Aviation in a sustainable world

Project JETCLIM Final Report-Executive Summary

Combining models of jet engine exhaust and climate impact to quantify the trade-offs of changes in engine design and aircraft operation

Main thematic area: Climate Change

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Overall JETCLIM Executive Summary

JETCLIM combined expertise in the climate impact of aviation emissions with expertise in aircraft and engine design. JETCLIM's purpose was to advance understanding of the climate impact of aviation and in particular to improve the assessment of the trade-offs that have to be considered, should changes in aircraft design or operation be contemplated.

Aviation emissions lead to a wide range of climate effects – CO_2, contrails and ozone changes (as a direct result of emissions of oxides of nitrogen (NO_x)) all have a warming influence. Decreases in methane, and an associated decrease in ozone, as an indirect result of emissions of NO_x, have a cooling influence. These climate effects can depend strongly on the height at which the emissions occur, and the persistence of the effects range from minutes to hours in the case of contrails, to around a decade for methane whilst a substantial proportion of the CO_2 perturbation persists for thousands of years.

This mixture of signs, height dependences and lifetimes of the climate effects makes it difficult to answer apparently simple questions such as "is it better to avoid forming contrails at the expense of emitting more carbon dioxide?" and "how would the climate influence of aviation change, if the fleet flew higher or lower?". The answers to such questions are further confounded by the fact that they depend on how the climate effect is defined and also on value-laden judgements on the timescale over which the climate effect is considered.

In JETCLIM, two important advances to an existing methodology, developed as part of the Airbus/DTI funded "Low Emissions Effect Aircraft" project, for assessing the height dependence of the climate effect of aviation emissions, were implemented. First, the representation of the climate influence of contrails was improved, by incorporating the way in which the properties (strictly the so-called ice water content) of the contrails depends on temperature. Secondly, a thermodynamic model of engine emissions was developed, which allows the computation of the dependence of fuel use (and hence CO_2 and NO_x emissions) on such factors as the size of the aircraft, the mission length and the Mach number. This allowed a much improved assessment of the effect of changes in cruise altitude on fuel use.

Results are presented for two different metrics of the climate impact of aviation emissions. The Global Warming Potential (GWP) (the time-integrated radiative forcing following a pulse emission of a gas) is a metric which has been adopted under the Kyoto Protocol to the United Nations Framework Convention on Climate Change as a means of converting emissions of non-CO_2 greenhouse gases to a CO_2-equivalent emission. The use of the GWP requires a value-laden choice of a time-horizon, and the Kyoto Protocol adopts 100 years (henceforth GWP(100)). A metric that has quite different properties is the Global Temperature Change Potential (GTP) which gives the temperature change (calculated using a simple climate model) at some time after a pulse emission – such a metric might be more applicable in the case of a climate policy which aims to keep warming below some given level. Its use also requires the choice of a time horizon. For longer time horizons, this metric tends to emphasize the role of long-lived emissions which, in the context of aviation, means CO_2.

The engine/airframe model is used to compute the configuration of an aircraft which minimises fuel-use (and hence CO_2 emissions and, approximately, NO_x emissions) for particular cruise altitudes. It is emphasized that if the present-day fleet is flown at heights other than the ones they were designed for, the penalty in fuel use would be significant.

The model shows that the minimum in fuel use, and hence in GWP(100) and GTP(100) for CO_2 occurs at around 35 kft, close to the cruise altitude of the present-day fleet. However, the two metrics give quite different views of the total climate impact, when the non-CO_2 influences are accounted for. In the case of the GWP(100), there is a local maximum for flights at around 35 kft, mostly because of the impact of contrails; for the GTP(100), there is a minimum at around the same altitude. This result stresses the importance of a careful choice of metric and time horizon which addresses the particular policy/technology question being posed.

Other results illustrate that the view of the altitude dependence of the GTP depends on the chosen time horizon. For short time horizons (10 and 20 years) the effect of the short-lived species is stronger and the climate effect has a local maximum for flights at around 35 kft. By contrast, at longer time horizons (50 and 100 years) the effect of CO_2 dominates, and there is a minimum at the same heights.

Other results illustrate the effect of other uncertainties – in particular, assumptions about the strength of the highly-uncertain aviation-induced cirrus forcing greatly affect the perceived height-dependence of the GWP (100), with results ranging from a very modest height dependence for flights below 40 kft, to a very strongly-peaked height dependence at 35 kft.

JETCLIM has advanced understanding of the height dependence of the climate effect of aviation, for aircraft that have been optimised to fly at particular heights. The methodology for calculating fuel use and the radiative forcing of contrails has been enhanced. The work has illustrated that there can be no definitive answer to the question of whether it is better to fly higher or fly lower. Firstly, the choice of metrics, and choices within those metrics (and in particular, the chosen time horizon) influence the perceived effects and choices will have to be made via consultations between scientists, policy makers and other interested stakeholders. Secondly, remaining uncertainties in climate science, and particularly the atmosphere's response to aviation emissions, can be severe and there is a need to lessen these uncertainties before authoritative answers can be given. Nevertheless, the techniques used in JETCLIM are advanced and could provide a basis for decision making.

NB. Academic papers in preparation for peer review.