UNIVERSITY OF CAMBRIDGE | Aviation Impact Accelerator

Searching for blue skies: Policy roadmap for navigational contrail avoidance

White paper

The Aviation Impact Accelerator
The Aviation Impact Accelerator is the global systems change initiative in aviation, based in the University of Cambridge. Combining data modelling and expertise across industry, governments and academia, we drive the transition to climate-neutral aviation.

The AIA's work draws upon the University of Cambridge's academic expertise and research rigour, together with the engineering capabilities of the Whittle Laboratory and the sustainability and policy expertise of the Cambridge Institute for Sustainability Leadership (CISL).

Authors
Edmund Dickens (CISL), Dr Conor Farrington, Dr Samuel Gabra, Noli Shelala, Brandon Staats

Acknowledgements
The authors would like to thank the significant number of individuals and organisations that have contributed their time and expertise through workshops, interviews and feedback to the development of the policy proposals in this report.

Citing this report
Aviation Impact Accelerator (2026). *Searching for blue skies: Policy roadmap for navigational contrail avoidance - White paper*. Cambridge, UK: University of Cambridge.

Published
18 November 2026

Disclaimer
This document is published by the Aviation Impact Accelerator, an initiative led by the University of Cambridge. The Aviation Impact Accelerator aims to collect evidence and knowledge by engaging a wide range of stakeholders. The findings and conclusions expressed within do not necessarily represent the views of the University of Cambridge, nor those of the Aviation Impact Accelerator's partners, funders and collaborators.

Copyright
Copyright © 2026 University of Cambridge. Some rights reserved. The material featured in this publication is licensed under the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International Licence (CC BY-NC-SA 4.0).

Table of contents

List of abbreviations 3

1 Executive summary 4

2 The case for action 7

2.1 The climate problem 7

2.2 Quantitative case 7

2.3 Technical feasibility 8

2.4 Cost effectiveness 8

2.5 Policy background 9

3 The UK context: airspace, traffic and the contrail burden 11

3.1 Three flight information regions with one ANSP 11

3.2 Traffic and the contrail burden 12

3.3 A unique position to act 12

4 Design principles 14

4.1 The three tests 14

4.2 Guardrails 15

5 Three UK policy building blocks 17

Building block 1: Data mandate 17

Building block 2: Capability standards 18

Building block 3: Surcharge-and-discount (feebate) 18

6 Phased roadmap 21

Phase 1: Foundations (2026 to 2028) 22

Phase 2: Voluntary demonstrations (2028 to 2030) 23

Phase 3: Surcharge-and-discount/feebate incentives (2030 to mid-2030s) 24

Phase 4: International expansion (2030 onwards) 25

Phase 5: Global system (parallel track from Phase 3; mature by 2040) 26

Priority demonstrations 27

Milestones 28

7 Scenario modelling: cost and climate impact 29

7.1 How flights are sorted and settled 29

7.2 Operating principles 34

7.3 Charging responsibility and legal basis 34

7.4 The fee, the rebate and the service charge 35

7.5 Headline results 38

7.6 Scheme finances 41

7.7 Validating the scheme 42

8 What government should do now 43

Annex A. Roadblocks and mitigations 45

A.1 Bottlenecks 46

Annex B. Roadmap modelling 48
B.1 Assumptions and sources 48
B.2 Formulae 50
B.3 Adoption: evidence for the ramp and the ceiling 52
B.4 Main model, central case 52
B.5 Money table, central case 53
B.6 Sensitivities 54
Annex C. Concept of operations (outline) 57
References 61

List of abbreviations

Abbreviation	Meaning	Abbreviation	Meaning
ADS-B	Automatic Dependent Surveillance–Broadcast	FCDO	Foreign, Commonwealth and Development Office
AI	Artificial Intelligence	FIR	Flight Information Region
AIA	Aviation Impact Accelerator	IATA	International Air Transport Association
ANSP	Air Navigation Service Provider	ICAO	International Civil Aviation Organization
ATC	Air Traffic Control	ISSR	Ice-Supersaturated Region
CAA	Civil Aviation Authority	KPI	Key Performance Indicator
CISL	Cambridge Institute for Sustainability Leadership	MRV	Monitoring, Reporting and Verification
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation	NERL	NATS (En Route) plc
CRCO	Central Route Charges Office	NGO	Non-Governmental Organisation
CSA	Customer Supplier Agreement	OCA	Oceanic Control Area
DACCS	Direct Air Carbon Capture and Storage	QAR	Quick Access Recorder
DBIST	Department for Business, Innovation, Science and Trade	RAD	Route Availability Document
DESNZ	Department for Energy Security and Net Zero	SAF	Sustainable Aviation Fuel
DfT	Department for Transport	UN	United Nations
EASA	European Union Aviation Safety Agency	WAFC	World Area Forecast Centre
ETS	Emission Trading Scheme		

Table 1: Abbreviations used in this report.

1 Executive summary

This report proposes a policy pathway designed to reduce aviation's non-CO_2 climate impacts – specifically, warming created by persistent aircraft contrails – in UK airspace and, subsequently, further afield. Building on technical work undertaken by the Aviation Impact Accelerator (AIA), and aligned with upcoming UK government-funded trials, this report sets out a phased approach for the implementation of targeted contrail avoidance with the aim of securing increasingly significant reductions in climate impact by 2040.

The opportunity. Persistent contrails from a small fraction of flights produce a warming effect comparable in scale to all of aviation's carbon dioxide emissions combined. Recent estimates place contrail warming in 2050 at a level similar to, and probably larger than, the warming from aviation CO_2 [1]. While a significant degree of uncertainty remains regarding precise impact, there is no doubt that aviation's CO_2 and contrails together represent a material and growing claim on the temperature headroom that remains below the +2°C limit set by the Paris Agreement. The precautionary, least-regrets course is to act on the capability that exists now. This roadmap treats uncertainty as a reason for adaptive design rather than delay. Navigational contrail avoidance, which involves small deviations in flight path to avoid ice-supersaturated regions where persistent contrails form, is one of aviation's fastest and most cost-effective near-term climate opportunities [2].

Why speed matters. New airframes and propulsion systems will take decades to reach the whole fleet and require capital investment in the tens of billions of pounds. The implementation of navigational contrail avoidance will require significantly less time and capital investment; further, it can be undertaken via minor operational changes to the flight plans airlines already file, deliverable with today's aircraft and today's forecasts at a cost of a few pounds per tonne of warming avoided. Phasing in at-scale avoidance between 2035 and 2045 – ie, significantly sooner than other aviation decarbonisation initiatives such as new airframes and propulsion systems – could recover up to 9 per cent of the remaining global temperature budget in line with Paris Agreement targets in 2050. A ten-year delay (ie, phasing in avoidance over 2045–2055) reduces the benefit of contrail avoidance in 2050 by about 75 per cent, demonstrating the urgency of operationalising navigational avoidance. The additional warming from the small fuel-burn penalty of avoidance is generally around 100 times smaller, or less, than the warming avoided. The principal climate risk associated with contrail avoidance is therefore inaction.

Why the United Kingdom? The UK is unusually well placed to lead in this area. It hosts well-established academic and industry capability with leaders in contrail, aerospace modelling and atmospheric science expertise (including Imperial College, University of Cambridge/AIA, Reading University and Leeds University), alongside an industrial chain including Rolls-Royce on engines and Airbus on space and remote-sensing technologies. The Met Office, an executive agency of the UK government, operates one of only two International Civil Aviation Organization (ICAO) World Area Forecast Centres, giving it direct institutional responsibility for the global upper-atmosphere forecast products on which any operational contrail forecast would be built [2]. UK airspace is controlled by a single regulated air navigation service provider (ANSP), NATS, a structural advantage over the fragmented European system. Furthermore, a

large share of the most warming contrails form over the North Atlantic, including in the Shanwick Oceanic Control Area managed by the UK. Recognising the potential for cost-effective, large-scale climate mitigation, the UK government is already establishing a leadership position by backing the world's first airspace-scale operational trials in partnership with leading technology and industry stakeholders. Dubbed 'Operation Blue Skies' (in reference to a 2024 Aviation Impact Accelerator proposal), the trials will leverage artificial intelligence (AI) technologies to deviate a subset of up to 10,000 transatlantic flights in the Shanwick area. The pathway put forward in this report proposes building on these trials by extending contrail mitigation to other UK airspaces and by establishing permanent machinery to embed contrail avoidance into business-as-usual operations, building on collaboration between academia, industry and government and developing a shared, independent and impartial evidence base. If implemented, this roadmap would make the UK the first country to make contrail avoidance part of routine flight operations, with forecasts, planning standards and incentives working together across its airspace.

Our core UK ask. We propose three mutually reinforcing measures. Each builds a capability the next depends on, but work on all three starts in Phase 1 and proceeds in parallel: the dependency governs the order in which they come into force, not the order in which they are developed (Section 6). A condition common to all three is that the incentives of the delivery bodies are aligned with the outcome, which requires consideration of NATS policies and operations (Section 7.3). The three measures proposed are:

1. **A contrail data mandate.** The Met Office should be required to include forecasts of contrail-forming regions in the standard aeronautical meteorological data packet supplied to flight-planning software providers, airlines, dispatchers, pilots and ANSPs.
2. **Flight-planning capability standards.** Government, via the Civil Aviation Authority (CAA), should set a minimum standard requiring flight-planning software to offer a contrail-avoidance option, and require airlines to consider avoidance in flight-by-flight planning.
3. **An airspace charge incentive.** A modest surcharge-and-discount (fee/rebate or 'feebate') mechanism, applied through existing NATS route charges, should make planned and evidenced avoidance the economically rational default.

A positive, pragmatic pathway. The envisaged roadmap progresses through multiple phases, from foundation and capability building, through voluntary demonstrations, to economic incentives and the embedding of contrail avoidance in business-as-usual commercial aviation as part of an eventual global system. Additionally, the envisaged geographic scope widens in step with the policy. One possible expansion pathway runs as follows: from the UK to the EU and Canada, and finally to a globally co-ordinated system, potentially administered through ICAO or another international body. While the global track is numbered last, the intention is that this runs in parallel with domestic delivery from the incentive phase onward, informed and driven by a strong, well-evidenced UK policy framework.

About this white paper

This white paper is one output of an Aviation Impact Accelerator project that seeks to progress understanding of the need for policymaking to support the scaling of contrail avoidance.

A high-level overview of the proposed policy roadmap can be found in the accompanying policymaker summary, ***Searching for blue skies: Policy roadmap for navigational contrail avoidance***.

Further information on the state of scientific understanding around contrails and the implications of this for policymaking can be found in ***Technical guardrails for contrails policy development***.

2 The case for action

2.1 The climate problem

Condensation trails, or contrails, are the white streaks aircraft sometimes leave across the sky. They form when hot, humid jet engine exhaust mixes with cold, moist air and water vapour freezes into ice crystals. Most contrails fade within seconds to minutes and have no meaningful climate effect. In certain atmospheric conditions, however, they can persist for hours, spreading into thin, hazy sheets that trap heat which would otherwise escape to space [2]. The goal of contrail management policy is simple: to prevent the small fraction of flights that create these persistent, warming contrails from doing so, thereby greatly reducing the climate-warming impact of aviation. Contrail management is possible using currently existing technology in weather forecasting and flight-planning domains, which collectively enable the navigational avoidance of contrail-forming regions at the cost of small increases in fuel burn ('fuel burn penalties').

Contrail warming is not currently captured by any UK aviation climate target or pricing mechanism. Accounting for these non-carbon-dioxide effects would give a more complete picture of aviation's true climate impact and make contrail management a meaningful complement to existing carbon reduction commitments [2].

2.2 Quantitative case

A 2026 study by Smith et al. uses the Aviation Climate and Air Quality Impacts model to quantify the temperature effect of fleet-wide contrail avoidance up to 2050 [1]. Its central findings anchor this roadmap, as detailed in Table 2.

