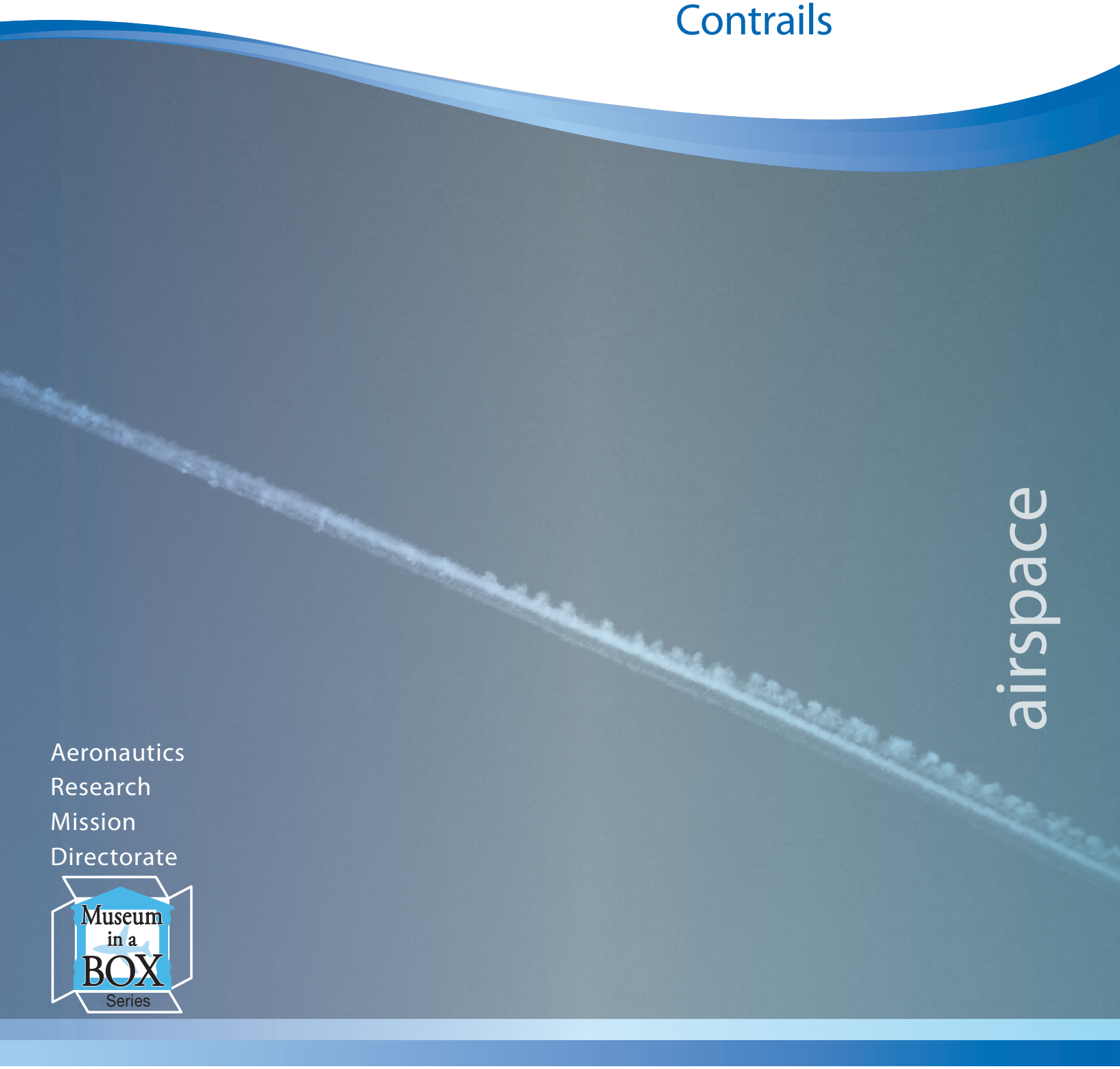
National Aeronautics and Space Administration

