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 understanding and mitigating negative effects of non-CO_2 aircraft engine emissions on climate change, including contrails and aviation-induced cloudiness.

What Are Contrails?

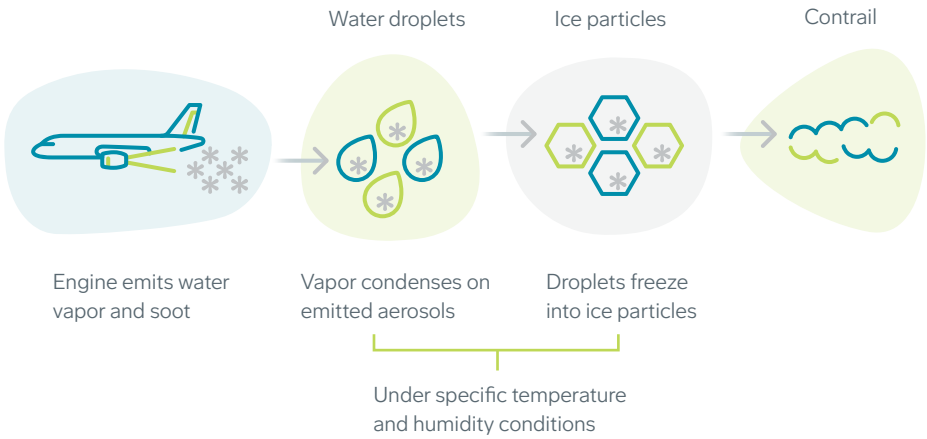
A contrail is a type of cloud that forms in the wake of an aircraft at high cruise altitudes under specific temperature and humidity conditions when water vapor condenses onto emitted aerosols and then freezes to form ice particles.

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, globally, the warming effect from contrails is greater than the cooling effect. However, there remains high uncertainty on contrail impacts, and more research is needed. It is difficult to compare contrails impact to CO_2 impact because, while CO_2 is evenly mixed in the atmosphere with a centuries-long lifespan, contrails form in more limited locations and are shorter lived.

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 **5%**

The percentage of flight distance estimated to contribute to the majority of contrail warming impacts

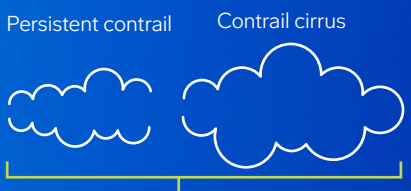
IMPACT ON WARMING

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

- Limited humidity observations available to improve contrail persistence and impact predictions
- Challenges of representing ice supersaturation, contrails and cirrus clouds in atmospheric models
- Ice-forming properties of particulate matter in engine emissions
- Impact of ambient conditions on warming or cooling effects

CONTRAIL PERSISTENCE

Short-lived contrails (seconds - minutes)



Long-lived contrails (minutes - hours)

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 operational contrail mitigation

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.

Boeing is collaborating with research partners to help mitigate the impacts of contrails through:

CRITICAL RESEARCH & TECHNOLOGY

Boeing has joined with partners across the industry to author a statement setting priorities for research and technology development needed to improve the science of aviation's non-CO_2 effects, including contrails, and enable the industry's path forward.

- Improve understanding of contrail formation, persistence, and climate impact.
- Improve understanding of emissions properties.
- Build research on aerosol cloud interactions.
- Improve understanding of the radiative impact and modeling uncertainty of NO_X emissions.
- Improve understanding of the interdependencies and trade-offs of aviation emissions (NO_X, soot, contrails, CO_2 and noise).
- Establish and improve common models for quantifying the effect of aviation on climate.
- Further investigate research on airspace network impacts of mitigation.

How Is Boeing Approaching Contrails?

Boeing has brought together a team of engineers and scientists from across airplane technology, emissions, atmospheric science, operational efficiency and digital services to drive progress on the path forward. Since achieving contrails impact mitigation requires involvement from standards bodies, global meteorological services, air traffic management, engine companies, fuel producers and more, Boeing is partnering and collaborating extensively within our work statement.

- Boeing has a multiyear partnership with NASA and others to study how sustainable aviation fuel (SAF) affects contrails and non-CO_2 emissions while in flight. From 2021-2023, the team conducted ground and flight tests to assess how SAF affects the characteristics of contrails. The researchers aim to understand how advanced fuels, engine combustor designs and other technologies may reduce contrail formation and persistence.
- Boeing is also working to enable operational mitigation through efforts to increase the fidelity of upper tropospheric humidity data to create more accurate contrail forecasts, develop digital services that incorporate uncertain contrail information into decision-making, and conduct research to better understand the airspace effects of scaled operational avoidance.
- Boeing is bringing airplane, emissions and atmospheric expertise to industry working groups to educate stakeholders, shape research programs and evolve industry standards to enable mitigation. One group, involving chief technology officers from across the industry, is building clarity on research needed and key learnings from ongoing industry research efforts.

Scan to see our animated explainer video on contrails.