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?

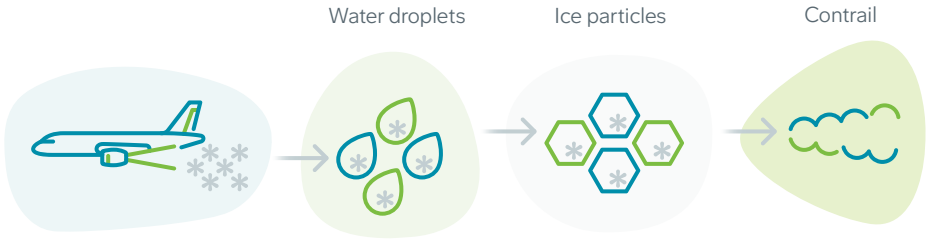
Contrails are clouds made up of ice particles that form due to water vapor in the engine exhaust condensing and freezing when aircraft are operated in cold temperatures at high altitudes. These contrails can have both a cooling or warming effect based on ambient conditions, timing and persistence.

Contrails that dissipate quickly have negligible climatic impact, while contrails that persist, which is a result of specific atmospheric conditions, block heat from escaping to space thus having a warming effect. Globally, it is 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.

How are Contrails Formed?



LESS THAN **10%**

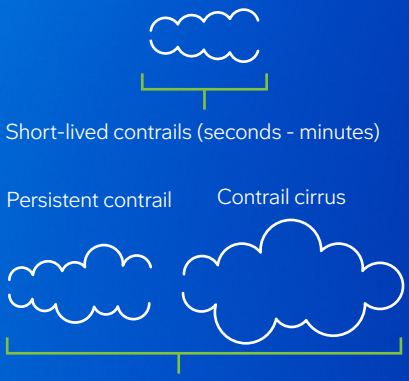
The percentage of flights estimated to contribute to the majority of contrail impacts.

IMPACT ON WARMING

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

- Limited humidity observations available to improve predictions
- Wide-ranging assumptions in atmospheric models
- Physical properties of particulate matter leaving gas turbines
- 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 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
- **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 their use.

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 also 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.