GRADES K-12

Contrails



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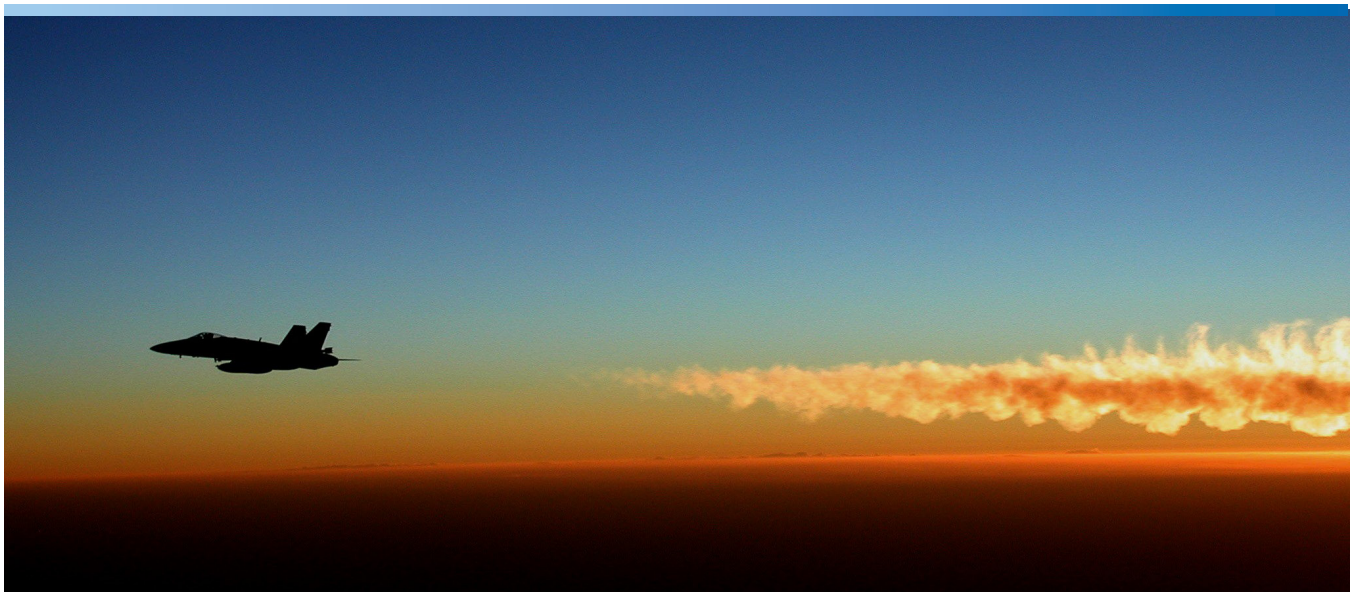


Contrails

Lesson Overview

Through demonstration, students will learn about properties and changes of properties of matter, as they witness firsthand how contrails are formed. This is shown by combining water vapor and the soot from an extinguished match within a glass flask, then adjusting the internal air pressure to form a cloud.

Objectives

Students will:

1. Learn how condensation nuclei and water vapor combine to create contrails.

Materials:

In the Box

500ml flat bottom flask

Rubber stopper & 60ml rubber bulb

Matches

Provided by User

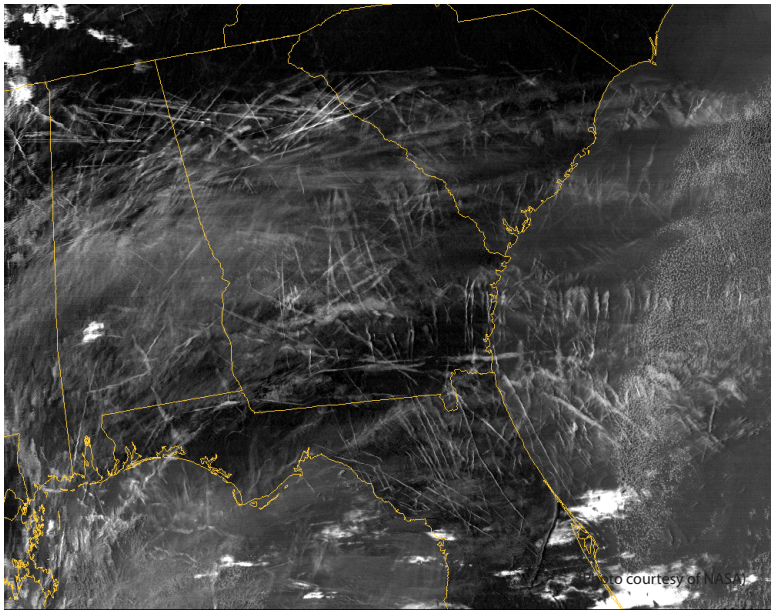
Water

GRADES **K-12** **Time Requirements:** 30 minutes

Background

What are contrails?

Contrails are a type of ice cloud, formed by aircraft as water vapor condenses around small dust particles, which provide the vapor with sufficient energy to freeze. The water vapor is already in the air surrounding the aircraft while the dust, or condensation nuclei, is comprised primarily of soot particles produced during the combustion process. They can also form when water vapor from the airplane's engines collide with the water vapor in the air.



Img. 1 Contrails over the southern United States, as seen from space

Contrails were initially discovered during the first high-altitude flights in the 1920s, although scientists and engineers were not overly concerned with them until WWII, when military bombers could be seen from miles away due to the long lines of contrails left in their wake. There are numerous veteran pilots who discovered issues both in navigation and warfare due to massive contrail formations. The contrail clouds occasionally became so thick that planes could not find their targets and sometimes, although rarely, even collided with each other! In 1953, a scientist named H. Appleman published a chart (Fig. 1) that was successfully used to determine when a jet aircraft would produce a contrail.

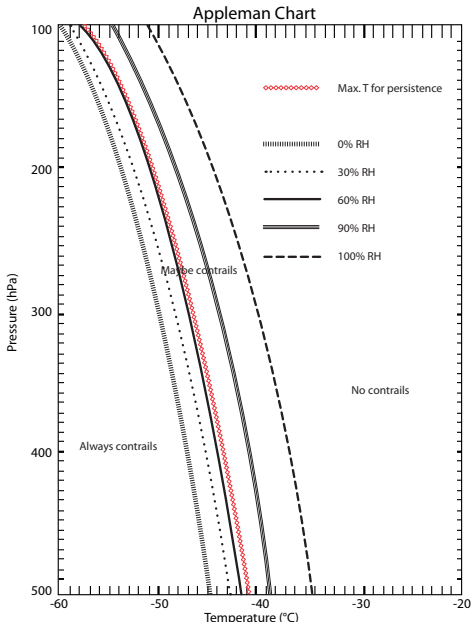


Fig. 1 The Appleman Chart for flight above 18,000 feet (500hPa)

There are three different families of contrail, but all are made from the same two components and formed in the same way. The primary difference is the amount of time the contrail remains visible. The first of the three, Short-Lived Contrails (Img. 2), appear as short white lines following along behind the aircraft, although disappear quickly - almost as fast as the airplane goes across the sky. Typically, Short-Lived Contrails survive for just a few minutes at most before the water vapor sublimates back into gas. In this scenario, the air mass through which the aircraft flies is quite dry with only a small amount of water vapor available to form the contrail.

Img. 2 Short-lived contrail

Persistent (Non-Spreading) Contrails (Img. 3) are presented as long white lines that remain visible long after the airplane has passed. A prerequisite for this type of contrail is a wet, humid atmosphere, with a large amount of water vapor/nuclei available to form the contrail. Due to the additional moisture, the ice takes much longer to sublimate, allowing the contrail to remain visible for up to an hour after the aircraft has passed. Also, the time the contrail is visible and the speed of the wind in the upper atmosphere often cause contrails to move from where they originated and have been known to travel many miles.