Finding	Value	What it means for policy
Scale of the problem	Contrail warming is of a similar magnitude and likely larger than aviation CO_2 (contributing ~0.05°C to global temperature rise each by 2050).	Contrails are not a secondary concern; by 2050, they are likely to exceed aviation CO_2 warming.
Share of budget	Total aviation emissions account for 19% of our remaining carbon budget in order to remain within the Paris Agreement limit of 2 °C warming.	Often overlooked until recently, contrails are a vital part of aviation's total climate impact.
The prize	Almost half of the climate warming from aviation can be avoided if contrail mitigation is phased in from 2035 to 2045.	Contrail avoidance can be a high-impact mitigation lever if undertaken in the near term.
The cost of delay	Delaying by ten years cuts this potential benefit by ~75%.	As time passes, the opportunity to reduce the climate impact of aviation in

Finding	Value	What it means for policy
		2050 shrinks; acting on today's capability beats waiting for perfect readiness.
Overall positive impact	Avoiding contrails exceeds the potential extra CO_2 penalty of additional fuel-burn by ~100x.	The net climate impact of contrail avoidance is expected to be strongly positive at scale, even where extra fuel burn is required.

Table 2: Smith et al. (2026) findings and their implications for this roadmap.

The central message. Even under pessimistic assumptions of an extreme 10 per cent fuel burn penalty, low effectiveness and slow demand growth, a net warming reduction from contrail management activity remains overwhelmingly likely; the study finds the mean contrail warming reduction is around 15 times the associated fuel burn penalty in 2050, even in the worst case, and over 400 times under the more realistic sub-1 per cent penalty [1]. Consequently, inaction is the dominant risk.

2.3 Technical feasibility

There already is a system in place that is very similar to what is needed to manage contrails: the way air traffic control and pilots currently avoid turbulence. Both turbulence and contrails are caused by temporary conditions in specific parts of the sky, so pilots are already accustomed to navigating around such regions. Today, turbulence management operates through weather services identifying risky regions, airlines using these forecasts to plan routes before take-off, and pilots reporting and navigating live conditions in the air while air traffic control co-ordinates any needed adjustments. A contrail management system can adopt a very similar process. While contrails require more precise height adjustments and are avoided for reasons of climate protection rather than flight safety, the underlying blueprint already exists. We do not have to build a new system from scratch.

This is reinforced by working precedents elsewhere: the US Graphical Turbulence Guidance and Mountain Wave Turbulence products publish hazard forecasts directly into flight-planning tools [3]; ICAO's Volcanic Ash Advisory Centres run a globally harmonised forecast-to-avoidance system [4]; and the EU's non-carbon-dioxide monitoring, reporting and verification (MRV) regime has, since January 2025, applied a model-based, portfolio-level approach to contrail effects [5]. Such systems are mature, legal and routine.

2.4 Cost effectiveness

Contrail management is one of the most cost-effective climate-impact mitigation strategies available to the aviation industry. In a 2025 report, Roland Berger places 2040 contrail abatement costs at €2–6/tCO_2e (tonnes of carbon dioxide equivalent) [6]; Google estimates US$5–25/t at today's capability [7]; Contrails.org's published fleet-level cost model [8] centres on ~US$1.75/t (range US$0.5–US$14, with added fuel burn making up over 90 per cent of the cost); and Transport & Environment's deliberately conservative upper bound, including all observation and equipment capital, is €20/t [9]. As such, four

cost estimates from four independent methodologies (strategy-house techno-economics, operator trial data scaled, a fleet-level cost model, and a non-governmental organisation (NGO) upper bound that deliberately includes all capex) all land at less than US$25/t avoided, with the difference between different estimates being driven by different assumptions about effectiveness of approaches rather than disagreement about the value of the core activity of contrail avoidance.

Per tonne abated, Transport & Environment finds contrail avoidance around one-third the cost of solar and wind generation (~€60/tCO_2e) and less than 10 per cent of the cost of direct air carbon capture and storage (DACCS). Set against the rest of the aviation decarbonisation portfolio, contrail management is likely to be 10 to 100 times cheaper per tonne than the sustainable aviation fuel (SAF) pathway which the UK government is already supporting through the SAF Mandate and Revenue Certainty Mechanism (and associated measures) [10]. It is also deployable this decade, unlike fleet renewal, which is cheap per tonne but rate-limited by 20-year fleet turnover, or hydrogen, which most abatement-cost studies do not expect to be viable before 2035.

2.5 Policy background

The policy landscape for contrails is young but no longer empty, such that this roadmap unfolds against the backdrop of several proposals for courses of action. On the regulatory side, the EU's monitoring, reporting and verification (MRV) system for aviation's non-CO_2 effects (including contrails) has been live under the EU Emission Trading Scheme (ETS) since January 2025. In addition, the European Commission proposed in July 2026 to dedicate three million free ETS allowances to contrail mitigation, with each EU Member State allocating allowances equal to 0.1 per cent of aircraft operators' verified emissions if those operators support contrail management through forecasting and navigational avoidance. (Additional allowances totalling 0.02 per cent of operators' emissions would be allocated to flights for which operators support MRV with trajectory and fuel burn data.) In the UK, the UK ETS Authority has stated, in its Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Part 2 consultation, that it is considering whether and how to include aviation's non-CO_2 impacts in the UK ETS, including MRV. Given (as of 2026) ongoing discussions between the UK and EU on closer integration of their respective ETS systems, there is a chance that the UK will eventually adopt a similar approach to the EU on contrails. However, no definite proposal, regulation or timeline for non-CO_2 incorporation yet exists – a gap this report is designed, in part, to fill.

Alongside EU ETS developments, civil society and think-tank proposals include: Transport & Environment's free-allowance subsidy and its 2026 recommendation to embed a climate key performance indicator (KPI) in the UK's 3Di efficiency framework; Opportunity Green's SASHA warming-proportional fee, with exemptions for operators demonstrating avoidance capability; and the Clean Air Task Force's fuel-composition route to soot reduction. In addition, recent trials have demonstrated that climate-optimised planning in European airspace is achievable at low operational cost, including: the EUROCONTROL/MUAC trials and Contrail Observatory, the American Airlines/Google trials; the SESAR 3 research programmes (CICONIA, CONCERTO, E-CONTRAIL); and the SATAVIA/European Space Agency DECISIONX trials.

2.5.1 The ‘feebate’ concept

Against this policy landscape, the distinctive contribution of this roadmap is the portfolio-assessed feebate, a mechanism which has been implemented in automotive (France) and infrastructural (Sweden and Norway) contexts but for which no direct precedent exists in aviation.

Sweden’s charge on nitrogen oxides from large combustion plants, in force since 1992, is the closest analogue [11]. A charge is levied on every plant above a size threshold, and the revenue, less administration, is refunded to the same plants in proportion to the useful energy they produce. A plant that emits less NOx per unit of energy than the average gets back more than it paid, and one that emits more gets back less. Because the refunds equal the income less administration, the industry as a whole pays only the administration cost, and the state keeps nothing.

NOx emissions from covered plants fell by about a third within 20 months, and emissions per unit of energy roughly halved; administration costs a small fraction of revenue; and the charge has survived changes of government because it transfers money within the industry rather than out of it. Norway’s NOx Fund (2008) applies the same logic by agreement: firms that join the NOx Agreement pay into a fund in lieu of the national NOx tax and draw on it to finance abatement.

The feebate in Section 7 applies the same principle with different mechanics. Only flagged flights take part: a flight that could have avoided a confirmed contrail region and did not pays a fee, a small share of the fee income meets running costs in the first years, and the rest is paid back in the same year, in equal shares, to the flights that verifiably avoided. The remaining running cost and the repayment of avoiders’ extra fuel come from a separate small service charge on every flight.

In France’s vehicle bonus-malus scheme, introduced in 2008, buyers of cars below a CO_2 threshold received a rebate and buyers above a higher threshold paid a surcharge. Market composition shifted within months, but three design faults appeared at once: the rates were set by bands, so manufacturers tuned models to sit just below a band edge; take-up of the bonus outran the malus, so that a scheme designed to be fiscally neutral cost more than €200 million in its first year, with a cumulative deficit of nearly €1.5 billion by 2012; and the scheme increased total car sales, so that on the leading evaluation aggregate emissions rose even as emissions per car fell [12]. The malus has since been reformed [13] into a per-gram schedule (each g/km above the threshold carries its own charge), with the thresholds and rates for several years ahead published in the Finance Act.

While feebates have yet to feature in aviation, the sector already modulates charges by environmental performance on the fee side. Noise-related landing charges that vary by certification category and time of day operate at Heathrow and most large European airports; NOx-based landing-charge elements have applied at Zurich since 1997 and at Heathrow since 2004; and EU Regulation 2019/317 (Article 32) [14] permits en-route charges to be modulated for environmental purposes as long as the provider’s total revenue is unchanged, although no State has yet used this power. The feebate in Section 7 therefore combines elements with precedent: an environmentally modulated airspace charge (aviation), fee income returned to the same operators (Sweden) and rules published ahead of time (France after reform).

3 The UK context: airspace, traffic and the contrail burden

In advance of specific design principles and policy measures, this section describes the airspace the roadmap would operate in: how it is organised, how much traffic it carries, how large its contrail climate burden is likely to be, and why the combination places the UK in a uniquely strong position to move first.

3.1 Three flight information regions with one ANSP

UK-administered airspace comprises three flight information regions (FIRs), all managed by NATS (formerly known as National Air Traffic Services), a single regulated air navigation service provider (ANSP) unlike the fragmented European system which has over 30 national providers. Licensed and price-controlled by the Civil Aviation Authority under the Transport Act 2000, NATS provides en-route services across the London FIR (England and Wales), the Scottish FIR (Scotland and Northern Ireland), and the Shanwick Oceanic Control Area (OCA), a roughly 700,000 square mile block of the north-east Atlantic (Figure 1). Operations are run from two centres: Swanwick in Hampshire, covering the congested airspace of London and the Southeast, and Prestwick in Ayrshire, covering northern and Scottish airspace and the oceanic operation [15]. Shanwick sets westbound courses; NAV CANADA, the Canadian ANSP, eastbound.

FIR / area	Coverage and character	Contrail relevance
London FIR	England and Wales; among the densest and most complex airspace in Europe, centred on the London terminal area.	High traffic volumes and frequent overflights; congested sectors constrain the re-routing envelope, favouring pre-tactical planning.
Scottish FIR	Scotland and Northern Ireland; managed from Prestwick, including transatlantic entry and exit flows.	Gateway between the European network and the North Atlantic; a natural location for trial corridors.
Shanwick OCA	Approx. 700,000 sq mi of the north-east Atlantic; air traffic control from Prestwick, with comms provided from Ireland.	Carries the bulk of North Atlantic oceanic traffic, including the eastbound overnight flow associated with the most strongly warming contrails.

Table 3: UK-administered flight information regions and their relevance to contrail mitigation.

