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Commitment to Environmental Excellence - Contrails

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Contrails (short for "condensation trails") are line-shaped clouds sometimes produced by aircraft engine exhaust. The combination of high humidity and low temperatures that often exists at aircraft cruise altitudes allows the formation of contrails. Contrails are composed primarily of water (in the form of ice crystals) and do not pose health risks to humans. Contrails have been a normal effect of aviation since its earliest days. Depending on the temperature and the amount of moisture in the air at the aircraft altitude, contrails can either evaporate quickly or they can persist and grow. Engine exhaust produces only a small portion of the water that forms ice in persistent contrails. Persistent contrails are mainly composed of water naturally present along the aircraft flight path.

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Aircraft engines emit water vapor, carbon dioxide (CO₂), small amounts of nitrogen oxides (NO_x), hydrocarbons, carbon monoxide, sulfur gases, and soot and metal particles formed by the high-temperature combustion of jet fuel during flight. Of these emittants, only water vapor is necessary for contrail formation. Sulfur gases are also of potential interest because they lead to the formation of small particles. Particles suitable for water droplet formation are necessary for contrail formation. Initial contrail particles, however, can either be already present in the atmosphere or formed in the exhaust gas. All other engine emissions are considered nonessential to contrail formation.

[In-flight Emergency Fuel Release](#)

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For a contrail to form, suitable conditions must occur immediately behind a jet engine in the expanding engine exhaust plume. A contrail will form if, as the exhaust gases cool and mix with surrounding air, the humidity becomes high enough (or, equivalently, the air temperature becomes low enough) for liquid water to condense on particles and form liquid droplets. If the local air is cold enough, these newly formed droplets then freeze and form ice particles that make up a contrail. Because the basic processes are very well understood, contrail formation for a given aircraft flight can be accurately predicted if atmospheric temperature and humidity conditions are known.

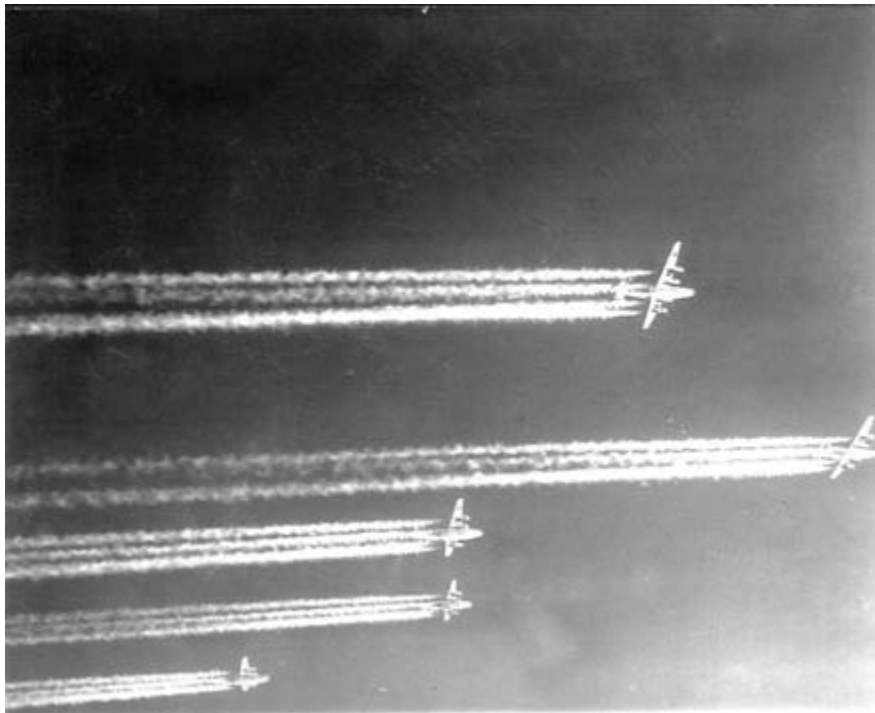
[References](#)

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After the initial formation of ice, a contrail evolves in one of two ways. If the humidity is low, the contrail will be short-lived. Newly formed ice particles will quickly evaporate. The resulting contrail will extend only a short distance behind the aircraft. If the humidity is high, the contrail will be persistent. Newly formed ice particles will continue to grow in size by taking water from the surrounding atmosphere. The resulting line-shaped contrail extends for large distances behind an aircraft. Persistent contrails can last for hours while growing to several kilometers in width and 200 to 400 meters in height. Contrails spread because of air turbulence created by the passage of aircraft, differences in wind speed along the flight track, and possibly through effects of solar heating.

Thus, the surrounding atmosphere's conditions determine to a large extent

whether or not a contrail will form after an aircraft's passage, and how it evolves. Other factors that influence contrail formation include engine fuel efficiency, which affects the amount of heat and water emitted in the exhaust plume. Contrails become visible roughly about a wingspan distance behind the aircraft. Contrails can be formed by propeller or jet turbine powered aircraft. During WWII, large formations of bombers left strikingly remarkable contrail formations. Typical contrails are shown below.

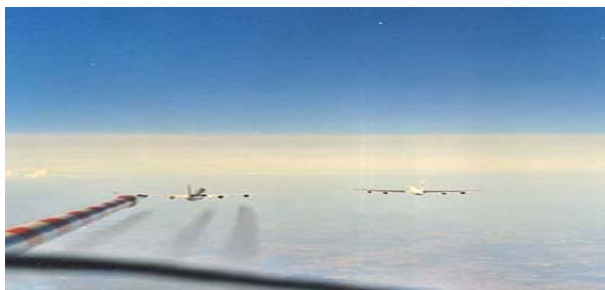


The contrails formed by the exhaust at high altitude are typically white and very similar to cirrus clouds. As the exhaust gases expand and mix with the atmosphere, the contrail diffuses and spreads. It is very difficult to distinguish aged contrails from cirrus clouds. It is very difficult to distinguish aged contrails from cirrus clouds. At sunsets, these contrails can be visibly eye-catching and striking as they reflect the blue, yellow, and red spectrum of the reflected sunlight.





Persistent contrails are of interest to scientists because they affect the cloudiness of the atmosphere. Scientists in the United States, Europe, and elsewhere have studied contrail formation, occurrence, and persistence, and research efforts on these topics continue. Shown below is a photo taken from the research aircraft Falcon of the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt (DLR) at about flight level 33,300 feet of an Airbus A340 with contrails (left) and a Boeing 707 without contrails (right). This illustrates a scientific effort to evaluate the effects of different engine characteristics on contrail formation.





The Air Force uses a Boeing 707 airframe for the KC-135 refueling and E-3 AWACS aircraft. The KC-135 fleet is in the process of upgrading to newer engines which produce fewer emissions and noise. Scientific research on contrails was recently summarized by an international group of experts. This summary can be found in Chapter 3 of the report, "Aviation and the Global Atmosphere," published in 1999 by Cambridge University Press for the Intergovernmental Panel on Climate Change (IPCC). The report describes current knowledge regarding the effects of aircraft emissions on the global atmosphere. The full report is available from Cambridge University Press and a summary of this report is at www.ipcc.ch/.

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