Img. 3 Persistent contrail

Persistent (Spreading) Contrails (Img. 4) are formed in an identical way to the non-spreading variety. However, the spreading occurs due to the air mass being unstable or turbulent. This turbulence dissipates the dense contrail lines and spreads them over a wide area, giving them a more cloud-like appearance.

Img. 4 An F/A-18 Hornet in flight

Wingtip vortices (Img. 5) are often thought to be a type of contrail but are actually produced from a different process. During very specific weather conditions you may see vapor trails form at the rear of the wingtips of jet aircraft on takeoff or landing. This phenomenon occurs due to a decrease in pressure and temperature as the wing generates lift.

Img. 5 An F-35 departing Elgin Air Force Base, Florida

How do contrails differ from other types of clouds?

Unlike clouds which form naturally, contrails are technically manmade clouds since they are formed due to the exhaust from an airplane. Also, contrails are nearly always made of ice crystals, unlike natural clouds which are often liquid water in suspension. Finally, they can only form at very high altitudes where the air is extremely cold, whereas natural clouds can form anywhere, from very close to the ground (fog), to very high altitudes (cirrus clouds).

How and where can we see contrails?

On a clear day, the sun's rays travel to Earth's surface unimpeded. When light runs into the cloud or contrail though, it is reflected by the water molecules within them, making the cloud visible and distinguishable from its background, the sky.

Activity 1 Creating a Contrail

GRADES **K-12**

Time Requirements: 30 minutes

Materials:

In the Box

500ml flat bottom flask

Rubber stopper & 60ml rubber bulb

Matches

Provided by User

Water

Worksheets

None

Reference Materials

None

Key Terms:

Cloud

Condensation nucleus

Contrail

Wingtip vortex

Objective:

In this demonstration, students will learn how condensation nuclei and water vapor combine to create contrails.

Activity Overview:

By combining water vapor and the soot from an extinguished match, then adjusting the internal air pressure, students will see a cloud form within a glass flask.

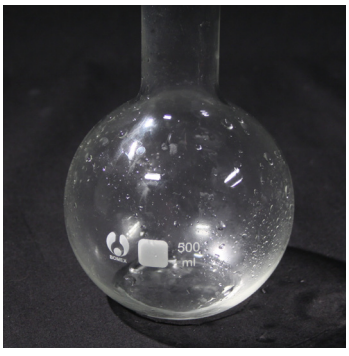
Activity:

1. **Using the Background information, discuss how condensation nuclei and water vapor combine to create a contrail.**
   Remember that younger students will not understand the vast majority of the concepts being presented and as such, care should be made to not confuse them with excessive specifics.

2. **Begin the demonstration by placing 5ml of tap water into the flask.** Next, insert the rubber stopper into the top of the flask and swirl the water around the sides.
   5ml of water is approximately a teaspoon; a precise quantity is not important. The swirling motion is designed to help some of the water evaporate within the flask, which is vital for this experiment to work correctly.

3. **Next, light a match and allow it burn for a few seconds.** Remove the stopper from the flask, extinguish the match and insert the burnt, smoking end into the flask. Allow some of the smoke to accumulate inside the flask and then reinsert the stopper.
The smoke contains the condensation nuclei component that is required for the cloud to form.

4. **Squeeze the rubber bulb to increase the air pressure within the flask.** Have the students watch the contents of the flask closely and when ready, release the bulb.
The rapid drop in air pressure vaporizes the water molecules and allows them to attach to the smoke molecules. This creates a cloud inside the flask in a similar way to how a contrail is formed behind an aircraft.



Discussion Points:

1. **What are the two components required for a contrail to form?**
   Water vapor molecules and condensation nuclei, such as dust, smoke or dirt, must join in order to form a contrail.