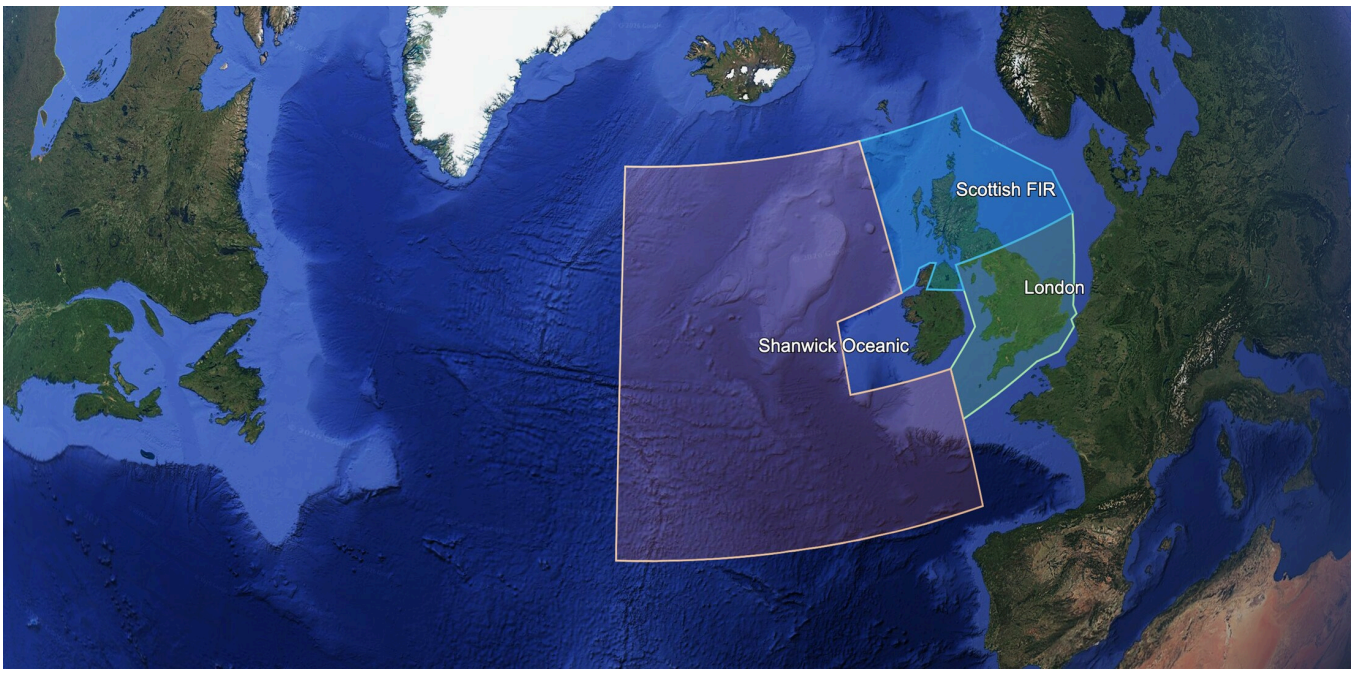


Figure 1: UK-administered airspace: the London and Scottish FIRs and the Shanwick Oceanic Control Area.

The UK sits at the centre of one of the world's busiest air traffic networks. In 2025, NATS handled more than 2.5 million flights, accounting for around 25 per cent of all European air traffic within just 11 per cent of Europe's airspace. The UK's North Atlantic operation is particularly important, with a record 1,970 transatlantic flights handled on 3 July 2025 [16]. Because of this scale, policies implemented in UK airspace could affect millions of flights every year and a significant share of global long-haul aviation.

3.2 Traffic and the contrail burden

The North Atlantic is one of the world's busiest air traffic corridors and one of its most intensively studied contrail regions. Simulations covering 2016 to 2021 estimate an annual mean contrail cirrus net radiative forcing of roughly 204 to 280 mW m^{-2} in the pre-pandemic years, with substantial inter-annual variability driven by meteorology, and find that around 12 per cent of flights cause approximately 80 per cent of the annual contrail energy forcing [17]. The most strongly warming contrails in the region form predominantly from night-time flights during winter cruising near the tropopause, a description that maps closely onto the eastbound overnight flow through Shanwick. Because the dataset underpinning that analysis captures flights entering the Shanwick region (~80 per cent of North Atlantic oceanic traffic), the majority of the corridor's contrail burden arises in airspace the UK already manages [17].

3.3 A unique position to act

The United Kingdom has a strong combination of assets – infrastructural, regulatory and geographical – that give it a near-unique capability to effect near-term contrail mitigation at scale.

The assets listed below are the practical basis for the three policy building blocks set out in Section 5.

Structural asset	Why it matters for contrail policy
Met Office as ICAO World Area Forecast Centre (WAFC)	One of only two WAFCs worldwide; the institutional home of the upper-atmosphere forecast products on which any operational contrail forecast, and the policy data mandate, would be built.
A single, regulated ANSP	NATS controls all three FIRs and sets route charges under CAA price control, providing one delivery counterparty and one charging lever (building block 3), in contrast to the fragmented European system.
Jurisdiction over Shanwick (in partnership with Ireland)	Through NATS Prestwick, the UK has air traffic control (ATC) of the airspace where a significant share of the most warming contrails form, enabling demonstrations and incentives to be focused where the climate return is potentially high. The Shanwick operation is shared with Ireland – AirNav Ireland provides the Shanwick communications service and holds delegated portions of the OCA – and NAV CANADA (Gander) sets the eastbound tracks. Operation Blue Skies runs without active participation from Gander, but future Canadian participation would greatly increase the impact.
Climate-policy machinery	The Climate Change Act 2008 precedent, the Jet Zero Taskforce, and adjacency to the EU's live non-CO_2 MRV regime give the UK a credible institutional route from evidence to regulation.
Academic and industrial base	World-leading contrail, aerospace modelling and atmospheric science expertise (Imperial College, Cambridge/AIA, Reading/Leeds), alongside an industrial chain – Rolls-Royce on engines, Airbus UK chairing the Jet Zero contrail group, and trial-experienced UK carriers – that lets the full forecast-to-flight-deck system be built domestically.

Table 4: Structural advantages supporting UK leadership in contrail mitigation

Taken together, the scale of traffic under UK management, the concentration of the North Atlantic contrail burden within it, and these structural assets are why this roadmap treats the UK not simply as one participant among many, but as the natural anchor for the internationally co-ordinated system described in Phase 5.

4 Design principles

How this roadmap was developed

The recommendations in this document are based on a combination of one-to-one interviews, desk research, technical analysis and workshop sessions. This included all-day policy workshops at the Whittle Laboratory in Cambridge, bringing together a deliberately diverse group of around 30 individual stakeholders to work through the design principles and practical challenges of contrail avoidance in the UK. Participants included representatives from airlines, ANSPs, UK government departments and regulatory authorities, academic experts, industry groups, and non-governmental organisations working on aviation sustainability. They were given free rein to suggest potential policy mechanisms, contribute expertise on possible operational constraints, and identify where additional information might be required to inform 'good' policy around contrail avoidance. The workshops were held under the Chatham House rule, so no view is attributable to any individual or organisation.

The workshops were structured to move from shared understanding to concrete choices. They opened with level-setting presentations on the rationale for acting, the outcomes of recent operational trials, the findings of the government's Jet Zero Taskforce (which tasked a group with investigating contrail avoidance in the UK), and the policy gap to be filled. Participants then split into three groups across two breakout rounds, first exploring the full range of policy options and then narrowing to the most promising. That process converged on three mutually reinforcing measures for the UK. These three building blocks, set out in Section 5, form the core of the roadmap, while the phased pathway in Section 6 sequences their delivery and extends the logic beyond the UK to an internationally co-ordinated system.

The roadmap is built on a small set of principles drawn from the Aviation Impact Accelerator's accompanying *Technical guardrails for contrails policy development* and aforementioned workshops. They are the tests any measure in this document must pass and the guardrails that keep the pathway credible.

4.1 The three tests

- → **Safe.** Every measure operates within the existing aviation safety framework. Safety-critical instructions always take precedence over climate-motivated routing. No measure introduces new risk to aircraft or airspace.
- → **Effective.** Every measure must deliver a reduction in contrail warming, with sufficient network coverage, high compliance, and a net climate benefit rather than displaced warming.
- → **Feasible.** Every measure reflects an honest assessment of what the science and operational systems can deliver today, distinguishing temporary gaps that investment can close from structural limits that policy must design around.

4.2 Guardrails

→ **Safety comes first.** Safety is the first of the three tests and a guardrail on every design choice. Contrail avoidance must remain subordinate to ATC instructions and operational safety requirements, safety-critical instructions always take precedence over climate-motivated routing, and flights that cannot avoid a contrail-forming region for safety or capacity reasons should not be penalised.

→ **Lead with pre-tactical navigational avoidance.** Planning avoidance before departure, through small changes of flight level in the filed flight plan, is the only mitigation mechanism that combines near-term deployability, meaningful climate benefit and compatibility with existing air traffic management infrastructure. It keeps avoidance within established flight-planning review processes and limits real-time controller workload.

→ **Use portfolio-level monitoring and reporting.** Observation of contrail avoidance by individual flights is currently impossible at scale, while the complexities of atmospheric science lend a degree of uncertainty to climate impact modelling for any specific contrail. Consequently, evaluation of success or failure in contrail avoidance is best judged using statistical methods in the aggregate, analysing portfolios of flights built from per-flight modelling at scale such that random errors in modelling average out across aggregates. Fees and rebates still attach to individual flights, because a charge must attach to a flight if it is to change a filing decision. Each flight is assessed on the central estimate of its modelled warming (Section 7.4), both for the 10 tCO_2e threshold and for whether a contrail region was present, and charges are settled per operator per billing period, so random errors in individual estimates cancel across the many flights on an operator's bill. Systematic uncertainty, such as the factor converting contrail forcing to CO_2e, is handled by updating the method at each three-yearly review rather than by a standing discount.

→ **Avoid reliance on SAF or future aircraft technologies in the near term.** The effect of SAF on contrails is not yet established, supply is far too small to make a fleet-scale difference, and the book-and-claim model through which SAF is traded cannot be reconciled with flight-specific contrail modelling. New airframes and engines face long certification times and decades of fleet turnover. Both remain worthwhile long-term investments, but neither can substitute for operational action now.

→ **Invest in infrastructure and weather data.** Upper-tropospheric humidity observations, contrail-relevant weather forecasting and interoperable flight-planning standards are the main constraints on avoidance that investment can close. They should be funded as an explicit workstream, with milestones that gate progression from voluntary to mandatory measures (building blocks 1 and 2, Section 5).

→ **Do not conflate CO_2 and non-CO_2 effects.** Contrail warming and carbon dioxide warming are not interchangeable. The exchange rate between them depends on the metric chosen and remains contested (see the accompanying ***Technical guardrails for contrails policy development***), so policy should keep the two separate: contrail obligations should not be met with CO_2 reductions or allowances, nor CO_2 obligations with contrail avoidance. Otherwise operators could offset action on one with inaction on the other. Within individual flight plans the two must still be weighed against each

other, since avoidance burns extra fuel, but the choice of metric mainly affects marginal flights, not the core case for avoidance.

- → **Name a single co-ordinating owner.** No single actor controls the chain from forecast to flown trajectory: airlines, NATS, the Met Office and the CAA each control one step. Without a named owner, each actor can wait on the others. A single co-ordinating owner, such as the Department for Transport or the Civil Aviation Authority, should hold the mandate for delivery, setting escalation milestones and resolving cross-actor issues, while operational obligations remain with the actors best placed to carry them.
- → **Adopt adaptive, ICAO-compatible regulation.** The framework should act on today's capability and overwhelming evidence that avoidance will have a positive climate impact, rather than waiting for the science or governance to be judged fully mature. Measures should begin as voluntary demonstrations and incentives, tighten as MRV and operational capability mature, and remain compatible with ICAO charging principles (Section 7.3).
- → **Apply to all operators equally, target by forecast.** Because a small share of flights, about 2 per cent globally and around 12 per cent over the North Atlantic, causes about 80 per cent of contrail warming, policy should concentrate avoidance on the highest-impact flights [18]. Such targeting is best delivered operationally: the obligation should cover all operators, while forecasts and routing software select the flights to avoid. Drawing scope around particular routes or airspace adds complexity, creates competitive distortions and invites reclassification. If a scope or phased rollout is defined geographically, it should be justified on technical grounds, time-limited and protected against routing around it, and should state what share of total contrail radiative forcing it captures, so that targeting is not used to reduce ambition.

