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EXECUTIVE COMMITTEE

Agenda Item 16: Environmental Protection – International Aviation and Climate Change

THE POTENTIAL FOR CLIMATE NEUTRAL GROWTH THROUGH NON-CO_2 MITIGATION

(Presented by the International Coalition for Sustainable Aviation (ICSA))

EXECUTIVE SUMMARY

ICAO's 41st Assembly concluded with agreement to achieve a collective long-term aspirational goal (LTAG) for international aviation of net-zero CO_2 emissions by 2050. At the meeting, ICSA presented its Vision 2050 net zero roadmap (A41-WP/413) alongside the industry's collective roadmap to reach net zero, Waypoint 2050. Since the last Assembly, there has been significant progress in characterizing the climate impact of short-lived climate pollutants (SLCPs), also referred to as non-CO_2 emissions. ICSA, through analysis and modelling by the International Council for Clean Transportation (ICCT), has now updated its Vision to include mitigation of SLCPs, including nitrogen oxides, black carbon and contrail cirrus. The analysis concludes that efforts to reduce CO_2 are necessary but not sufficient to align aviation with the Paris Agreement. Near-term cuts in SLCPs can complement GHG mitigation by limiting additional warming while low carbon aircraft and fuels mature. Combining aggressive GHG and SLCP controls could avoid more than 90% of additional aviation warming after 2025 and enable climate neutral growth starting in 2035.

Strategic Goals:	This working paper relates to the Strategic Goal – *Aviation is Environmentally Sustainable* by achieving net-zero carbon emissions by 2050 and mitigating aircraft noise and emissions.
Financial implications:	None
References:	A42-WP/384, *Next steps to develop a comprehensive framework for addressing international aviation's climate impacts* Resolution A41-21

1. INTRODUCTION

1.1 At its 37th Assembly in 2010, ICAO established an aspirational goal to keep the global net carbon dioxide (CO_2) emissions from international aviation from 2020 at the same level, and requested States and relevant organizations to work through ICAO to achieve an aspirational global fuel efficiency improvement rate of 2 per cent per annum from 2021 to 2050.

1.2 The 41st Assembly recognized that these goals are not sufficient to achieve the reductions needed to reduce aviation's absolute emissions contributions to climate change, and that more ambitious goals are needed to ensure the sector's sustainability. At the meeting, ICSA presented its Vision 2050 net zero roadmap to the 41st session of the Assembly (A41-WP/413) alongside the industry's collective roadmap to reach net zero, Waypoint 2050. The 41st Assembly concluded with agreement to achieve a collective LTAG for international aviation of net-zero CO_2 emissions by 2050.

1.3 Since the agreement, there has been significant progress in characterizing the climate impact of short-lived climate pollutants (SLCPs), also referred to as non-CO_2 emissions. The best available scientific assessments highlight that the net warming impact of non-CO_2 emissions is at least the same magnitude as that of aviation's cumulative CO_2 emissions. The scale of the impact from non-CO_2 emissions, even allowing for remaining scientific uncertainties, requires international aviation to accelerate its efforts to find solutions.

1.4 To contribute to this discussion, ICSA, with analysis and modelling by the International Council for Clean Transportation (ICCT), has now updated its Vision and this is presented in the Appendix to this information paper. This report updates ICCT's Aviation Vision 2050 decarbonization roadmap by quantifying how the mitigation of SLCPs, including nitrogen oxides, black carbon and contrail cirrus, can complement CO_2 strategies to align aviation with the Paris Agreement. Using high fidelity models, the report projects aviation warming through 2050 across five scenarios that span the full range of GHG and SLCP controls. Key conclusions of this work are set out below:

1.4.1 Efforts to reduce GHGs are necessary but insufficient on their own to align aviation with the Paris Agreement. While maximum efforts to reduce GHGs through aircraft and fuels is estimated to cut additional aviation warming by 48% below the Historical Trends scenario, we still project a 31 mC (0.031 °C) additional temperature rise due to aviation activity above 2025 levels in 2050, with continuing warming afterwards. Given a remaining climate budget of 340 mC to achieve 1.7 °C, airlines would consume 9% of the remaining 1.7 °C climate budget, more than double its historical share of 4%, under the maximum GHG reduction scenario.[1]

1.4.2 SLCP controls can provide faster and cheaper reductions in Earth's temperature response to international aviation activity than GHG controls. Contrail avoidance in particular is modelled to be the most impactful and cost-effective lever, providing 40% of total avoided warming by 2050 in the Full Breakthrough scenario, with mitigation costs orders of magnitude lower than for SAF. Still, without additional action on lower carbon fuels and planes, the short-term cooling from SLCPs cuts is projected to be overwhelmed by accumulating GHGs in the atmosphere by 2045, driving more warming.