2. **If no condensation nuclei are present, what happens to the water?**
   Nothing. The water remains vaporized until another particle, required for cloud formation, becomes present.

3. **Why can you see the "clouds", or contrails, created by a jet engine on a clear day?**
   The clear sky lets the sun's rays travel to Earth's surface unimpeded. When light runs into the cloud or contrail, it is reflected by the water molecules, making the cloud visible and distinguishable from its background.

4. **Can contrails move, or do they stay in the location where they were formed?**
   Because contrails are formed at high altitudes where the winds are usually very strong, they will often move away from the point where they originated. When looking up into the sky you can frequently see older persistent contrails that formed many miles away but moved into view because of the wind.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Reference Materials

Glossary

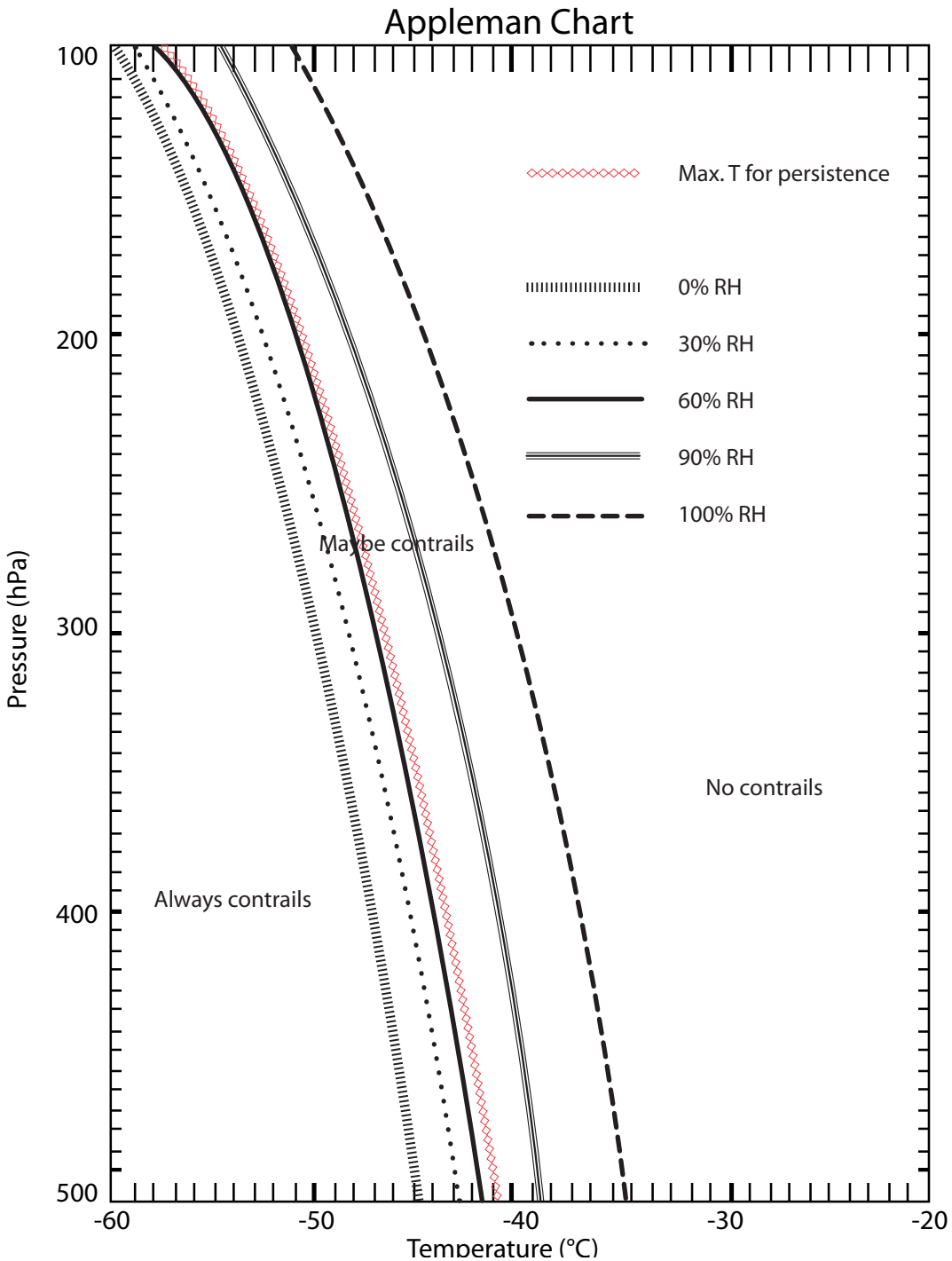
Cloud:
A collection of visible water droplets or frozen ice crystals suspended in the atmosphere above the surface of the planet.