5 Three UK policy building blocks

As Section 4 describes, the stakeholder workshops used to develop this roadmap converged on three concrete, mutually reinforcing UK policy measures. They are presented here in dependency order: data first, because nothing can be planned or priced without a common data layer; then capability, because the data must be usable in the tools airlines already operate; then incentive, because acting on the data must be economically rational. The third building block, the surcharge-and-discount/feebate scheme, is designed to create strong incentives to embed contrail avoidance into business-as-usual commercial aviation.

Building block 1: Data mandate

Aspect	Detail
Proposal	Require the Met Office to provide forecasts of contrail-forming regions (ice-supersaturated regions, ISSRs) as part of the standard aeronautical meteorological data package supplied to airlines, dispatchers, pilots and ANSPs. The product should be generated using a published methodology, specify forecast issue times, validity periods and update frequency, and be made openly available to all stakeholders. The Met Office forecast would serve as the common reference baseline used to identify flights potentially exposed to contrail-forming conditions. Operators may use any forecasting system that meets the capability benchmark established under building block 2 and verified through the open validation framework established in Phase 1 (Section 6). A technical specification should be published by the Met Office, setting out forecast issue times and update frequency as well as the contrail prediction methodology used and a change-control process to ensure continued compatibility with international frameworks. To support international interoperability, the forecasting methodology should be designed to align as far as possible with emerging international standards, including the EU contrail monitoring, reporting and verification (MRV) framework.
Mechanism	Directive route via the Department for Business, Innovation, Science and Trade (the sponsoring department for the Met Office), working with the Department for Transport and the Civil Aviation Authority on aviation implementation. Delivery could be achieved through the Public Weather Service Customer Supplier Agreement (CSA) as part of a rolling refresh of the current agreement.
Why it is needed	There is currently no single source of contrail-forming-region information for all aviation stakeholders. A standardised forecast provides a common baseline for planning, accountability and future policy measures, while still allowing innovation and competition between forecasting providers.
Why the UK	The Met Office is one of only two ICAO World Area Forecast Centres worldwide, positioning the UK to help shape future international practice. By developing an openly specified approach that is interoperable with European and international frameworks, the UK can accelerate convergence towards a common global standard for contrail management.

Aspect	Detail
Near-term variant	Pilots could be fed ISSR forecasts in the same way they currently request turbulence information, potentially achievable within around three years.

Table 5: Building block 1 (Data mandate): proposal, delivery mechanism and rationale.

Building block 2: Capability standards

Aspect	Detail
Proposal	Set a minimum standard for flight planning and air traffic management systems requiring support for contrail mitigation. Airlines should be required to consider avoidance of contrail-forming regions during flight planning, while ANSP systems should be capable of receiving, displaying and operationalising contrail-related information where compatible with safety and capacity requirements. Compliant flight-planning software must include the expected contrail fee in the cost function it minimises when choosing a route, alongside fuel, time and existing charges, so that the optimiser offers the contrail-avoiding plan whenever it is cheaper. Systems used by airlines and ANSPs should use interoperable data formats and interfaces to enable co-ordination across UK and international airspace.
Mechanism	Standard-setting via the CAA. A published, regularly updated list of compliant providers. Airlines need not use a listed provider but face a fee if they do not. Voluntary phasing-in period, then mandatory. Compliant software may use any contrail forecast that meets a published skill benchmark, judged against the open verification standard adopted in Phase 1 (Section 6).
Why it is needed	Only one major provider (Flightkeys) currently offers a contrail-optimised routing option. Providers have little commercial incentive to build the capability, leaving even willing airlines unable to act. A clear market signal resolves this upstream bottleneck. Effective contrail mitigation depends on co-ordination between airlines and ANSPs. Establishing compatible capabilities on both sides reduces implementation risk and enables avoidance measures to be delivered operationally rather than remaining solely a flight-planning exercise.
Co-benefits	By embedding a new layer of responsiveness to externalities, software that optimises routing around contrail regions may also improve resilience to airspace disruptions caused by volcanic ash or geopolitical closures, aligning with airspace modernisation objectives.

Table 6: Building block 2 (Capability standards): proposal, delivery mechanism and rationale.

Building block 3: Surcharge-and-discount (feebate)

Aspect	Detail
Proposal	A fee and rebate attached to existing airspace charges, applying to warming modelled to have occurred in UK-administered airspace. A flight that the forecast flagged, that kept its route, and that is confirmed after the fact to have crossed a contrail-forming region pays a flat fee of five

Aspect	Detail
	times the fuel cost of avoiding, ~£325 per flight in 2030. Fee income is paid back in the same year as an equal rebate to each flight confirmed to have avoided a region that was there, after a 10% share is kept towards running costs in 2030 to 2034. Alongside this, a small service charge on every flight in UK-administered airspace covers the rest of the running cost and the extra fuel burned on accepted avoidance plans, which is repaid in full to 2035 and on a falling scale to zero in 2040. Fuel is repaid on planned fuel, capped at a published benchmark, and credited on the route-charge bill in the same settlement as fees and rebates (Section 7.1). Avoidance means a change of flight level; lateral re-routing is neither rewarded nor charged. The scheme is designed to carry no net public cost in any year: fee income is spent within the scheme in the year it is collected, mostly as rebates, and the service charge is reset each year to cover the remaining running costs and fuel repaid. Any shortfall or surplus is corrected in a later year's charge (Section 7.6). Set-up costs in Phases 1 and 2 fall outside this ongoing cost structure.
Mechanism	In the London and Scottish FIRs, NATS sets charges and EUROCONTROL invoices and collects them monthly; verified fees, rebates and fuel repayments would be applied as a net adjustment to a later month's invoice, from a verification file supplied by NATS. EUROCONTROL is to be consulted in Phase 1 on its ability to apply the adjustment and on any system cost. In Shanwick, NATS collects directly through NATS (En Route) plc (NERL). Section 7.3 sets out the lines of responsibility. Only one plan is filed with air traffic control. The normal, cost-optimised plan that the operator's planning system generates first is kept with its audit record and supplied to the verifier; if the operator chooses to avoid, the avoidance plan is the one filed (Section 7.1). The normal and flown routes are then re-run through reanalysis weather data, using ADS-B or GPS tracks, to confirm whether a contrail region was present and whether the flown route avoided it, and the verifier assigns the flight to one of the scenarios in Table 15. Inclusion criteria are feasibility (could the flight be safely altered, and did any ATC restriction prevent it being flown as planned?) and net climate benefit (does the warming avoided outweigh the fuel-burn penalty?). The CAA is the regulatory route, given its price-control role over NATS En Route.
Resources	Scheme administration cost is provisionally modelled at £5 million annually, on the basis that billing uses the existing NATS and EUROCONTROL charging infrastructure, that verification is automated against reanalysis weather data and ADS-B tracks, and that the only new functions are forecast provision, plan comparison and appeals. The running cost is met in part from fee income to 2034 and otherwise, with the fuel repayment, through the service charge, around £2.30 per flight in 2030. The running cost therefore affects what operators pay but not the public purse (Annex B.6).
Initial focus	Shanwick first, building on Operation Blue Skies. Scottish FIR follows in 2032 and London FIR in 2034, building on Operation Blue Skies and Shanwick experience. Pre-scheme engagement with operators over 2027 to 2030 aims to raise initial uptake above the roughly 10% voluntary take-up recorded in the 2023 American Airlines, Google and Contrails.org trial (Annex B.3).
Constraints	NERL's charges are set for five-year periods, the next (NR28) from January 2028. Substantive changes to the charging framework normally wait for a periodic review, so the NR28 settlement should include a provision allowing the CAA and NERL to consult users on, and if justified introduce, a contrail-avoidance variation within the period; the opportunity to secure it ends in

Aspect	Detail
	late 2027. Government, as a 49 per cent shareholder and via the CAA, is the vehicle for directing the change. The scheme must comply with the NERL Licence, Article 15 of the Chicago Convention and the ICAO Doc 9082 [19] principles of non-discrimination, cost-relatedness, transparency and consultation with users (Section 7.3). Scope is UK-administered airspace in Phase 3; whole-flight accounting is an option for Phase 4.
End state	The rebate is transitional: because it is paid from fees, it shrinks as fewer flights pay them. Fuel repayment ends in 2040. The fee remains as a standing charge on avoidable warming, and the service charge covers the running cost. At that point contrail avoidance is business as usual (Section 7.6).

Table 7: Building block 3 (Surcharge-and-discount feebate): proposed design and implementation.

6 Phased roadmap

The pathway progresses through five phases. Each begins with an objective, sets out what needs to happen, identifies who is responsible with a UK focus, states the dependencies that must be in place, and defines the decision point that governs progression to the next phase. Geographic scope widens in step with maturity, from the UK outward. The global system (Phase 5) is numbered last but is not sequential: the international groundwork begins as the UK feebate goes live in Phase 3, so the domestic and global tracks develop in parallel rather than one after the other.

In terms of responsibility for stakeholder engagement, the UK Department for Transport (DfT) leads international engagement and represents the UK at ICAO, with the Foreign, Commonwealth and Development Office (FCDO) supporting bilateral work with Canada, Ireland and the EU. DfT deals with Transport Canada, Ireland's Department of Transport and the European Commission, with the Department for Energy Security and Net Zero (DESNZ) involved on any link to the EU ETS. The CAA works with Transport Canada, the Irish Aviation Authority and the European Union Aviation Safety Agency (EASA) on standards and charging. NATS works with NAV CANADA and AirNav Ireland on operations, including through the ICAO North Atlantic Systems Planning Group, and the Met Office works with transatlantic partners through the World Area Forecast System on forecast standards.

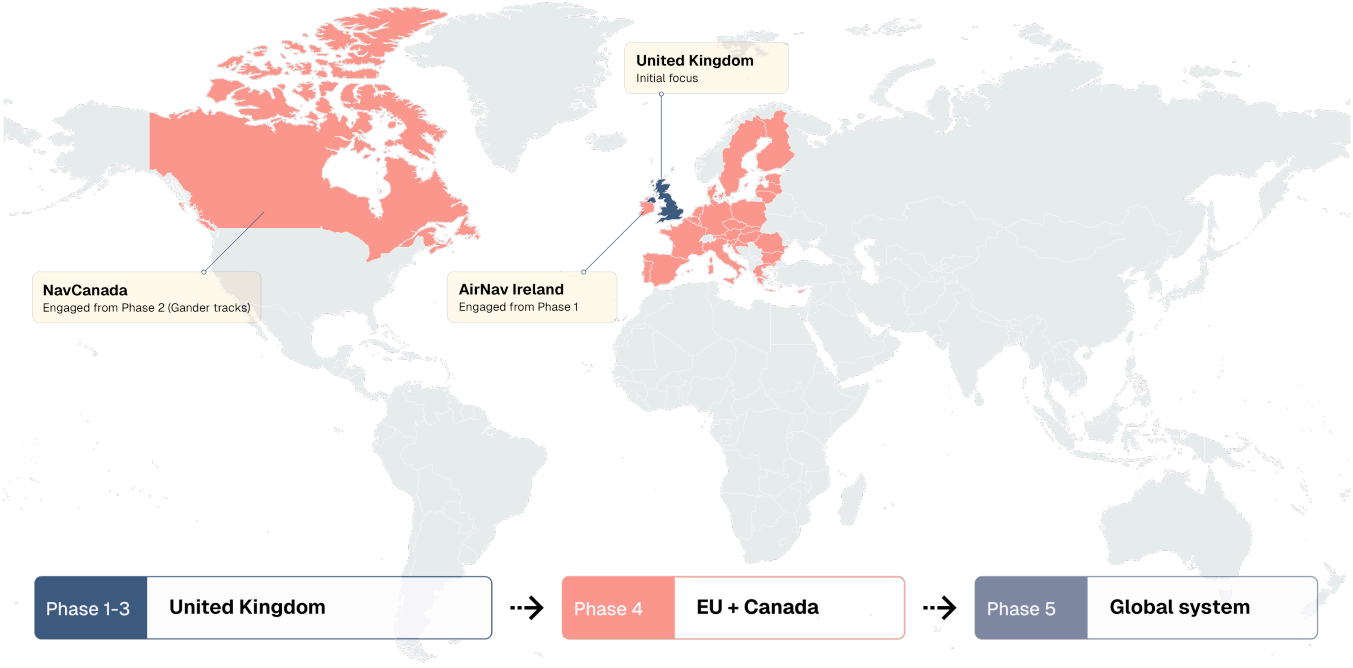


Figure 2: Geographic expansion pathway for contrail mitigation policy, from UK implementation to EU, Canadian and global adoption.

