PhD project title: Observation-Based Investigations of Contrail Formation & Evolution

Keywords: aviation, air traffic control, climate, non-CO2, contrails,

Overview:
Applications are invited for a fully-funded PhD scholarship that will use state-of-the-art observations to advance understanding of aircraft contrail formation and evolution.

Approximately half of aviation's climate impact can be attributed to the radiative forcing of contrails and contrail cirrus. Contrails are linear shaped ice clouds that form in the wake of aircraft when water, sourced from both the ambient humidity of the atmosphere and from the fuel combustion process, condenses in the aircraft's exhaust plume as droplets which then subsequently freeze. Soot and other particulates contained in the exhaust plume also play a key role in this process, providing a site onto which the water can nucleate. Some contrails last only a short time (e.g., less than 5 minutes). However, contrails can spread and persist for many hours (i.e., forming contrail cirrus) if there is sufficient humidity in the ambient atmosphere, and it is these contrails that lead to a large fraction of the climate impact.

Recent evidence indicates that different aircraft/engine types can lead to different contrail properties and climate impacts due to the varying amount of soot particles they output. Lower soot particle emissions are generally associated with lower contrail lifetimes and impacts. Similar effects can be achieved by using alternative fuels, such as sustainable aviation fuel. However, as soot particle emissions are reduced, other types of particles may become important in providing nucleation sites for ice formation. These could include semi-volatile particles, arising from lubrication oil particles vented by the engine, or sulphates sourced from sulphur compounds present in the fuel.

Advancements in contrail observations using ground-based and satellite imagery are now enabling us to attribute specific contrails to specific flights of origin. This project will utilise and develop upon such advancements, using a variety of observation tools to carry out contrail-flight matching and contribute towards a "ground-truth" dataset of such matches. This dataset will then be used to perform novel observation-derived analysis of contrail properties tied to aircraft-engine properties, with such analyses having previously been limited to modelling and experimental works.

The successful applicant will be based in the Department of Civil and Environmental Engineering, supervised by Prof Marc Stettler (Professor in Transport and Environment) and will be supported in supervision by Dr Sebastian Eastham (Aeronautics), Dr Ed Gryspeerdt (Physics) and Dr Jonathan Itcovitz.

The project is in collaboration with Google Research.

Project details:
The objectives of the project are as follows:

1. Combining different contrail observation and flight attribution

The project will continue work on contrail-flight attribution methods, using a variety of observation inputs, including (i) geostationary satellite imagery, (ii) low-Earth orbit satellite imagery, (iii) ground-based imagery (e.g. global meteor network), and (iv) cockpit-/aircraft-based imagery. Such inputs have all previously been used in work focused on contrail observations (e.g., Schumann et al. 2013, Meijer et al. 2022, Geraedts et al. 2024), and in a combined manner in some cases (e.g., Mannstein et al. 2010, Meijer et al. 2024). The novelty of this project's methodology lies in investigating the combinations of such observations (and tools used to access them) that can lead to a high-fidelity dataset of flight attributions.

2. What are we observing?

An additional consideration in the project will be investigating what the observations truly represent. Recent work has suggested that there are fundamental limits to the observable size and lifetimes of contrails. Therefore, once the attributions dataset is initially constructed, the project will seek to extract (i) biases in observed distributions of contrail properties, and (ii) practical guidance on what “observable” means in terms of how contrail management may be implemented in future industrial and policy strategies.

3. Dataset of “ground-truth” observations

Further work will be done to feed back the derived biases in observations into the flight attribution algorithms. Such feedbacks would serve to increase confidence in contrail-flight matching. This project will produce a data set of attributed contrail observations that will be made available to the wider community.

4. Does aircraft / engine type affect the properties and climate impacts of contrails?

Statistical methods will be used to investigate relationships between aircraft-engine properties and observed contrail properties, with particular focus on the low-soot regime (i.e., building on Gryspeerdt in prep.) and effects of different fuel specifications, including different sulphur content in fuels at different airports and the effect of high SAF blends available at specific airports. Contrail properties such as optical depth and lifetime will be used to estimate a climate impact. This work is expected to benefit from Google’s own work on quantifying the radiative forcing of contrails.

References:

Geraedts, S., Brand, E., Dean, T. R., Eastham, S., Elkin, C., Engberg, Z., ... & Goyal, N. (2024). A scalable system to measure contrail formation on a per-flight basis. Environmental Research Communications, 6(1), 015008.

Gryspeerdt, E., Stettler, M., Teoh, R., Burkhardt, U., Delovski, T., Driver, O. G., & Painemal, D. (2024). Operational differences lead to longer lifetimes of satellite detectable contrails from more fuel efficient aircraft. Environmental Research Letters, 19(8), 084059.

Mannstein, H., Brömser, A., & Bugliaro, L. (2010). Ground-based observations for the validation of contrails and cirrus detection in satellite imagery. Atmospheric Measurement Techniques, 3(3), 655-669.

Meijer, V. R., Kulik, L., Eastham, S. D., Allroggen, F., Speth, R. L., Karaman, S., & Barrett, S. R. (2022). Contrail coverage over the United States before and during the COVID-19 pandemic. Environmental Research Letters, 17(3), 034039.

Meijer, V. R., Eastham, S. D., Waitz, I. A., & Barrett, S. R. (2024). Contrail altitude estimation using GOES-16 ABI data and deep learning. EGUsphere, 2024, 1-25.

Schumann, U., Hempel, R., Flentje, H., Garhammer, M., Graf, K., Kox, S., ... & Mayer, B. (2013). Contrail study with ground-based cameras. Atmospheric Measurement Techniques, 6(12), 3597-3612.

Requirements:

- A First Class Degree (or international equivalent) in engineering, mathematics, physics or computing
- A Masters level degree qualification
- Research experience on a project related to aviation, transport, aeronautical or environmental engineering is desirable
- Strong computational programming skills are desirable

- Experience with Python is desirable
- Excellent English communication skills, including strong writing abilities (for journal and industry publications) and excellent presentation skills (for industry meetings and public outreach)

How to apply:
Applicants are recommended to contact Prof Marc Stettler (m.stettler@imperial.ac.uk) for further details, informal discussions and information about the project.

Applicants wishing to be considered for this opportunity should send the following application documents to Prof Stettler:

1. Current CV including details of their academic record, and if possible, class ranking (2 pages maximum)
2. Covering letter explaining their motivation, suitability, skills and/or experiences (1 page maximum)
3. Contact details of two academic referees

Application via the Imperial College Registry is not necessary at this stage. Applications will be regularly reviewed until the position is filled.

Administrative questions should be emailed to civilphdadmin@imperial.ac.uk.

Funding:
The studentship will provide funding for 4 years from the start date of the PhD. The PhD project must start before 1 October 2025. The funding includes tuition fees (at the home rate, for 2024/25 this is ~£7,340/year) and a tax-free stipend at the standard UKRI London rate (for 2024/25 this is ~£21,237/year). The successful candidate will receive the to-be-announced equivalent 2025/26 funding. This funding can also be used to partly support an international student.