Condensation Nuclei:
Small particles, typically under 0.2 μm (0.002mm), about which moisture can coalesce, or merge, in order to form a larger body such as a contrail or cloud.

Contrail:
An artificial cloud created from the condensed, instantly-frozen water vapor and condensation nuclei.

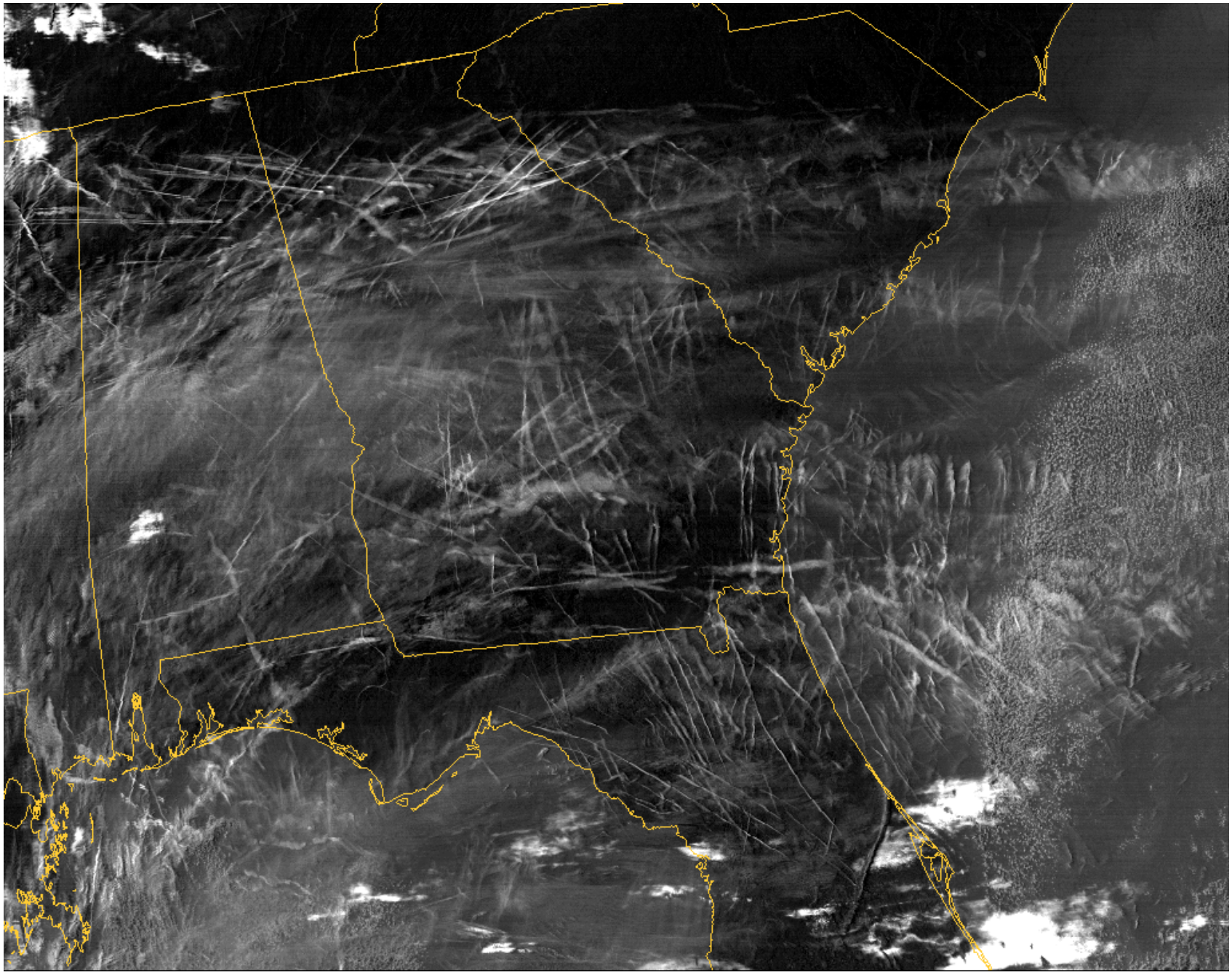
Wingtip Vortex:
A tube of circulating air that is created by an aircraft's wing as it produces lift.

