

NATIONAL
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Developing a Research Agenda on Contrails and Their Climate Impacts

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Download the report and report resources:
nationalacademies.org/persistent-contrails

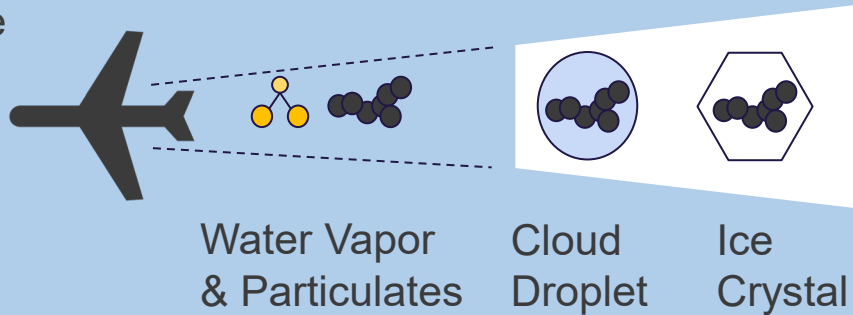
CONTRAILS 101



SW cooling offsets **LW warming** during the day. There is only **LW warming** at night.

FORMATION

Aircraft at Cruise



Occurs under low temperature and high humidity conditions (Schmidt-Appleman Criteria)

EVOLUTION



Decreasing Confidence

Linear Contrail



- Lasts for seconds
- Predicted by thermodynamics

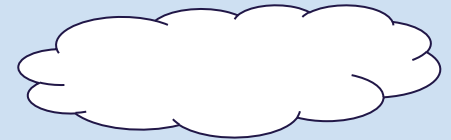
Persistent Contrail



- Lasts for 10s of minutes
- Develops from linear contrail
- Depends on ice supersaturation and temperature

Increasing Climate Effect

Contrail Cirrus



- Lasts for 10s of minutes to hours
- Develops from spreading persistent contrails
- Depends on

Why is Studying Persistent Contrails Important?

Aviation's climate impacts extend beyond CO₂, persistent contrails are the largest non-CO₂ contributor to aviation radiative forcing.

Persistent contrails form under specific atmospheric conditions and can evolve into cirrus clouds, which trap heat and contribute to warming.

The U.S. aviation sector (airlines & manufacturers) faces growing regulatory and competitive pressures as international bodies begin addressing aviation climate impacts.

Improved data, modeling, and mitigation strategies can enable the US aviation industry to protect its market position and lead in the global market for sustainable aviation solutions



Study Statement of Task

“The National Academies will convene an ad-hoc committee to develop a national research agenda to understand better, quantify, and support the development of technical and operational solutions to significantly reduce the global climate impact of aviation-induced cloudiness and persistent contrails from commercial aviation.”



Study Committee

Timothy C. Lieuwen, *Chair*
National Academy of Engineering
Georgia Institute of Technology

Steve Barrett
Cambridge University

Sean Bradshaw
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Study Director



Key Takeaways

- The current overall **aviation impact on climate comprises approximately 4%** of all anthropogenic climate forcing.
- There is confidence that **contrails contribute to warming the planet**, but the magnitude is uncertain
- The warming effect of **contrails and aviation-induced cloudiness is comparable to that from aviation CO₂**
- A relatively **small percentage of flights account for most of the contrail warming effect.**
- More and **better data on contrail formation can enable mitigation strategies.**



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About the Report

Chapter 1 – **Introduction**

Chapter 2 – **Aircraft Engine Emissions**

Chapter 3 – **Atmospheric Measurements**

Chapter 4 – **Contrail Modeling Systems**

Chapter 5 – **Contrail Forecast and Verification**

Chapter 6 – **Operational Concepts**



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Report Recommendations

Short-Term Priorities



SHORT-TERM PRIORITY RECOMMENDATION

Improve Humidity Observations

NASA should support the development, testing, and certification of advanced and accurate commercial-aircraft-capable humidity and temperature sensors for contrail-forming regions as well as onboard contrail-detecting cameras and automated contrail detection image recognition algorithms.

MORE INFORMATION IN CHAPTER 3

SHORT-TERM PRIORITY RECOMMENDATION

Improve Obs and Simulation of Ice Supersaturation

NASA should support research and observational studies to improve the understanding of the extent and frequency of ice-supersaturated regions (ISSRs) and the level of skill in simulating ISSRs and contrails.

MORE INFORMATION IN CHAPTER 3

SHORT-TERM PRIORITY RECOMMENDATION

Models to Support Contrail Forecasting

NASA should apply its current Earth system modeling efforts in support of simulating ice-supersaturated regions and contrails as a pathway to demonstrate the use of observations and advanced modeling tools for developing a contrail forecast and prediction system and estimating contrail radiative forcing.

