Time To Contrail

Objective:	To explore the dissipation of contrails using an equation.

Grade Level: 9-12
Subject(s): Mathematics, Physics, Technology
Prep Time: < 10 minutes
Duration: 30 minutes
Materials Category: Classroom

National Education Standards	
Science	3e, 3f
Mathematics	3, 6c, 18
Technology (ISTE)	6, 13
Technology (ITEA)	
Geography	

Materials:

- Student Sheets
- Calculators

Related Links:

National Weather Service
http://www.wrh.noaa.gov/Flagstaff/science/contrail.htm

United States Air Force—Condensation Trails From Aircraft Engine Exhaust
http://www.af.mil/environment/contrails_contrail.shtml

NASA Langley Research Center—Cloud and Radiation Research
http://www-pm.larc.nasa.gov/

NASA Goddard Institute for Space Studies
http://www.giss.nasa.gov/research/intro/mishchenko_01/

NASAexplores 5-8 Lesson, "On The Contrail."
http://www.nasaexplores.com/lessons/02-075/5-8_1.pdf

Supporting NASAexplores Article(s):

Man-Made Clouds
http://www.nasaexplores.com/show2_articlea.php?id=02-075

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Teacher Sheet(s)

Pre-lesson Instructions

- Duplicate the Student Sheets (one per student).
- Divide the class into groups of two.
- Write the contrail equation (listed in the Background Information) on the board.

Background Information

Condensation trails are line-shaped clouds that can be produced by propeller- or jet-powered airplanes. Contrails, as they are called, result from a combination of high humidity and low temperatures of the atmosphere at high altitudes. Contrails are made mostly of water, which freezes rapidly at those heights to form ice crystals. Depending on the temperature and the humidity, contrails can remain for just a few seconds or for several hours. The airplane's exhaust produces very little of the actual water in a contrail. Most of the water in a contrail is already in the air as the plane passes through it.

An airplane's exhaust produces water vapor, carbon dioxide, nitrogen oxide, hydrocarbons, carbon monoxide, sulfur gas, and other particles formed by the combustion of jet fuel. Of these, only water vapor is necessary to form a contrail. For a contrail to form, the right conditions must occur immediately behind a jet engine. As the exhaust gases cool and mix with the air, a contrail will form if the humidity becomes high enough for liquid water to condense on particles and form liquid droplets. If the air is cold enough, these water droplets will freeze and form ice crystals. Because the basics are understood, contrail formation for a given aircraft can be accurately predicted if the air temperature and humidity conditions are known. Contrails become visible about a wingspan distance behind the aircraft.

After the formation of a contrail, it evolves in one of two ways. If the humidity is low, the contrail will not last long. The ice crystals will quickly melt and evaporate. The resulting contrail will only last for a few seconds behind the aircraft. If the humidity is high, the contrail will last much longer. The ice crystals will continue to grow in size by taking water from the surrounding air. The resulting line-shaped contrail extends for large distances behind an aircraft. These contrails can last for hours while growing to several kilometers in width. Contrails spread out because of air turbulence created by

other aircraft, wind, temperature and humidity variations, and solar heating. So, the surrounding air determines whether or not a contrail will form and how it evolves. We can approximate the lifetime of the contrail. If we ignore a few quantities, we can determine how long a contrail will last during the daylight hours. Using this equation, $t = m (Q_C + Q_L) / P$, we can determine any one of the variables by knowing the other four. In this equation, t is the time for the contrail to dissipate in seconds (s), m is the mass of the ice crystals in kilograms (kg), Q_C is the heat per kilogram of ice to change the crystals' temperature in Joules per kilogram (J/kg), Q_L is the heat per kilogram to change the crystals' phase in Joules per kilogram (J/kg), and P is the power from the Sun in Watts (W).

Guidelines

1. Read orally the 9-12 NASAexplores article, "Man-Made Clouds."
2. Distribute the Student Sheets to each student.
3. Write the equation on the board. Go over what the variables mean and their units.

Discussion / Wrap-up

- Discuss the properties of contrails and why they dissipate.
- Ask students, "Does this equation explain all the characteristics of contrail dissipation? What else should be included?"
- Ask students, "Is this a good approximation of the dissipation, or have we assumed too much?"
- Answers to chart:

t (seconds)	m (kilograms)	Q_C (J/kg)	Q_L (J/kg)	P (Watts)
38.2	9.17×10^{-14}	8.24×10^{4}	3.34×10^{5}	1.0×10^{-9}
46	**7.32×10^{-14}**	6.18×10^{4}	3.34×10^{5}	6.3×10^{-10}
12	4.59×10^{-13}	**3.22×10^{5}**	3.34×10^{5}	4.5×10^{-10}
81	5.50×10^{-5}	1.03×10^{5}	3.34×10^{5}	**2.97×10^{-11}**
650.7	1.83×10^{-12}	9.27×10^{4}	3.34×10^{5}	1.2×10^{-9}

- Answers to questions:
  - *We are ignoring humidity, wind, and air pressure.*
  - *Regardless of "real" numbers, this is still a poor approximation.*
  - *$Q_C = C \Delta T$ (specific heat times the change in temperature), and $Q_L = L$, where L is the latent heat of fusion.*
  - *L is a constant for ice (3.34×10^5 J/kg).*
  - *Maybe, increase air temperature and/or decrease visibility*

Extensions

- There are many advanced equations on the Internet. You could use those to get a better approximation of the dissipation of the contrails.
- For a graphic lesson, use the 5-8 NASAexplores lesson, "On The Contrail." See the Related Links section.

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Student Sheet(s)

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We can approximate the lifetime of a contrail during daylight. Using this equation, $t = m (Q_C + Q_L) / P$, we can determine any one of the variables by knowing the other four. In this equation, t is the time for the contrail to dissipate in seconds (s), m is the mass of the ice crystals in kilograms (kg), Q_C is the heat per kilogram to change the crystals'

temperature in Joules per kilogram (J/kg), Q_L is the heat per kilogram to change the crystals' phase in Joules per kilogram, and P is the power from the Sun in Watts (W).

Materials

- Calculators

Procedure

1. Look over the equation to be sure you understand each quantity.

2. Using the chart, fill in the missing data using your calculator and the equation.

t (s)	m (kg)	Q_C (J/kg)	Q_L (J/kg)	P (W)
	9.17×10^{-14}	8.24×10^{4}	3.34×10^{5}	1×10^{-9}
46		6.18×10^{4}	3.34×10^{5}	6.3×10^{-10}
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	1.83×10^{-12}	9.27×10^{4}	3.34×10^{5}	1.2×10^{-9}

3. Answer the following questions:
   a. In our approximation, what are some things we have ignored?
   b. The numbers given in the chart are taken from actual data. How does that affect the validity of our answers? In other words, will using "real-life" numbers make up for our approximations?
   c. What are the equations that determine Q_C and Q_L?
   d. Why does the Q_L not change?
   e. Based upon what you have learned about contrails, do you think they could ever become a problem? Explain.