound – for example, Mach .95 or Mach .98 – the faster airflow on the upper surface of the wing may accelerate enough to be traveling faster than the speed of sound (at supersonic speed).

Slide 10: Vehicles that fly at "supersonic" speeds are flying faster than the speed of sound, which is approximately 1,120 ft/s or 762 mph at sea level. Any vehicle going faster than the speed of sound is traveling at supersonic speeds.

As an example, the SR-71 was developed during the Cold War to obtain pictures and intelligence by overflying enemy and hostile territories. The aircraft routinely flew at speeds exceeding Mach 3 (three times the speed of sound).

Slide 11: An object traveling at a speed more than five times the speed of sound is considered "hypersonic." The X-15 (a hypersonic research program that NASA conducted with the Air Force, the Navy, and North American Aviation, Inc.) set the world's unofficial speed and altitude records of 4,520 mph (Mach 6.7) and 354,200 feet. Research completed in this hypersonic aircraft program contributed to the development of the Mercury, Gemini, and Apollo piloted spaceflight programs, as well as the space-shuttle program.

Slide 12: Flight speeds also may be referred to by Mach numbers. The Mach number is the ratio of the speed of the aircraft to the speed of sound. Flight that is faster than Mach 1 is supersonic. Supersonic includes speeds up to five times faster than the speed of sound, or Mach 5 (where the object becomes hypersonic).

Elicit answers to the final question on the slide. Students should deduce that Mach 5 would be five times (500 percent) greater than the speed of sound.

EXPLAIN

Teacher Material: **Supersonic Aircraft Presentation**

Slide 13: Explain to students what happens when an object travels faster than the speed of sound. An object traveling through the air pushes air molecules aside with great force. This creates a bow wave of air, similar to a boat moving through the water. As the object accelerates, these waves build up and get closer together. All these individual pressure waves are forced together into a single shock wave that is traveling at the speed of sound. This wave is being created as long as the object is traveling supersonic. When the aircraft exceeds the speed of the shock wave, a sudden and dramatic change in pressure causes a sonic boom. It happens twice in rapid succession, actually—once when the pressure reaches its peak and once when it returns to normal. When the wave hits the ground, receivers (humans, animals, microphones, etc.) hear the shock wave as a thunder-like boom, hence the term "sonic boom." This shock wave can, in extreme cases, damage objects on the ground (e.g., shattered windows).

Slide 14: To reinforce what the students have learned in the past few slides, show the video that explains sonic booms.

- "What is a Sonic Boom?" (Length 1:49)
  http://video.link/w/0t2f

Slide 15: Provide other examples of common items that exceed the speed of sound. The cracking sound of a bullwhip is a small sonic boom. A bullet fired from a hunting rifle is traveling faster than the speed of sound. Most of today's military fighter jets are capable of traveling faster than Mach 1.

Slide 16: Discuss the history of breaking the sound barrier for the first time and that even in the 1940s, many objects already had exceeded the speed of sound. German-built V1 and V2 rockets traveled at supersonic speeds, even nearing hypersonic speeds. The bullets used from many large-caliber rifles in the war traveled faster than the speed of sound.

For years, many believed that man was not meant to fly faster than the speed of sound, theorizing that transonic drag rise would tear any aircraft apart. All that changed on Oct. 14, 1947, when U.S. Air Force Capt. Chuck Yeager flew the *X-1* over Rogers Dry Lake in Southern California. The *X-1* was lifted to an altitude of 25,000 feet by a B-29 aircraft and then released through the bomb bay, rocketing to 40,000 feet and exceeding 662 miles per hour (the speed of sound at that altitude). The rocket plane, nicknamed "Glamorous Glennis," was designed with thin, unswept wings and a streamlined fuselage modeled after a .50-caliber bullet.

Slide 17: There have been only two aircraft built and operated in commercial supersonic passenger service. The Soviet *Tupolev Tu-144* conducted only 55 passenger-carrying flights. The British-French *Concorde* operated in passenger service between 1976 and 2003. While it was a technological success, it was noisy and required a lot of fuel. It had never been very profitable, so after a major crash in 2003 that killed all the passengers and crew, Air France retired the aircraft. The downturn in commercial aviation after the terrorist attacks on Sept. 11, 2001, and the end of maintenance support for the aircraft by Airbus also contributed to Air France's decision to retire the airplane.

Cost and noise are the two main reasons why supersonic commercial travel stopped when the *Concorde* was retired. The future of supersonic passenger travel will depend on engineers achieving two major goals: 1) designing a way to reduce the intensity of the sonic boom created when an airplane goes supersonic; and 2) designing an aircraft that is much more economical and efficient to operate.

Slide 18: Conduct the **Formative Assessment.** This will complete the first session of this lesson.

Formative Assessment

Students will complete a watch-think exercise linked to a video about why the world's most-flown commercial supersonic aircraft, the *Concorde*, is no longer flying. Have students view the video "Why Did Concorde Fail." At the conclusion of the video, have students write down responses to two questions, and ask them to share their responses in a group discussion.

1. Why did the *Concorde* fly mostly over the ocean?
2. Why was the *Concorde* retired?

- "Why did Concorde fail?" (Length 10:23)
  http://video.link/w/By2f

[DOK 1; *recall*; *report*, DOK 2; *summarize*]

Questions

Why did the Concorde fly mostly over the ocean?
The Concorde flew mostly over the ocean so people wouldn't hear the sonic boom. Supersonic airplanes can't be flown on standard overland routes because nobody wants sonic booms shaking their houses. Therefore, the Concorde had to fly out over the ocean before breaking the sound barrier.