1.4.3 Both aggressive GHG and SLCP controls will be needed to contain aviation's contribution to global warming and achieve climate-neutral growth. Combining aggressive GHG and SLCP controls (Full Breakthrough scenario) is projected to cut more than 90% of additional aviation attributable warming

[1] Forster et al. 2025. https://doi.org/10.5194/essd-17-2641-2025

by 2050 compared with the Historical Trends scenario, limiting aviation's share of remaining 1.5 °C climate budget consumed by 2050 to 4% and share of the remaining 1.7 °C budget consumed to 2%. This can occur despite a 150% increase in traffic compared with 2023, providing climate-neutral growth between 2035 and 2050, and potentially beyond 2050 with further GHG controls.

1.4.4 Four mitigation levers - contrail avoidance, SAF, hydrotreating, and operational efficiency - account for nearly 90% of avoidable warming in 2050. Policymakers could prioritize measures to mature these key technologies, such as widescale avoidance trials coordinated by air navigation service providers, mandates and incentives for SAF and hydrotreating fossil jet fuel, and carbon pricing policies to promote more fuel-efficient operations. Deployment of SAF in particular would deliver both GHG and SLCP mitigation benefits.

1.4.5 Control of SLCP is estimated to result in a climate benefit despite the expected increase in GHG emissions from their implementation. The benefit of reducing SLCPs is projected to outweigh the increased fuel consumption from applying SLCP control measures. This is still true when assuming the climate impact of SLCPs is at the lower end of the 95% confidence interval from our uncertainty analysis.

1.4.6 The report concludes that current actions focused on GHG emissions are insufficient to align aviation with the Paris Agreement. To achieve mid-term climate stabilization, policymakers should incentivize SLCP controls - especially contrail mitigation - while continuing to develop GHG-reduction technologies for reducing long-term climate impact.

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APPENDIX

EXECUTIVE SUMMARY OF ICCT REPORT

Full study will be posted here: theicct.org/publication/aviation-vision-2050-sept25

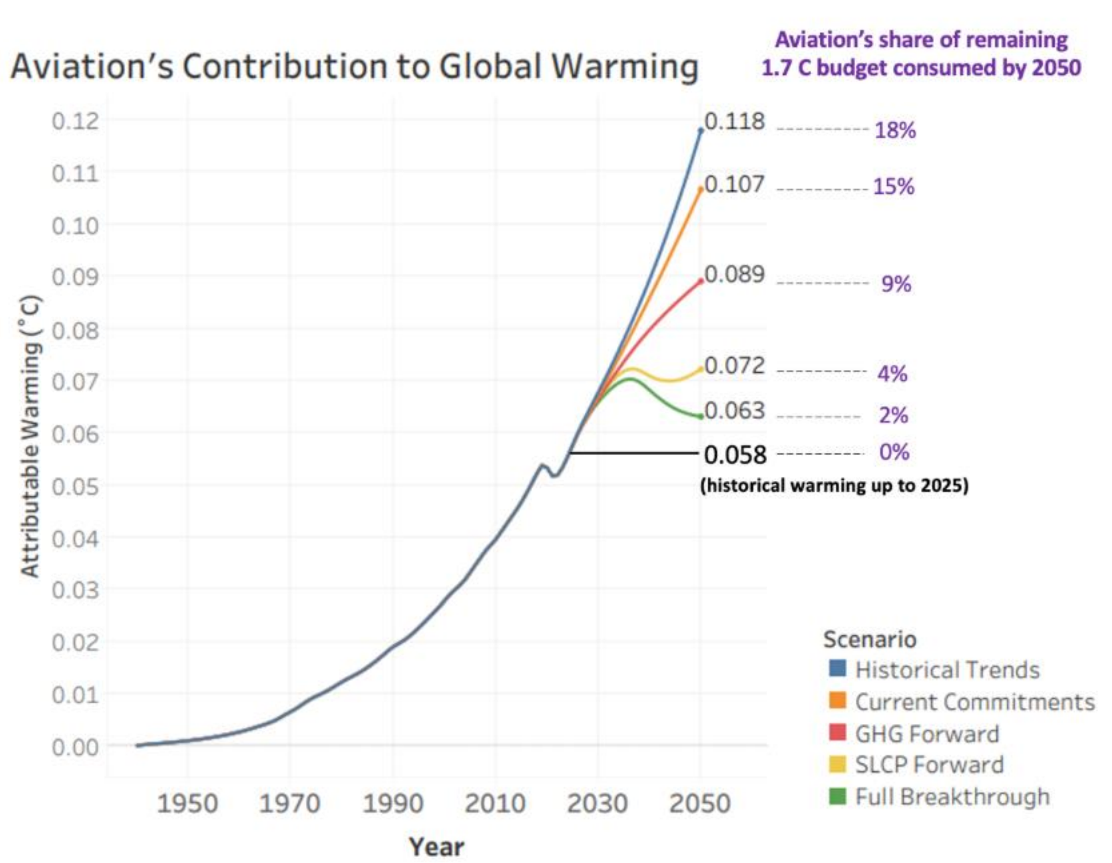
Aviation is a growing contributor to climate change, with effects extending beyond carbon dioxide (CO_2) emissions to include short-lived climate pollutants (SLCPs) such as nitrogen oxides, black carbon, and contrail cirrus. In 2022, the aviation sector agreed to achieve net-zero CO_2 emissions by 2050, but industry is not on track to deliver the scale of fuel efficiency improvements, sustainable aviation fuel (SAF) uptake, and zero-emission aircraft development required to meet that goal. Recent advances in the scientific understanding of SLCPs have attracted attention to the potential rapid reductions in aviation-attributable warming through contrail mitigation. But no deep decarbonization roadmaps for aviation have been updated to reflect SLCP controls.