Fig. 1 The Appleman Chart for flight above 18,000 feet (500hPa)



Images

Img. 1 Contrails over the southern United States, as seen from space



(Photo courtesy of NASA)

Img. 2 Short-lived contrail

(Public Domain)

Img. 3 Persistent contrail

(Photo courtesy of NASA)

Img. 4 An F/A-18 Hornet in flight

(Photo courtesy of the United States Navy)

Img. 5 An F-35 departing Elgin Air Force Base, Florida

(Photo courtesy of the United States Air Force)

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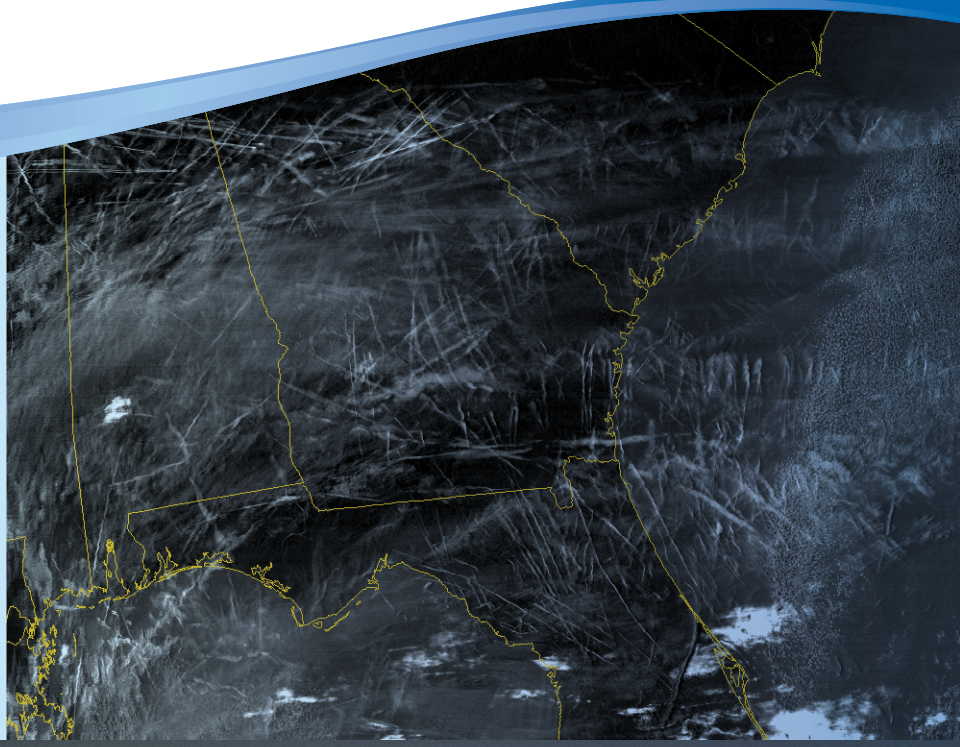