Why was the Concorde retired?
The Concorde was retired for a combination of reasons:

- *It couldn't fly over land because of restrictions on sonic booms. This limited the routes that the Concorde could fly.*
- *It couldn't carry very many people, and it was expensive to operate (burned a lot of fuel). This made tickets expensive.*

- *After a major crash in 2003 that killed all passengers and crew, the aircraft was grounded for a period of time. The downturn in commercial aviation after the terrorist attacks on Sept. 11, 2001, and the end of maintenance support for the aircraft contributed to the decision to park the airplane, too.*

EXTEND

Teacher Materials: Supersonic Aircraft Presentation, Supersonic Aircraft Teacher Notes
Student Material: Supersonic Aircraft Student Activity

Slide 19: During the second session of this lesson, students will research what it will take to make supersonic commercial flight a reality once again and describe several pros and cons of supersonic air travel.

Using Internet research, students should write a minimum of one paragraph for each of the following challenges or issues related to supersonic air travel. Provide time for students to share their answers with the class. This may be assigned as individual or group work.

1. Why is supersonic flight over U.S. soil prohibited? Provide some examples of why this regulation was put in place.
2. What will it take for supersonic aircraft to be allowed to fly over U.S. soil again?
3. What environmental concern must be addressed related to supersonic flight (besides noise)? How might this be accomplished?
4. List and explain several pros and cons for supersonic air travel.

Questions

Student research may reveal the following. They should expound on each of these ideas.

1. Why is supersonic flight over U.S. soil prohibited? Provide some examples of why this regulation was put in place.
Noise abatement regulations halted supersonic flight (by civil aircraft) over U.S. soil in 1973. The Concorde could still take off and land in the U.S. because it broke the sound barrier over the ocean. There are many articles online about the effects of sonic booms on humans, wildlife, and buildings /structures.

2. What will it take for supersonic aircraft to be allowed to fly over U.S. soil again?
Students should explain that a change is needed in the regulation that prohibits flight over U.S. soil.

3. What environmental concern must be addressed related to supersonic flight (besides noise)? How might this be accomplished?
Previously, supersonic passenger jets were very inefficient to operate. They burned a lot of fuel considering the small number of passengers they carried.

4. List and explain several pros and and cons for supersonic air travel.
Pros – faster travel (reduce flight time for passengers), able to complete more trips than a

conventional aircraft, give airlines a competitive advantage
Cons – expensive aircraft to acquire and operate, limited demand due to cost per ticket

Slide 20: As students learned during the research exercise, to make supersonic passenger jets possible again, it is critical that the airplanes be allowed to fly over land. This may mean that engineers must discover a way to take the "boom" out of the sonic boom.

Using the **Supersonic Aircraft Student Activity**, students will learn about the creative work that NASA and industry partners are doing to solve the sonic boom problem with the X-59 QueSST aircraft. Find answers for the activity in **Supersonic Aircraft Teacher Notes**.

This may be assigned as homework and will complete the second session of the lesson.

EVALUATE

Teacher Material: Supersonic Aircraft Presentation

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

Summative Assessment

Have students answer the question: Do you think there should be a supersonic commercial travel in the future?

In several paragraphs, students should write their opinions and provide at least two reasons why with an explanation for each. Finally, they will prepare a one- to two-minute presentation that explains whether or not they believe there should be supersonic commercial travel in the future and their reasoning. Students should use resources to support their points.

Encourage students to address the issues of value and society that are broader than a simple opinion on whether or not supersonic aircraft are inevitable once the technical problems are solved.

[DOK 3; *cite evidence; develop a logical argument*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Writing and presentation shows evidence of the following:
  - Demonstrates knowledge of future aircraft types and the benefits they will bring
  - Understands technology that will make supersonic passenger travel possible in the future
- Uses evidence from what was learned in class and cites other resources to support their opinions
- Contributions show in-depth thinking, including analysis or synthesis of lesson objectives
- Student writing and presentation include an organized explanation with correct grammar (and spelling)

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

During an outside activity, students can measure the speed of sound by timing an echo. Teachers may split the students into small groups or elect to have them complete this activity together as an entire class. Refer to **Supersonic Aircraft Teaching Aid** for a description of the activity and a link to a video that demonstrates parts of the activity.

Show students a NASA video that describes the X-59 QueSST project and its goals: http://video.link/w/Kf3f (Length 2:21).

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-ETS1-1** – Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
  - 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
    - Systems and System Models
    - Influence of Science, Engineering, and Technology on Society and the Natural World
- **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
    - Constructing Explanations and Designing Solutions
  - Disciplinary Core Ideas
    - ETS1.C: Optimizing the Design Solution
  - 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
    - Influence of Science, Engineering, and Technology on Society and the Natural World

COMMON CORE STATE STANDARDS

- **HSG.MG.A.1** – Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).
- **WHST.9-10.2** – Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
- **WHST.9-10.4** – Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
- **WHST.9-10.6** – Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.
- **WHST.9-10.7** – Conduct short and more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- **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.
- **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.
- **RST.9-10.7** – Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

REFERENCES

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