MORE INFORMATION IN CHAPTER 5

Report Recommendations

Long-Term Priorities



Laboratory and Engine Research Studies

NASA, in coordination with the Federal Aviation Administration, the Department of Energy, and the Department of Defense, should support laboratory and engine research studies to improve the understanding of how fuel composition, combustor technology, and engine operating conditions impact particulate emissions (volatile and non-volatile) and contrail properties.

MORE INFORMATION IN CHAPTER 2

In-Flight Observations of Contrails and Emissions

NASA should continue to collect in-flight observational data of contrails, cruise emissions (CO₂, NO_x, and ice-nucleating particles) from aviation that advance the understanding of the factors that influence contrail properties.

MORE INFORMATION IN CHAPTER 2

Key Aerosol Observations

NASA should identify and enable a minimum set of key aerosol instruments that can be flown on multiple missions with the goal of characterizing the aerosol composition of the upper troposphere and uncovering the contribution of aviation emissions relative to other sources.

MORE INFORMATION IN CHAPTER 3

Low-Particle Engine Technologies and Sustainable Fuels

NASA, in coordination with the Federal Aviation Administration, the Department of Energy, the Department of Defense, other relevant federal agencies, and the private sector, should support development of low-particle-emitting combustion technologies, as well as sustainable aviation fuels with inherently low particulate-formation tendencies.

MORE INFORMATION IN CHAPTER 2

Informing Contrail Forecasts Systems and Verification and Avoidance Efforts

NASA should support observing system simulation experiments to define widespread water vapor sensor deployment to best inform contrail forecasts systems and individual verification and avoidance efforts.

MORE INFORMATION IN CHAPTER 3

Prepare for Next-Generation Satellite Observations

NASA should support satellite remote sensing research for diagnosing persistent contrails and ice-supersaturated regions to develop readiness for the next-generation geostationary sounders and imagers.

MORE INFORMATION IN CHAPTER 3

Multi-Scale Contrail Prediction Models

As part of a national strategy, NASA should support development and assessment of models for all scales of contrail prediction. These models range from wake vortex to global climate to contrail plume to ice supersaturation forecasting.

MORE INFORMATION IN CHAPTER 4

Establish a Global System to Observe Contrails

NASA should support development of a global contrail observing system as a foundation for research, analysis, and future verification.

MORE INFORMATION IN CHAPTER 5

Operational Contrail Avoidance Through ATC Innovation

NASA, in collaboration with airline operators and Air Navigation Service Providers, should continue research, development, and operational evaluation of advanced high-altitude air traffic control concepts of operations to enable flexibility to accommodate fuel efficient and contrail avoidance flight trajectories.