Phase 1: Foundations (2026 to 2028)

Geographic scope: United Kingdom

Objective. Establish the essential technical, operational and policy building blocks on which everything else depends.

What needs to happen

→ Improve the availability and quality of upper tropospheric humidity data, closing the single largest tractable forecasting gap.

→ Develop and validate contrail forecasting and measurement capabilities, adopting or building on an open verification standard such as ContrailBench rather than constructing from scratch.

→ Agree on technical standards and guardrails, including portfolio-level MRV principles.

→ Secure the Met Office data mandate (building block 1) through the next CSA renewal, and begin CAA work on flight-planning standards (building block 2).

→ Build institutional and stakeholder support and designate a single co-ordinating owner, aligning with Operation Blue Skies activities and stakeholders as needed.

→ Consult EUROCONTROL on applying verified fees, rebates and fuel repayments to its monthly invoices, and agree with NATS an analysis of the fee level at which routing around UK airspace would pay to avoid 'gaming' of the system.

Who is responsible (UK focus)	Dependencies	Decision point to progress
DfT or CAA (co-ordinating owner, to be designated); Met Office (data); CAA (standards); DBIST (Met Office oversight); AIA and CISL (evidence and convening).	Nature and Primer evidence base (in hand); humidity observation investment; open verification benchmark; ministerial willingness to act on today's capability.	Core data, forecast, and standards building blocks agreed and a delivery owner named. Proceed when a usable ISSR forecast product meeting pre-set standards and a compliant-provider standard are specified.

Table 8: Phase 1 foundations: responsibilities, dependencies and progression criteria.

Phase 2: Voluntary demonstrations (2028 to 2030)

Geographic scope: United Kingdom, with transatlantic partners (eg NAV CANADA/AirNav Ireland) engaged.

Objective. Generate operational evidence and demonstrate feasibility in UK FIRs, distinct from existing trials by focusing on pre-tactical and strategic planning.

What needs to happen

- → Run voluntary pilot programmes with airlines and ANSPs, centred on pre-tactical navigational avoidance as the most promising near-term mechanism, and including a hybrid of airline-led and ATC-led avoidance, which the SESAR CICONIA project recommended developing further.
- → Test operational procedures and data-sharing approaches in the Shanwick Oceanic Control Area (2029–30, following the end of Operation Blue Skies) and, once Operation Blue Skies has shown a clear benefit, in the Scottish FIR and then the London FIR. This would be a new demonstration that follows Operation Blue Skies: pre-tactical avoidance, with the filing, verification and settlement process of Section 7 as a dry run before any charge applies.
- → Evaluate climate benefit, airspace impact and implementation cost against agreed cross-cutting criteria.
- → Measure the effect of avoidance on capacity and on the wider network at busy times as well as quiet ones. Operation Blue Skies is planned for low-traffic periods in the Shanwick Oceanic Control Area, with a feasibility study for the Scottish FIR and no London FIR element, so it will not settle the capacity question.
- → Develop the monitoring, reporting and verification approach that later phases will rely on.
- → Open dedicated NAV CANADA and AirNav Ireland engagement workstreams, given their role in setting eastbound overnight North Atlantic tracks/co-ordinating westbound North Atlantic communications respectively.

Who is responsible (UK focus)	Dependencies	Decision point to progress
Co-ordinating owner (DfT or CAA); NATS (airspace and demonstrations); airlines (operations); Met Office (forecast supply); CAA (oversight); AIA (evaluation); DfT (international engagement, supported by FCDO); NATS with NAV CANADA and AirNav Ireland (operational engagement).	Phase 1 data and standards; flight-planning tools able to ingest contrail forecasts; willing airline and ANSP trial partners; MRV methodology.	Demonstrations yield a measurable, verifiable net climate benefit at acceptable operational cost. Proceed when voluntary avoidance is shown to work at the pre-tactical stage.

Table 9: Phase 2 voluntary demonstrations: responsibilities, dependencies and progression criteria.

Phase 3: Surcharge-and-discount/feebate incentives (2030 to mid-2030s)

Geographic scope: United Kingdom, with transatlantic partners and EU engaged.

Objective. Create economic incentives for airline participation in contrail mitigation so that planned and evidenced avoidance becomes the rational default.

What needs to happen

- → Introduce the airspace-charge feebate (building block 3) from 2030 rewarding avoidance actions that deliver verified climate benefit and covering the cost of additional fuel burn. The envisaged sequence is: Shanwick OCA from 2030; Scottish FIR from 2032; London FIR from 2034. Earlier introduction in the domestic FIRs is possible based on success of voluntary trials.
- → Gather evidence on behavioural responses and system effectiveness to refine the price signal.
- → Refine market design and governance, keeping reward at the portfolio level and avoiding per-flight credit framing, and ensuring fairness across operator types and routes.
- → Deepen Canada and Ireland engagements; begin alignment with the EU, whose non-CO_2 MRV and allowances regime provides a ready platform for engagement.
- → Register the scheme's success criteria before launch, publish verification statistics for each FIR and billing period, and commission an independent evaluation (Section 7.7).

Who is responsible (UK focus)	Dependencies	Decision point to progress
Co-ordinating owner (DfT or CAA); NATS (charge-setting and collection via NERL); CAA (price control and direction); EUROCONTROL (collection); DfT and DESNZ (policy); EU institutions (alignment).	Verified MRV from Phase 2; accommodation within the NATS charging framework (potential changes tied to the typically five-year price control cycle, next in 2028, or a within-period provision agreed in NR28); treaty-compatibility clearance; EU co-ordination.	The incentive demonstrably shifts routing behaviour without compromising safety, discriminating between operators or unduly distorting competition. Proceed when the price signal is shown to change planning by default.

Table 10: Phase 3 feebate implementation: responsibilities, dependencies and progression criteria.

Phase 4: International expansion (2030 onwards)

Geographic scope: United Kingdom, the EU and transatlantic partners.

Objective. Scale beyond the initial regions and trial corridors to the markets where impact is greatest; formal accession of the EU and transatlantic partners to compatible contrail incentive schemes.

What needs to happen

→ Align approaches across major aviation markets including the EU, Canada and the United States. Expand participation among airlines, ANSPs and states, potentially using the Commonwealth as a natural next ring of co-ordination.

→ Develop the international governance arrangements that a larger, global system will require.

Who is responsible (UK focus)	Dependencies	Decision point to progress
Co-ordinating owner (DfT or CAA); DfT and FCDO (diplomacy); CAA (technical); ICAO (framework); partner states and ANSPs.	A proven Atlantic-scale market; harmonised standards and data requirements; diplomatic channels through the Commonwealth and multilateral bodies.	Multiple major markets operate compatible schemes. Proceed to a unified system when co-ordination costs outweigh the benefits of separate regimes.

Table 11: Phase 4 international expansion: responsibilities, dependencies and progression criteria.

Phase 5: Global system (parallel track from Phase 3; mature by 2040)

Geographic scope: Global, potentially United Nations (UN) or ICAO supported.

Objective. Deliver a globally recognised and operationally embedded contrail avoidance framework. Although numbered last, this is a parallel workstream that begins as the UK feebate goes live in Phase 3 and matures alongside the domestic system, rather than a step that waits for every prior phase to complete (Figure 3).

What needs to happen

→ Begin international groundwork early: from Phase 3 onward, use ICAO and multilateral channels to socialise the UK approach, share evidence, and build consensus in parallel with domestic delivery.

→ Administer the eventual framework through ICAO or a comparable international mechanism, drawing on the Volcanic Ash Advisory Centre model as precedent.

→ Adopt common standards, data requirements and reporting approaches worldwide.

→ Achieve widespread operational adoption across international aviation, with contrail avoidance functioning as routine practice.

Who is responsible (UK focus)	Dependencies	Decision point to progress
ICAO (administration); World Area Forecast Centres, including the Met Office (data); states, ANSPs and airlines worldwide.	Runs in parallel with Phases 3 to 4; a credible global data and verification backbone; growing international consensus built up over the period.	Contrail avoidance is embedded as standard operating practice, sustained by standing incentives rather than by discretionary effort.

Table 12: Phase 5 global system: responsibilities, dependencies and progression criteria.

The visual below brings the phases, the three building blocks and the milestones together on one timeline:

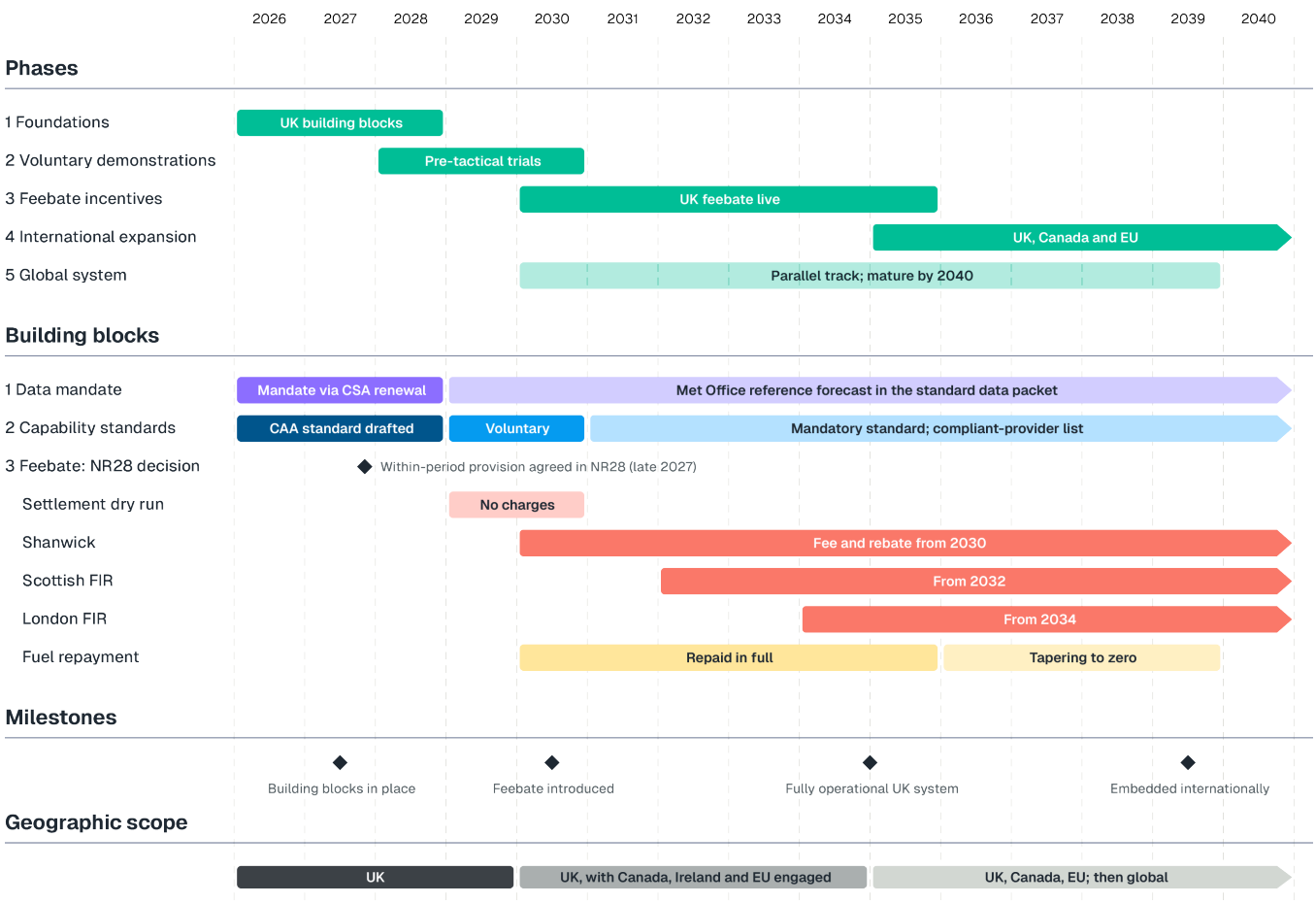


Figure 3: Contrail mitigation roadmap showing phases, policy building blocks, milestones and geographic expansion (2026-2040).

