CONTRAILS AND CONTRAIL MANAGEMENT

Greener by Design Specialist Group

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- Contrails and contrail cirrus are currently responsible for half of aviation's effective radiative forcing. Their management provides an opportunity to radically reduce this forcing, offsetting some, if not all, of the effects of both CO_2 and NO_x.
- Implementation could be achieved in a matter of years, not decades, and aviation's stakeholders need to seize this opportunity now.

1. INTRODUCTION

The most common metric for assessing the climate impact of aviation is effective radiative forcing (ERF)[1]. As shown in Figure 1 (opposite Page), the ERF of aviation's non-CO_2 effects is estimated to be twice that of its CO_2 emissions, with contrails/contrail-induced cirrus clouds accounting for up to 75% of the non-CO_2 component.

Until very recently, the aviation industry has been focused on CO_2. This is because, at the global level, it is the most important greenhouse gas, the warming effect of CO_2 emissions being long-lasting and, hence, cumulative. In addition to developing new technologies and designs to reduce conventional kerosene use and, hence, reducing CO_2 emissions, industry and governments are concentrating on sustainable aviation fuels (SAF), electric, hydrogen and hybrid propulsion and ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). **However, it is now time to also consider the largest net warming component of aviation's emissions, namely contrails and contrail-induced cirrus clouds** – in addition to continuing the CO_2 mitigation strategies.

2. FORMATION OF CONTRAILS AND CONTRAIL-INDUCED CIRRUS CLOUD

Under certain meteorological conditions aircraft produce contrails (condensation trails). Jet exhaust is hot, humid and contains soot. At an air temperature below about –40C, exhaust water vapour condenses on the soot particles and the droplets freeze. The resulting ice crystals reflect sunlight and a contrail appears. If the atmosphere is dry, the water from the engine freezes and, since the ice sublimes quickly, the contrail extends for just a few kilometres. However, if the aircraft is flying through a region of air that is supersaturated with respect to ice (ISSR – ice supersaturated region), the contrail will not only contain ice from the exhaust water vapour, but also water vapour from the surrounding atmosphere. In this case, a 'persistent' contrail forms, with its characteristic very long twin parallel white lines, caused by the ice crystals being trapped in the aircraft's trailing vortex system. Persistent contrails can be hundreds of kilometres long, with a lifetime of several hours. As the contrail ages, it may develop into contrail cirrus, the twin parallel lines disappear, but lenticular cloud or clouds remain. It is important to note that these conditions are only present for a fraction of all flights.

3. CONTRAIL RADIATIVE EFFECTS

Contrails and contrail-induced cirrus cloud affect global mean temperature by influencing natural radiation. Firstly, outgoing thermal (long-wave) radiation from the Earth is absorbed by the ice crystals, causing a warming effect like a greenhouse gas. Secondly, during the day, some incoming (short-wave) solar radiation is reflected back into space, causing cooling. The degree to which both effects occur depends on several factors, including time of year, time of day and the position of other cloud formations. Some persistent contrails are overall warmers and some overall coolers, with the warmers being about twice as effective as the coolers. Therefore, the current overall effect of contrails and contrail cirrus is a net warming – about 1.5 times that of aviation's CO_2.

4. CONTRAIL MITIGATION OPTIONS

The likelihood of contrails' formation can be modified along with some of their properties, eg engines with tailored combustion systems and synthetic fuels may result in fewer, or smaller, particulates upon which the ice can form. However, these approaches will take a long time to have any effect and, even then, the impact will only be a partial mitigation. Therefore, **the option that**

Figure 1

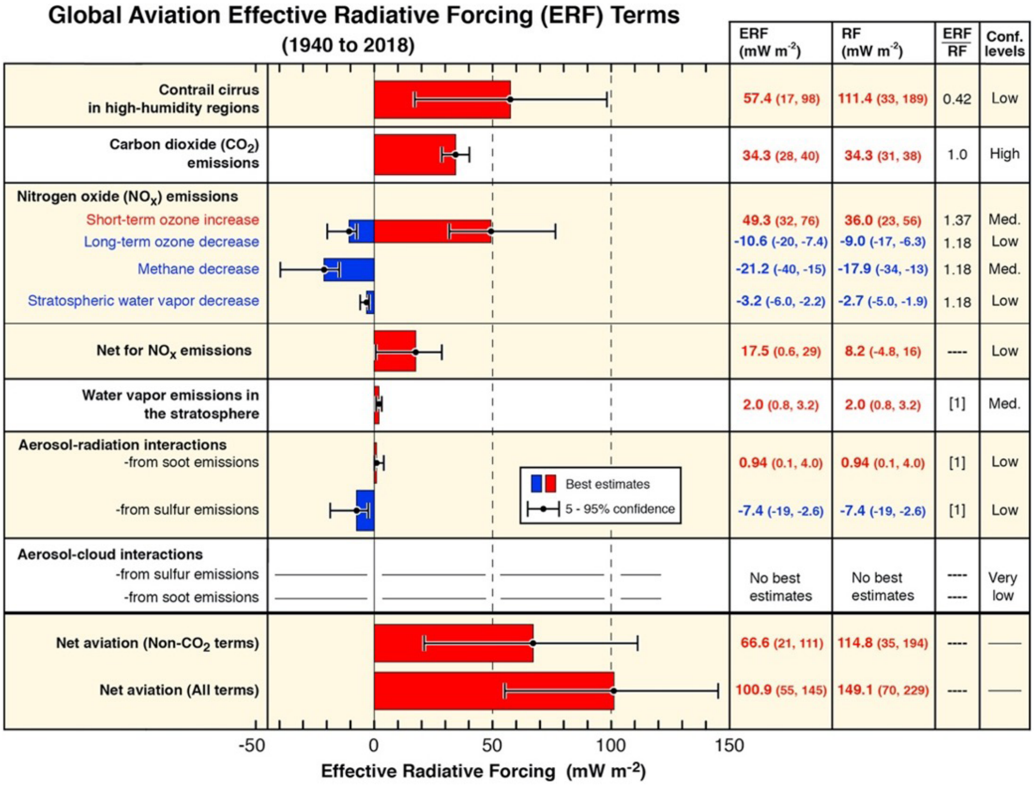

Figure 1. Global aviation effective radiative forcing (ERF) terms(2).

offers the quickest and the biggest impact is direct contrail management.