MORE INFORMATION IN CHAPTER 6

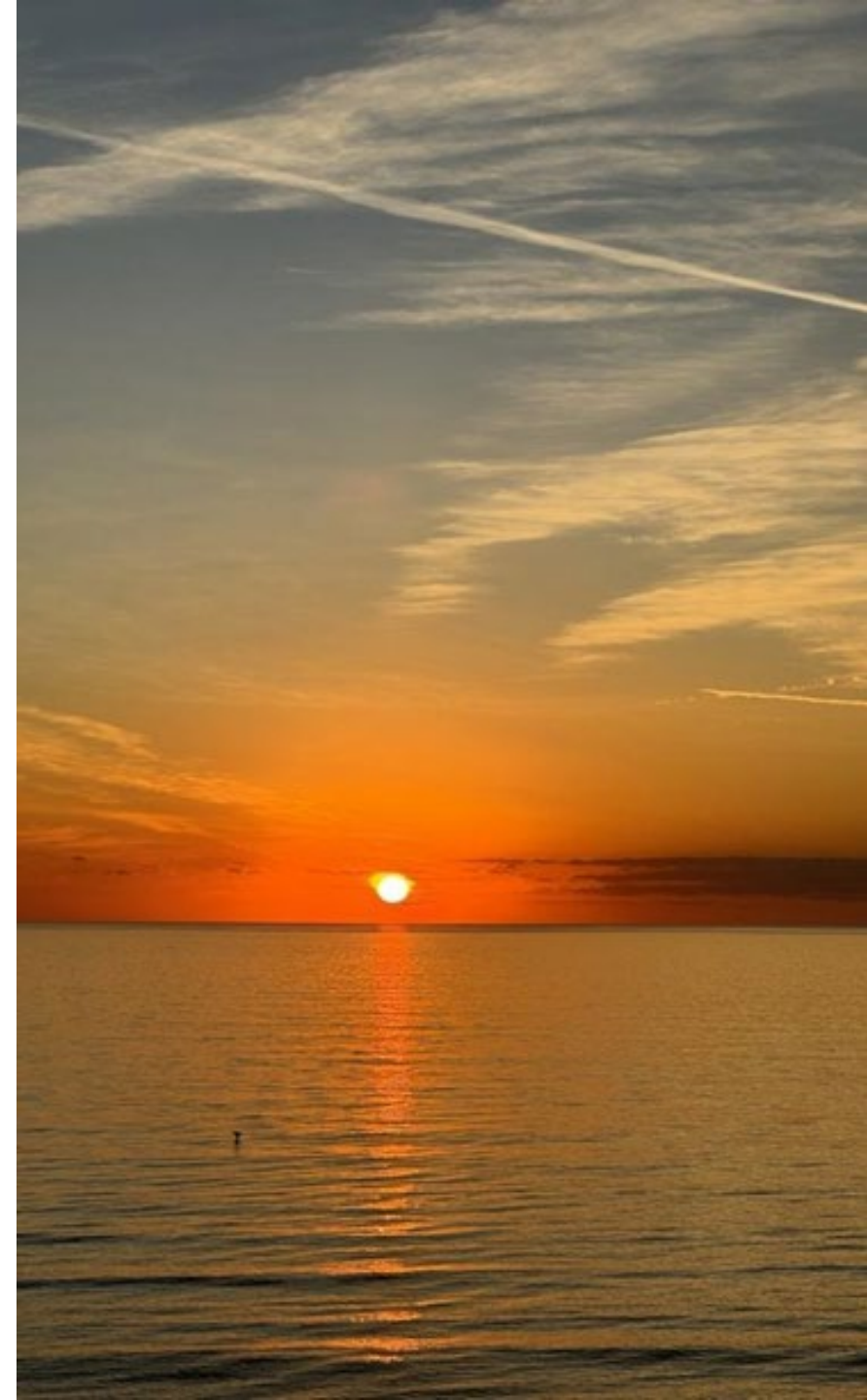
Vision for Contrails Research

Contrail research is a strategic opportunity for the United States to address a growing issue in aviation.

A **national research strategy** will help ensure that government, industry, academia, and international partners have the knowledge needed for mitigation efforts.

The United States is **well-positioned to lead**, leveraging existing research capabilities and partnerships to maintain an economic and diplomatic **competitive edge**.

NASA's coordination role across agencies and sectors is essential to advancing this work and ensuring the United States is not left behind.



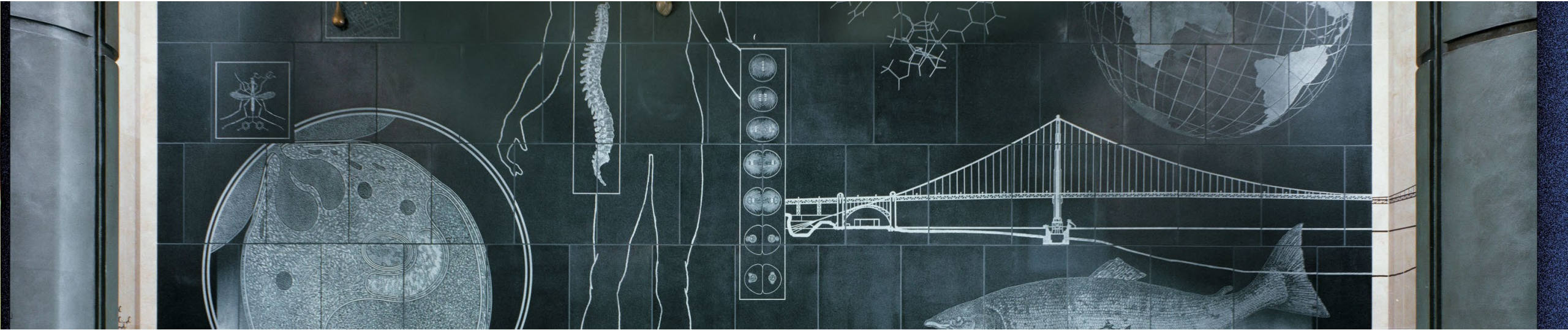
Thank You

Once the report has been released,
the full-report and resources can be found at:

nationalacademies.org/persistent-contrails



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The National Academies of Sciences, Engineering, and Medicine provide independent, objective advice to inform policy with evidence, spark progress and innovation, and confront challenging issues for the benefit of society.

For each of our studies, committee members are chosen for their expertise and experience, and they serve pro bono to carry out the study's statement of task.

The report went through a rigorous peer review process and represents the consensus view of the committee.