Priority demonstrations

Across the early phases, four operational domains are the priority candidates for demonstrations. Each should be assessed against the same cross-cutting criteria: climate impact, airspace implications, operational feasibility, and implementation cost.

Domain	Focus for trialling
Air traffic management	Incorporating contrail intelligence into North Atlantic track-setting (engaging NAV CANADA and AirNav Ireland) and into ANSP flight-planning and traffic-management processes.
Flight planning and decision support	Including contrail-avoidance information within commercial flight-planning platforms and testing decision-support tools for dispatchers and operations teams.
Meteorological capability	Assessing Met Office capability to generate operational contrail-relevant forecasts, and evaluating data standards, update frequency, and service-delivery requirements.

Domain	Focus for trialling
Airline operations	Integrating avoidance into operational, strategic, fuel-management and network decisions, and assessing organisational and training needs for routine adoption.

Table 13: Priority demonstration domains and trial objectives.

Milestones

Year	Target
2027–28	Core technical, operational and policy building blocks established; voluntary adoption underway through trials and demonstrations.
2030–31	Surcharge-and-discount/feebate scheme introduced in Shanwick OCA, targeting increasing % contrail avoidance adoption rate over time via economic incentives
2032–34	Feebate scheme extended to Scottish (2032) and London (2034) FIRs.
2034–36	Fully operational, widely adopted UK contrail avoidance system, with incentives in force in all three FIRs, and with international governance and scalable implementation pathways in place.
2039–40	System embedded internationally and functioning as routine practice across the UK, EU and beyond, on a pathway to global co-ordination.

Table 14: Roadmap milestones and target outcomes.

7 Scenario modelling: cost and climate impact

This section describes how the feebate described in building block 3 would work in UK-administered airspace from 2030 and what it would achieve. Section 7.1 explains how flights are sorted and settled, Section 7.2 the rules the scheme follows, Section 7.3 the charging arrangements and legal basis, and Section 7.4 how the fee, the rebate and the service charge are set. Section 7.5 gives results for four uptake cases, Section 7.6 the scheme's finances and Section 7.7 how the scheme is checked. Annex B sets out the assumptions, formulae and full results, and Annex C an outline concept of operations. The modelling covers the Shanwick Oceanic Control Area and the London and Scottish FIRs, each modelled separately, and will be extended to other regions, starting with the EU. Following the sequence in Section 6, the scheme starts in Shanwick in 2030 and is modelled as extending to the Scottish FIR in 2032 and the London FIR in 2034.

Warming avoided is shown in tonnes of CO_2-equivalent (GWP100) so that its size can be compared with aviation's CO_2 impact. CO_2-equivalence is used only to set the flagging threshold and to report results; the fee is set by the fuel cost of avoiding, not by a carbon price, and the choice of metric changes which flights are flagged only at the margin, consistent with the guardrail in Section 4.2. In the central case of 50 per cent initial adoption rising to 95 per cent adoption by 2040, the scheme avoids about 52 $MtCO_2e$ of contrail warming over 2030 to 2040, avoiding 2.1 $MtCO_2e$ in 2030 rising to 6.7 $MtCO_2e$ a year by 2040. It costs the taxpayer nothing. Avoiding flights have their extra fuel repaid, with the repayment funded by a service charge on all flights, so the aviation industry as a whole bears the running cost and the fuel: about £53 million and £47 million over the decade, or £100 million in total. That is £3.07 per flight across all UK flights, or £1.91 per tonne of warming avoided. Fees and rebates move money between operators and do not add to this cost. All money figures are quoted in 2026 prices.

7.1 How flights are sorted and settled

Scope. The scheme applies to every flight that uses UK-administered airspace, whether it overflies, departs or arrives, as route charges already do. Only the part of each flight inside the Shanwick Oceanic Control Area or the London or Scottish FIR counts: a flight is flagged only if its route there crosses a contrail-forming region, the 10 tCO_2e threshold applies to the warming modelled in that segment, and the fee and rebate depend only on what happens there. The fee and rebate apply in each area once the scheme is live there (Shanwick from 2030, the Scottish FIR from 2032 and the London FIR from 2034), while the service charge applies to all flights in all three areas from 2030. This sequence is an implementation phasing, not a targeting boundary: within each area every flight is covered and the forecast selects the flights flagged, in line with the guardrail in Section 4.2. Shanwick goes first because it carries the most strongly warming North Atlantic flow and NERL sets and collects its charges directly, and the risk of routing around the boundary is assessed in Section 7.4. Fuel is repaid for the whole avoidance manoeuvre, including any part of the level change or the return to the planned level that falls outside UK-administered airspace, up to the published benchmark. Repaying only the fuel burned inside

UK airspace would penalise flights whose avoidance starts or ends near a boundary. The scheme applies to all operators regardless of nationality, with the same exemptions as route charges. No rebate is paid if the avoidance only moves the contrail to just outside UK-administered airspace.

Operation. Each day the reference forecast, the mandated Met Office product (Building block 1), is used to identify the flights whose planned route crosses a region where warming contrails are likely to form. These flights are flagged. Operators may plan with any forecast that meets a published skill benchmark. The reference forecast is used only to decide which flights are flagged, so the flagged set is the same for every operator.

Over the North Atlantic, around 12 per cent of flights cause about 80 per cent of contrail warming [17]. A change of cruise level of about 2,000 ft is usually enough to leave a contrail-forming region, the size of change used in the EUROCONTROL Maastricht trials. Shanwick figures from Operation Blue Skies will replace both estimates.

The operator of a flagged flight decides whether to create and file a contrail-avoiding plan, subsequent to an initial cost-optimised plan already created and kept in reserve. Only one plan is filed with air traffic control. The normal plan, which the operator's planning system produces before any contrail information is applied, is kept with its audit record and supplied to the verifier. After the flight, the verifier re-runs the normal route and the flown route through reanalysis weather data (for example ERA5), using the aircraft's tracked position (ADS-B or GPS), and assigns the flight to one of the seven scenarios set out in Table 15. The verifier is NERL or a body it appoints, working to published rules, and operators can appeal a decision (Annex C).

Scenario	What happened?	What did reanalysis show?	Fee	Rebate	Fuel repaid
1. No contrail risk	No avoidance plan was filed and the original route was flown.	Reanalysis shows no contrail-forming region on the flown route.	No	No	No
2. Avoidable warming not avoided	No avoidance plan was filed and the original route was flown.	Reanalysis shows the flight passed through a forecast contrail-forming region that could reasonably have been avoided.	Yes	No	No
3. Avoidance prevented by ATC	Airline filed a valid avoidance plan, but ATC rejected it or subsequently issued instructions that prevented execution.	Irrelevant for charging purposes.	No	No	No

Scenario	What happened?	What did reanalysis show?	Fee	Rebate	Fuel repaid
4. False positive forecast	Airline filed and flew an avoidance route.	Reanalysis shows no contrail-forming region would have occurred on either the original or flown route.	No	No	Yes
5. Successful avoidance	Airline filed and flew an avoidance route.	Contrail-forming region existed on the original route but was avoided on the flown route.	No	Yes	Yes
6. Unsuccessful avoidance	Airline filed and flew an avoidance route.	Reanalysis shows contrail-forming conditions on both the original and flown routes.	No	No	Yes
7. Airline did not execute avoidance plan	Airline deviated from the cleared avoidance plan for reasons unrelated to ATC instructions or safety requirements.	Reanalysis shows avoidable, forecast warming on the flown route.	Yes	No	No

Table 15: Scenarios for the contrail avoidance feebate. A fee arises only when a flight could have avoided warming and did not (scenarios 2 and 7). Flights not flagged by the forecast are out of scope.

An operator that files an avoidance plan is not charged unless it leaves the cleared plan of its own accord (scenario 7). Forecast errors (scenario 4) and failed attempts (scenario 6) are not penalised. In the central case, 30 per cent of targeted flights pay a fee and 20 per cent earn a rebate in 2030; by 2040 the figures are 3 per cent and 35 per cent.

Settlement. Fees, rebates and fuel repayments are worked out flight by flight and settled per operator, as one net line on the operator's route-charge bill. EUROCONTROL invoices domestic route charges monthly, so each month's verified results would be applied to a later month's invoice once verification is complete. Fees and fuel repayments are settled in full each month. Because the rebate is an equal share of the whole year's fee income, it is paid in two parts: each month, every verified avoiding flight receives an interim payment of 80 per cent of the rebate forecast for the year, and after the year ends a final payment brings every avoiding flight to the actual equal share. Holding back a fifth of the forecast means the final payment should rarely need to recover money. In Shanwick, NERL bills directly. Whether EUROCONTROL's systems can apply the adjustment, and at what cost, is to be confirmed with EUROCONTROL in Phase 1.

