Climate Impacts from Contrails

Boeing is supporting the commercial aviation industry's net zero by 2050 goal through strategies to reduce CO_2 emissions through fleet renewal, operational efficiency, renewable energy transition and advanced technologies.

Boeing is also focused on fully understanding and mitigating negative impacts of climate change from non-CO_2 aircraft engine combustion emissions and effects, including contrails and aviation induced cloudiness, which are produced by aircraft and can contribute to both warming and cooling effects.

What are Contrails?

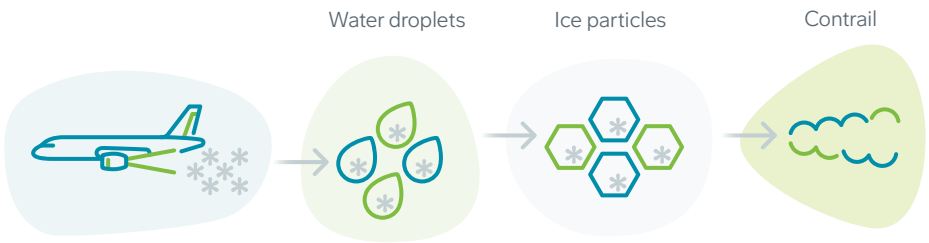
Contrails are a type of cloud that forms in the wake of an aircraft at high cruise altitudes under specific temperature and humidity conditions when water vapor condenses onto emitted aerosols and then freezes to form ice particles.

Some contrails dissipate quickly and have a negligible climate impact, but those that persist may contribute to either a warming or cooling climate impact, depending on ambient conditions and the timing of formation.

Studies have estimated that the warming effect from contrails are greater than the cooling effect. Unlike CO_2 that can stay in the atmosphere for centuries, contrails are much shorter lived so their warming impacts occur on much shorter timescales. However, there remains high uncertainty on contrail impacts and more research is needed.

Boeing has an opportunity to lead research and technology development critical to understanding the impact of contrails and avoiding their contribution to climate change.

How are Contrails Formed?



LESS THAN **10%**

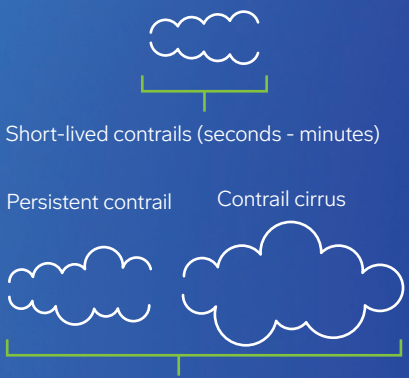
The percentage of flights estimated to contribute to the majority of contrail impacts.

IMPACT ON WARMING

Contrail contributions to warming are difficult to quantify due to these factors:

- Limited humidity observations available to improve contrail formation predictions
- Wide-ranging assumptions in atmospheric models
- Ice forming properties of particulate matter leaving gas turbines vary
- Impact of ambient conditions on warming or cooling effects

CONTRAIL PERSISTENCE



The Path Forward

Possible pathways to minimize the climate impacts of contrails include:

- **Advancing engine combustion technology** to reduce particulate matter
- **Changing fuel composition** to lower fuel aromatic and sulfur content
- **Improving upper tropospheric humidity forecasts** and leveraging satellite observations to enable aircraft route optimization.

Significant research over the next decade could lead to the deployment of a suite of technologies to enable the cost-effective mitigation of the climate impacts of contrails.

CRITICAL DATA AND MODELING

Collecting water vapor data and optimizing meteorological models will help to better evaluate the impact of contrails, reduce uncertainties, and pave the way to effectively mitigate the climate impacts of contrails.

- **Affordable and accurate water vapor sensors** need to be developed and installed on a fleet of airplanes to obtain reliable atmospheric measurements
- **Better contrail predictive modeling** is needed to inform contrail avoidance
- **Development and evaluation of higher-fidelity modeling tools** is needed to assess climate impacts and predict contrail persistence regions
- **Alternative fuels and new engine technology** could help minimize the impacts of contrails on the climate. More data is needed to understand the potential reductions in contrail impacts from use of such fuels.

How is Boeing Approaching Contrails?

Boeing has conducted testing and research on non-CO_2 and contrail effects and collaborated with industry, governmental, and academic research partners for the past three decades.

A Boeing and NASA partnership includes multi-year emissions testing research on the Boeing ecoDemonstrator program that began in 2021.

- The work to date has involved examining the levels of particulate matter emissions, such as soot and aerosols, from burning sustainable aviation fuels (SAF) with changes in fuel composition such as lower fuel aromatic and sulfur content.

Boeing will build on this research with future testing programs that will collect more data to understand how changes in fuel composition and advances in combustor technologies may impact contrail formation and their climate impacts.

Boeing is working with industry to gather the necessary atmospheric data to enable the accurate prediction of contrail persistence such that industry could deploy effective operational measures to mitigate the overall climate impacts of aviation.

- **The U.S. Department of Energy awarded funding to Boeing** in August 2023 to work with industry partners to develop and test new water vapor sensors for aircraft, and with machine learning experts to further develop a satellite-based AI contrail detection model.