This report updates ICCT's Aviation Vision 2050 decarbonization roadmap by quantifying how SLCP mitigation can complement greenhouse gas (GHG) strategies to align aviation with the Paris Agreement. Using a high fidelity 2023 flight emission inventory (JETSTREAM), an emission projection model (PACE 2.0), and a simplified climate model (FaIR), the report estimates aviation's warming potential through 2050 across five scenarios that span the full range of GHG and SLCP control: Historical Trends, Current Commitments, GHG Forward, SLCP Forward, and Full Breakthrough.

The Paris Agreement, adopted in 2015, commits countries to limit global warming to well below 2 °C and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels. This report compares aviation's warming contributions to the remaining 1.7 °C warming budget, reflecting recent findings that global warming is likely to surpass the 1.5 °C threshold before 2030.

As shown in Figure ES-1, under the Historical Trends scenario we project an additional 60 millidegrees Celsius (mC), or 0.06 °C, of warming from aviation activity between 2025 and 2050, which is double its contribution to temperature change over its entire history from 1940 to 2024. Policies announced to curb aviation GHG emissions to date are illustrated via Current Commitments, which projects a 11 mC (19%) reduction in warming by mid-century. The GHG Forward case, which models maximum levels of GHG mitigation through SAF uptake, zero emission planes (ZEPs), and improved fuel efficiency, is projected to cut future warming by 29 mC, or 48% below the Historical Trends case. However, aviation would double its historical 4% share of global warming, to 9% of the remaining 1.7 C budget, under this scenario.

Figure ES1
Aviation's projected contribution to global warming by scenario, 1940 to 2050



Larger reductions are modeled via the SLCP Forward scenario, which adds contrail avoidance, fuel quality improvements, and advanced engines to the Current Commitments scenario; the SLCP Forward scenario reduces additional warming by 46 mC, or 76% below Historical Trends. The SLCP Forward scenario keeps aviation to a 4% share of remaining 1.7 C climate budget up until 2050, but the share will likely increase beyond 2050 as unmitigated GHG emissions continue to drive warming. In the Full Breakthrough scenario, which blends maximum GHG and SLCP mitigation, aviation's contribution to global warming is cut by 91% below the Historical Trends scenario and limits aviation's share of additional contribution to remaining 1.7 C budget to 2%.

By comparing the Historical Trends and Full Breakthrough scenarios, we can characterize the relative contribution that different mitigation levers may play in curbing aviation's climate impact. Table ES-1 summarizes the relative contribution of each mitigation lever to avoided temperature response in 2050. The share of total warming by mitigation lever is shown at the far right; the breakdown of GHG vs. SLCP control is shown at the bottom of the table.