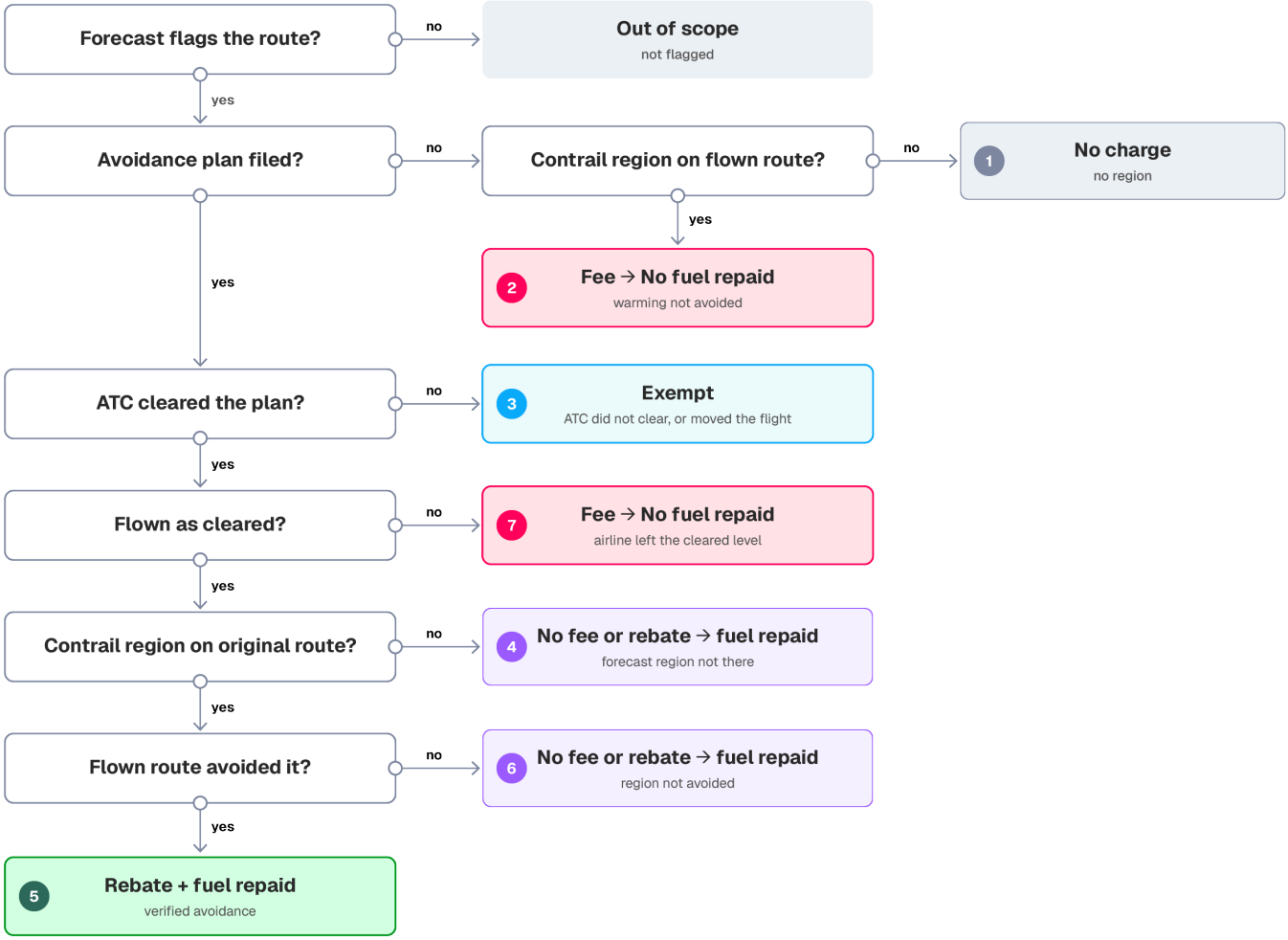


Figure 4: Decision sequence determining the charge outcome for each flight. Scenario numbers correspond to Table 15. A fee arises only when a flight could have avoided warming and did not (scenarios 2 and 7). Flights not flagged by the forecast are out of scope.

Fuel repayment. The extra fuel is the difference in planned trip fuel between the normal plan and the avoidance plan, priced at a published reference fuel price and capped at a published benchmark for the aircraft type and size of level change. It is paid on planned fuel so that no operator gains by burning more. The verifier may call for recorded fuel data (quick access recorder (QAR) or flight data monitoring) on a sample of flights to check for inflated plans.

Protecting the normal plan. The scheme compares the flown route with the normal plan, so the normal plan must be genuine. Following the Gold Standard methodology for contrail prevention (GS4GG PAA M400-11, 2026) [20], the normal plan must be generated by the operator's planning system in the ordinary way, optimised for fuel, time, payload, weather and charges, before any contrail information is applied, and the sequence must be recorded in the system's audit trail. Deliberately choosing a contrail-prone normal plan, or overriding the system while generating it, is a breach: the rebate is withheld, and repeated breaches lead to exclusion from rebates for a period. The verifier also compares each operator's routes with its own past routes and with the forecast contrail regions, to detect routes chosen to earn rebates or escape fees, and analyses lateral deviations at the boundaries of UK-charged airspace. None of this requires the contrail forecast to be withheld from anyone.

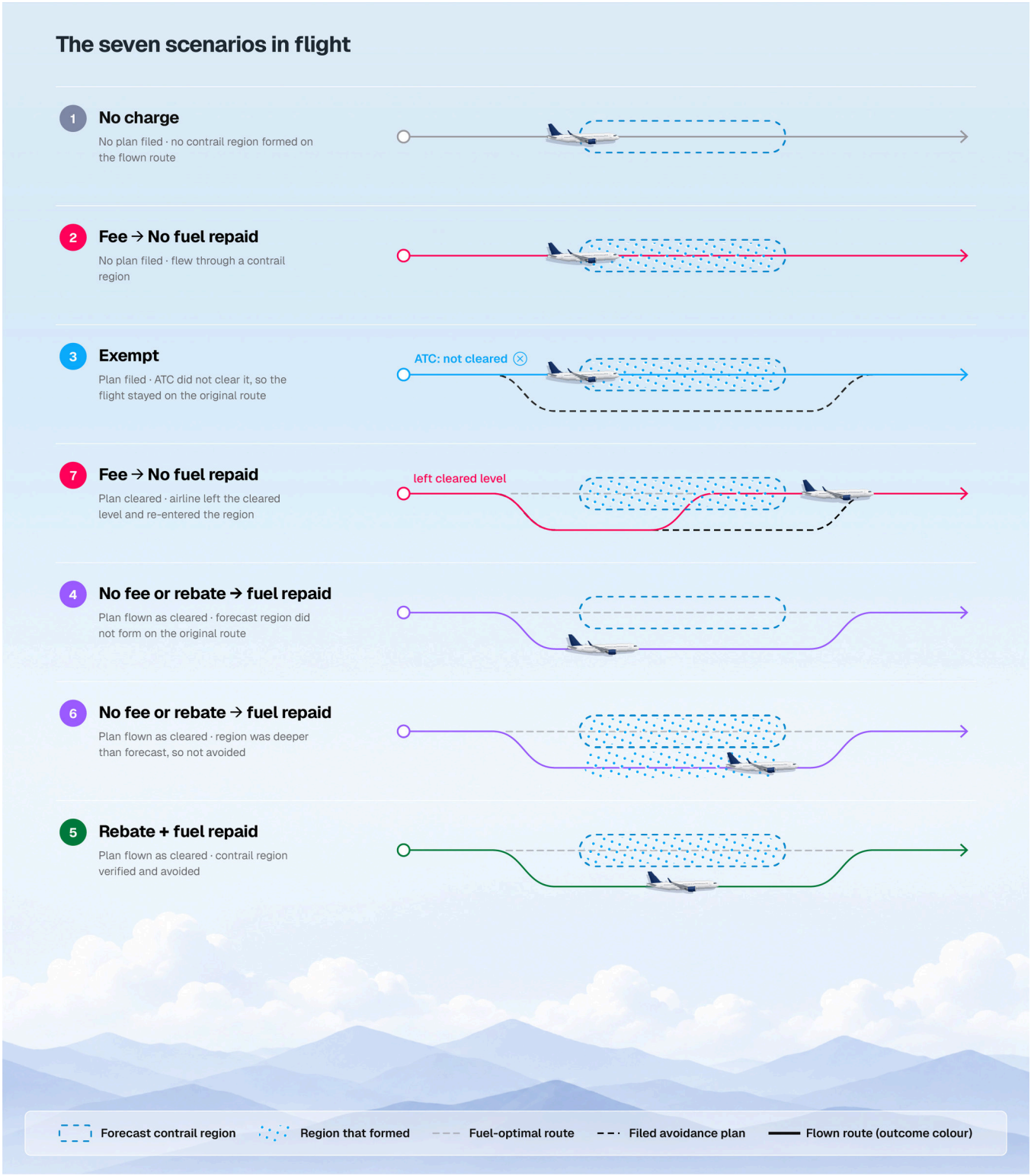


Figure 5: The seven scenarios as flight paths, showing what was planned, what was flown and what each flight pays or receives.

7.2 Operating principles

The scheme follows five rules.

1. **It pays for itself.** Fee income funds the rebates, with a small share kept towards running costs in the first five years. A service charge on every flight in UK-administered airspace funds the rest of the running cost and the fuel repayment. The net cost to the taxpayer is zero in every year.
2. **Operators are treated alike.** Every flagged flight is judged against the same reference forecast and the same verification and pays the same published fee and service charge, and every verified avoiding flight in a year receives the same rebate.
3. **No perverse incentives.** An operator that files an avoidance plan is never charged unless it abandons the cleared plan; fuel is repaid on planned fuel; the normal plan is protected (Section 7.1); the rebate is capped so that it cannot become a windfall when few operators avoid; and the fee is set low enough that only flights very close to the boundary could gain by routing around UK airspace (Section 7.4).
4. **Rebates are transitional; the fee is permanent.** The rebate is paid from fees, so it shrinks as fewer flights pay them. The fee stays, so that avoiding remains the cheaper choice.
5. **Fuel repayment ends.** Extra fuel is repaid in full until 2035, then on a falling scale to zero in 2040, so that the cost of avoidance becomes part of normal operations.

7.3 Charging responsibility and legal basis

Three bodies are involved. NATS En Route plc (NERL) is the licensed provider. Its en-route charges are set under a periodic price control administered by the CAA under the Transport Act 2000 and must comply with the NERL Licence and with international non-discrimination obligations. The Department for Transport holds the policy lead and, as a 49 per cent shareholder, a direct line of influence. In the Shanwick Oceanic Control Area NERL sets and collects the charges itself. In the London and Scottish FIRs NERL sets the unit rate under CAA price control, and EUROCONTROL's Central Route Charges Office bills and collects it under the Multilateral Agreement on route charges, to which the UK remains a party. The feebate is a variation of these charges. NERL sets the fee, the service charge and the fuel benchmarks under direction from the CAA; EUROCONTROL applies the variation to domestic bills from a verification file supplied by NERL; and NERL applies it directly to Shanwick bills.

Performance indicator. NERL's licence performance measures do not at present reward climate-motivated routing. The 3Di flight-efficiency metric measures fuel and CO_2 efficiency, so avoidance can count against NERL. The Department for Transport should ask the CAA to add a contrail-avoidance indicator in the form of a reporting requirement: NERL clears each flight on its contrail-avoiding plan or records why it could not, by category (safety, capacity, staffing or other). This rewards NERL for enabling avoidance and shows how often air traffic control is the constraint.

Timetable. NERL's charges are set for five-year periods, and the next period (NR28) starts in January 2028. Charges can be adjusted within a period through established mechanisms, but a substantive change to the charging framework would normally wait for the next periodic review. The NR28 settlement

should therefore include a provision allowing the CAA and NERL to consult users on, and if justified introduce, a contrail-avoidance variation within the period. That needs a decision in principle by late 2027. Once the scheme is running, the fee multiple, the service charge, the reference fuel price and the fuel benchmarks would be confirmed each autumn for the following year, on the same cycle as unit rates. An annual cycle also fits the current framework's maximum permitted average charge per flight; how the scheme sits with that limit is to be confirmed with the CAA.

Charge or tax. ICAO Doc 9082 (10th edition, paragraph 1.3) [19] sets four charging principles: non-discrimination, cost-relatedness, transparency and consultation with users. Article 15 of the Chicago Convention also bars charges levied solely for the right of transit. The scheme is designed to meet these tests. It is a revenue-neutral variation of an existing charge: fee income returns to operators as rebates or meets the scheme's own running costs, and the service charge recovers only the scheme's costs. The same published rules apply to every operator, and the fee is modest in relation to existing charges. Noise- and NOx-related airport charges already work this way, and Regulation (EU) 2019/317 [14] allows environmental modulation of en-route charges on the same basis. Whether that provision has been carried into UK law and the NERL Licence is to be confirmed with the CAA; if it has, it would be the cleaner legal route. For the London and Scottish FIRs, the EUROCONTROL principles for en-route charges also allow charges to be modulated to reduce the environmental impact of flying (paragraph 3.4.2(b)) [21]. They require such incentive schemes to be limited in time, scope and amount, and the estimated savings from operational efficiency improvements to at least offset the cost of the incentives. Contrail avoidance adds fuel burn, and the fee is meant to be permanent, so the scheme would need an exception or a change to that wording, agreed with the other EUROCONTROL Member States. Shanwick oceanic charges are set by NERL outside the EUROCONTROL route-charges system, so the first stage may not depend on this point. A formal legal opinion, commissioned by the Department for Transport, on compatibility with the Chicago Convention, ICAO charging policy, the EUROCONTROL principles, UK law and the NERL Licence is a Phase 1 deliverable.