5. DIRECT CONTRAIL MANAGEMENT

The ISSRs are typically several hundred kilometres across, but are usually less than 1,500m deep. Therefore, they can be avoided by flying above or below them. This can be achieved by either incorporating avoidance in advance through the flight plan on the day before departure (D-1), or, if contrail generation is encountered en route, by the independent action of aircrew with co-operation from the Air Navigation Service Provider (ANSP) – or a hybrid of the two, updating the flight plan in the light of the latest ISSR forecast(3).

> the current overall effect of contrails and contrail cirrus is a net warming – about 1.5 times that of aviation's CO_2

If the airline had filed an absolute minimum fuel route, (which would be very unusual in normal operations) avoiding contrail formation could use a little more fuel. However, in this worst possible case, the 'cost' of the avoiding manoeuvre is equivalent to increasing the distance flown within the ISSR by about 2.5%. Hence, on a flight encountering ice supersaturated air for 20% of the journey, the worst-case total fuel penalty would be about 0.5%(4) However, since flights routinely use between 1% to 10% more fuel than absolutely necessary, performance can be adjusted in real time to offset any increases in fuel that may be required to avoid ISSRs(5).

It is also known that a small fraction of the contrails is producing the majority of the net warming. The days when this high contribution to radiative forcing occurs are called 'big hit' days. In the airspace over Japan, a study has shown that 2.2% of flights gave rise to 80% of the energy forcing resulting from persistent contrails(6). However, the equivalent proportion of flights over the North Atlantic has been found to be closer to 10%.

Avoidance in the vertical axis would be the most effective route, though, in congested airspace, horizontal avoidance may be necessary.

6. DIFFERENT APPROACHES

The first option is to simply seek to avoid the formation of all persistent contrails. This would achieve an immediate halving of aviation's ERF, leaving only the NO_x and CO_2 effects to be addressed by other means.

A second option that is both more effective and operationally less onerous is to avoid the formation of **warming** contrails. Typically, these are the ones initiated in the early evening through to the middle of the night. **Achieving an initial target of avoiding half of the potential warming persistent contrails would result in the net ERF from contrails being reduced to zero, ie the same as removing all the persistent (warming and cooling) contrails.**

If it were possible to remove all the persistent warming contrails, then aviation's net total effective radiative forcing from NO_x, CO_2 and contrails and contrail cirrus would fall to zero, ie the effects of CO_2 and NO_x would be fully offset and aviation would make no net contribution to radiative forcing.

7. SIMPLIFIED SUMMARY OF GLOBAL AVIATION FORCING AGENTS AND MITIGATION

GHG	Nature	ERF*	Solutions	Timing of solutions
CO^2	Long-term climate forcer	1/3	Technology/design	Slow penetration of fleet
			SAF	Slow penetration of fleet
			CORSIA	Temporary placeholder
Contrails	Very short-lived climate forcer	1/2	Contrail avoidance	After trials, could be implemented around the world with whole fleet.
			SAF	Partial reduction and slow
			Engines with tailored combustion systems	Partial reduction and slow
NO_x	Short-lived climate forcer	1/6	Low NO_x technologies	Over time – once science clearer

Figure 2. *Share of aviation's net Effective Radiative Forcing.

8. RECOMMENDATIONS

A. Government and industry should take action as follows:

Policymakers / CAEP / ICAO

- Engage actively in reducing the uncertainty of non-CO_2 effects, specifically contrail reduction
- Consider appropriate standards/recommended practices.
- Harmonise ATC charges to encourage flying of minimum fuel or preferably minimum climate routes.

Weather organisations

- Provide investment and focus on improved accuracy of ISSR forecasting.

ANSPs, airlines, weather organisations, flight planners etc

- Support trials to explore the practicalities of contrail avoidance (pre-tactical, tactical and hybrid).

Way forward

- Development of a contrail management or non-CO_2 Roadmap.

B. The Royal Aeronautical Society intends to continue its series of conferences on Non-CO_2 and address the following key questions through facilitating further discussion with stakeholders, including government and regulators:

- Leadership: Who should be leading and who follows? Is it government, regulators or the airline industry?
- Motivation: Why should airlines and ANSPs adopt contrail management? What is government and the regulator's role in this?
- Validation: If action is taken, how can we be sure that it is having a beneficial effect? This is a high-level environmental science question
- Reward: Airlines are focused on profit. How do we structure a non-carbon-based financial reward system that puts commercial benefit and environmental benefit into alignment?

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CONTACT

The Royal Aeronautical Society (RAeS) welcomes and encourages further engagement on this topic. Please direct all correspondence to the RAeS Greener by Design Committee via the contact details below:

Jordan Penning, Policy and Public Affairs Executive: Jordan.Penning@aerosociety.com

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