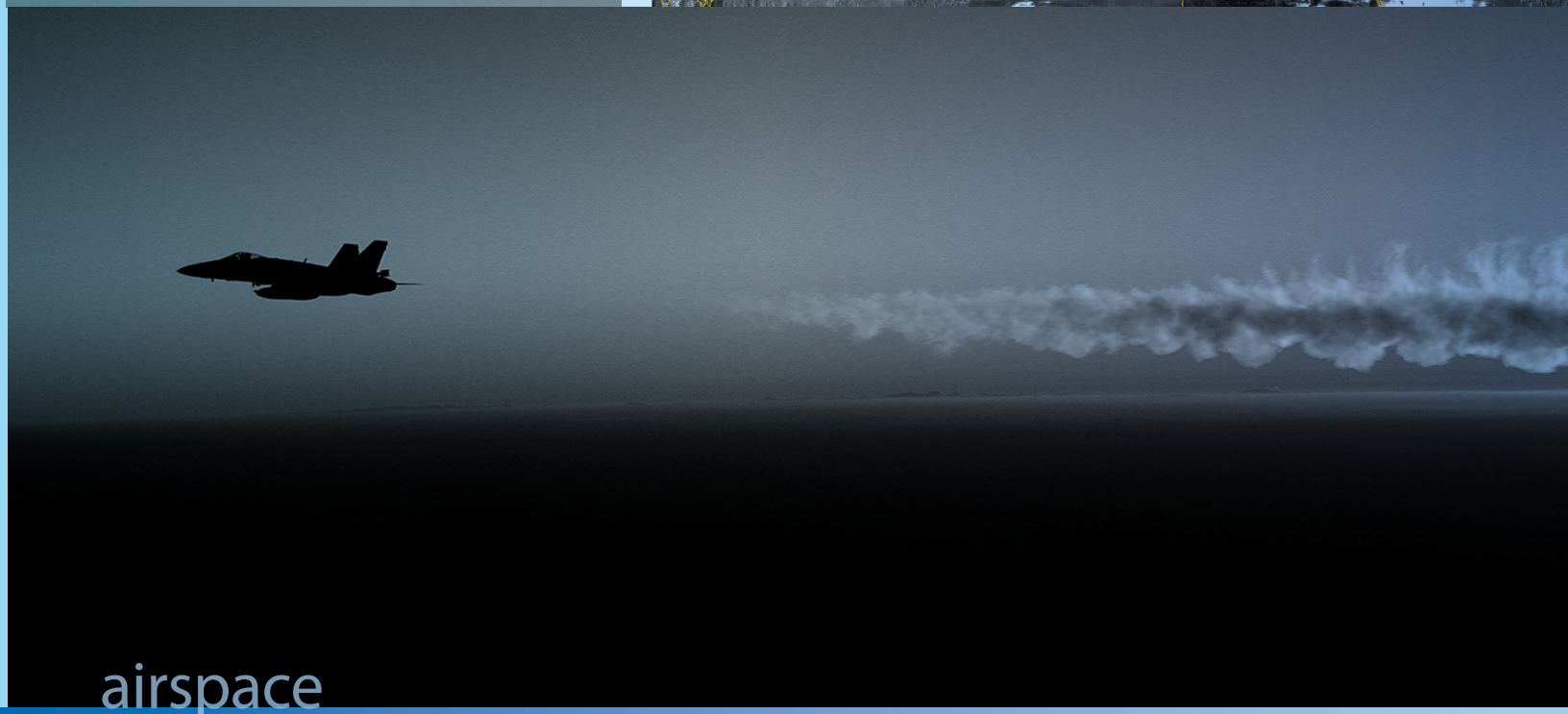

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