Table ES1
Share of avoided warming by mitigation lever in 2050 under the Full Breakthrough scenario

Rank	**Mitigation lever**	**Avoided warming (mC)**			**% of total**
		GHGs	SLCPs	Total	
1	Contrail avoidance	0.07	-23.4	-23.3	42.5%
2	Sustainable aviation fuel	-5.90	-5.68	-11.6	21.1%
3	Hydrotreating	0.05	-6.35	-6.30	11.5%
4	Operational efficiency	-1.37	-4.58	-5.95	10.8%
5	Low NOx/nvPM engines	0.00	-4.39	-4.39	8.0%
6	Technical efficiency	-0.84	-1.80	-2.64	4.8%
7	Demand response	-0.12	-0.30	-0.42	0.8%
8	Modal shift	-0.07	-0.17	-0.25	0.5%
9	Zero-emission planes	-0.02	-0.02	-0.05	0.1%
Total		-8.20	-46.6	-54.9	100%
% of total		15%	85%	100%	-

As shown in the table, contrail avoidance contributes the largest share (23 mC, or more than 40%) of all potential avoided warming. That includes a small (0.07 mC) temperature increase due to the fuel burn penalty of rerouting. The use of SAF contributes 21% of avoided temperature increase, the second largest amount. Hydrotreating and operational efficiency are the third and fourth most important levers, both contributing about 11% of the total avoided warming; three-quarters of the operational efficiency enabled mitigation comes from SLCPs due in part to a reduction in kilometers flown. Other levers, including low NO_x and low non-volatile particulate matter (nvPM) engines, hydrotreating, technical efficiency, ZEPs, demand response, and modal shift contribute only modestly to avoided warming. Overall, 85% of avoided temperature increase is linked to SLCPs. Because contrail abatement technologies would take less time to develop and scale compared to SAF, and at lower cost (US$5–US$20 per tonne CO_2e, versus more than US$300 per tonne CO_2e), SLCP reduction emerges as a more easily obtained option with large potential in mitigating aviation's climate impact.

Key conclusions of this work include:

- **A 2050 net zero CO_2 target is a necessary but not sufficient condition to align aviation with the Paris Agreement.** While a maximum level of GHG mitigation through aircraft and fuels is estimated to cut additional aviation warming by 48% below the Historical Trends scenario, we still project a 31 mC temperature rise due to aviation in 2050, with continuing warming afterwards. Given a remaining climate budget of 340 mC to achieve 1.5 °C (Forster et al., 2024), airlines would consume 9% of the remaining 1.7 °C climate budget, more than double its historical share of 4%, under a maximum GHG reduction scenario.
- **SLCP controls, notably contrail avoidance, can complement GHG mitigation by delivering substantial near-term reductions via easier to implement technology solutions.** Contrail avoidance in particular is modeled to be the most impactful and cost-effective lever, providing 40% of total avoided warming by 2050 in the Full Breakthrough scenario, with mitigation costs orders of magnitude lower than for SAFs. Still, without additional action on lower carbon planes and fuels, the short-term cooling due to SLCP cuts is projected to be overwhelmed by 2045 due to accumulating GHGs in the atmosphere, driving more warming.

- **Both aggressive GHG and SLCP controls will be needed to contain aviation's contribution to global warming and achieve climate-neutral growth.** Combining aggressive GHG and SLCP controls (Full Breakthrough scenario) is projected to cut more than 90% of additional aviation attributable warming by 2050 compared with the Historical Trends scenario, limiting aviation's share of remaining 1.5 °C climate budget consumed by 2050 to 4% and share of the remaining 1.7 °C budget consumed to 2%. This can occur despite a 150% increase in traffic compared with 2023, providing climate-neutral growth between 2035 and 2050, and potentially beyond 2050 with further GHG controls.
- **Four mitigation levers—contrail avoidance, SAFs, hydrotreating, and operational efficiency—account for nearly 90% of avoidable warming in 2050.** Policymakers could prioritize measures to mature these key technologies, such as widescale avoidance trials coordinated by air navigation service providers, mandates and incentives for SAF and hydrotreating fossil jet fuel, and carbon pricing policies to promote more fuel-efficient operations. Deployment of SAF in particular would deliver both GHG and SLCP mitigation benefits.
- **Control of SLCP is estimated to result in a climate benefit despite the expected increase in GHG emissions from their implementation.** The benefit of reducing SLCPs is projected to outweigh the increased fuel consumption from applying SLCP control measures. This is still true when assuming the climate impact of SLCPs is at the lower end of the 95% confidence interval from our uncertainty analysis.

The report concludes that current actions focused on GHG emissions are insufficient to align aviation with the Paris Agreement. To achieve mid-term climate stabilization, policymakers can incentivize SLCP controls—especially contrail mitigation—while continuing to develop GHG-reduction technologies for reducing long-term climate impact.

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