Delivery through the UK ETS would avoid a new charging line, but it would not reach Shanwick traffic outside the UK ETS, would not recycle revenue within the industry, and could not start before non-CO_2 effects are brought into the ETS. It is retained as an option for Phase 4, in particular if the UK and EU systems are linked. Any ETS route would need to keep contrail obligations separate from CO_2 allowance surrender, in line with the guardrail in Section 4.2.

7.4 The fee, the rebate and the service charge

The scheme borrows its central principle from Sweden's charge on nitrogen oxides (Section 2.5.1): money paid by those that pollute more is returned to those that pollute less, so it stays within the industry. The mechanics differ. In Sweden every plant pays based on its emissions and every plant is refunded in proportion to its output. Here, only flagged flights take part, and there are two separate flows of money. First, a flight that could have avoided a confirmed contrail region and did not pays a fee, and that fee income is paid back in the same year, in equal shares, to the flights that verifiably avoided. As in Sweden, a small part of the income meets administration costs first, and the rebate can never exceed what was

collected. Second, every flight in UK-administered airspace pays a small service charge, which funds the rest of the running cost and repays the extra fuel burned by avoiding flights.

The fee. A flight in scenario 2 or 7 pays a flat fee of five times the published fuel cost of avoiding for that flight, using the fuel benchmark for its aircraft type and size of level change at the reference fuel price. At the modelled average of 100 kg of fuel at £0.65/kg using 2026 prices, avoiding costs £65 and the fee is £325. That is about three times the Shanwick crossing charge, which in 2026 is £60.07 for the core charge plus £39.70 for ADS-B data [22]. Flights whose modelled warming is below 10 tCO_2e are not charged, because for such small contrails the modelling error is close to the size of the effect. Operators cannot plan around this threshold, since a flight's modelled warming depends on the weather on the day.

Why five times. The fee has to make avoiding the clearly cheaper option. The closest aviation precedent, ReFuelEU Aviation [23], sets the penalty on fuel suppliers that miss the SAF mandate at no less than twice the price gap between sustainable and conventional fuel (Article 12). The fuel cost of avoiding understates what avoiding costs an operator, because the main barriers are dispatcher workload, habit and a preference for the organised track system, and none of these appears in the fuel figure. In the 2023 American Airlines trial, dispatchers released the contrail-avoiding plan for about 15 per cent of flights, and fewer than one in ten was flown as planned, even with both plans on screen (Annex B.3). A multiple of five allows for those costs while keeping the fee well below the point at which routing around UK airspace pays. The multiple is reviewed every three years against Phase 2 and Phase 3 evidence on how operators respond (Annex B.6 tests a fee of four times the fuel cost of avoiding, £260 in 2030, and of ten times, £650).

The fee share kept for running costs. From 2030 to 2034, 10 per cent of fee income is kept to meet running costs. In the central case that is about £0.4 million in 2030, around 8 per cent of that year's running cost, and about £2.0 million over the five years. From 2035, when fee income is forecast to have fallen to about £5 million a year, the share ends and all fee income is paid out as rebates. The share is kept small because the rebate matters most for uptake in the early years (Annex B.6 tests 0 per cent and 20 per cent).

The rebate. The fee income paid out in a year is divided equally among that year's verified avoiding flights (scenario 5). It is paid as a monthly interim payment with a final adjustment after the year ends (Section 7.1), so the figures below are the final amounts for each year. In the central case the rebate is about £440 per verified avoiding flight in 2030, falling to about £160 in 2033 and about £39 in 2040 as fewer flights pay fees. It rises for a year, to about £223, when the London FIR joins in 2034 and its first flights pay the fee. When uptake is slow, more flights pay and the rebate reaches the £500 cap in 2030 (otherwise reaching ~£1,300 without it); when uptake is fast, it is about £148. In 2030 in the central case, a flagged flight that files an avoidance plan can expect about £200 in rebate, and one that does not can expect about £210 in fees. The rebate falls away as avoidance becomes routine, and the fee remains.

The rebate cap. The rebate is capped at £500 per flight in 2030, about eight times the fuel cost of avoiding, rising with the fuel price. Without a cap, the rebate would become a windfall when few flights avoid: about £1,313 per flight in 2030 in the slow case, and about £3,926 if uptake stays at 10 per cent.

That would also give operators that avoid contrails an interest in their competitors failing to avoid contrails. Fee income above the cap lowers the service charge for every flight, and if it is more than the service charge needs, the rest is returned as a small credit on every flight.

Why avoiding always pays. For each flagged flight an operator compares two choices. If it does not avoid, it risks the fee, which applies about two times in three, when the contrail region is confirmed. If it avoids, its extra fuel is repaid until 2035, and it may earn the rebate, which is paid about one time in two, when the region was real and the avoidance worked. Table 16 shows the economic benefits of adoption. The saving is largest when few operators avoid, because the fees of the many are shared among the few. It shrinks as more avoid, but it never falls below the value of the fee avoided, shown in the last row, so doing nothing is never the cheaper choice. The cases are assumptions about how operators respond, and the saving has to outweigh costs the model leaves out, mainly dispatcher workload, which is what Phase 2 is to test.

Uptake case	2030	2035	2040
Uptake held at 10%	445	492	464
Slow (25%)	445	471	227
Central (50%)	418	318	200
Fast (75%)	283	270	197
Fee avoided, with no rebate paid	**214**	**237**	**182**

Table 16: How much better off an operator is by avoiding, per flagged flight (£, 2026 prices). The saving is the expected fee avoided plus the expected rebate, less any extra fuel not repaid; from 2036 fuel repayment tapers and by 2040 avoiding costs about £79 of fuel. Assumes forecast precision of 66 per cent and execution success of 70 per cent (Annex B.1).

Re-routing around UK airspace. An operator could escape the fee by routing a flagged flight around UK-charged airspace. That pays only if the extra distance costs less than the expected fee plus the Shanwick charge saved. At £15 to £25 per extra nautical mile for a wide-body aircraft, a £325 fee makes such a detour pay only if it is shorter than about 13 to 21 nm. Most North Atlantic tracks cross the middle of Shanwick, where leaving it would add hundreds of miles, so the exposure is limited to flights already close to the boundary. Planning routes around Shanwick in advance pays even less, because operators do not know beforehand which flights will be flagged: the expected fee per planned Shanwick flight is about £23. A northern detour would also attract Icelandic and Danish North Atlantic charges, which this estimate leaves out. Further analysis of how many flights route near the boundary is needed to confirm the figure (Annex B.6). The fee is set from fuel benchmarks for each aircraft type, so the break-even detour will be longer for wide-bodies.

The service charge. The running cost not met from fees, and the fuel repayment, are recovered through a contrail service charge on every flight in UK-administered airspace. This charge is set in the same way as unit rates. Each autumn NERL, under CAA direction, estimates the next year's running cost and fuel repayment, subtracts the fee share it expects to keep, and divides the result by the forecast number of flights. The result is a flat amount per flight, added to each flight's route-charge bill. Any difference

between the estimate and the outturn is corrected in the charge two years later, so over time it recovers the actual cost and no more. In the central case it is about £2.28 per flight in 2030, peaks at about £3.41 in 2035 as fuel repayments grow, and falls to £0.95 in 2040, when only the running cost remains. It recovers the cost of a service that every operator uses: the forecast, the verification and the fuel repayment. It applies across UK-administered airspace from 2030, including the FIRs that have not yet joined, because the forecast and verification systems are built for the whole of UK airspace. If it applied only where the scheme runs, Shanwick flights would pay about £16 each in 2030 and £17 in 2031 (Annex B.6).

Fuel repayment. Extra fuel is repaid in full until 2035, then at 80, 60, 40 and 20 per cent in 2036 to 2039, and not at all from 2040.

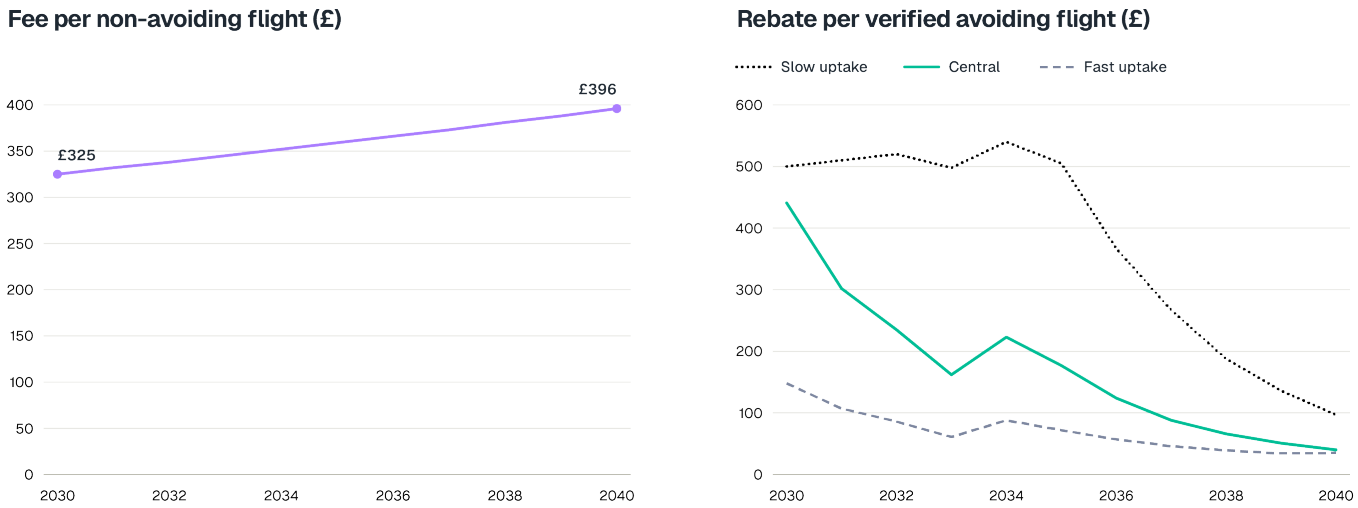


Figure 6: Fee per non-avoiding flight (left), rising with fuel price, and rebate per verified avoiding flight in the slow, central and fast cases (right).

7.5 Headline results

Four uptake cases are modelled, differing in how quickly operators start filing avoidance plans when flagged: from 25, 50 or 75 per cent of flagged flights in the first year of the scheme in each FIR, each rising to a ceiling of 95 per cent. A fourth case, low uptake, holds the rate at 10 per cent throughout, close to the voluntary rate seen in trials. Climate-warming impact is calculated via conversion to a CO_2 equivalent using GWP100 [18] so that its size can be compared with aviation's CO_2. This is modelled warming rather than estimated avoided emissions. It is not added to or offset against CO_2 emissions, and the scheme does not generate carbon credits.

Measure	Slow (25%)	Central (50%)	Fast (75%)	Uptake held at 10%
Warming avoided, 2040 ($MtCO_2e$ a year)	6.53	6.75	6.77	0.73
Warming avoided, 2030–40 ($MtCO_2e$)	41.6	52.5	57.7	6.5
of which Shanwick	35.9	44.4	48.4	5.4
of which London FIR	4.2	6.0	7.0	0.8

Measure	Slow (25%)	Central (50%)	Fast (75%)	Uptake held at 10%
of which Scottish FIR	1.6	2.1	2.3	0.3
Targeted flights paying the fee, 2030 / 2040 (%)	45 / 8	30 / 3	15 / 3	53 / 53
Flights paying the fee, 2030–40 (thousands)	218	111	57	509
Fees collected (£m)	77.6	39.1	20.2	186.6
paid out as rebates (£m)	65.4	37.0	19.2	21.1
kept for running costs, 2030–34 (£m)	3.6	2.1	1.0	5.4
Rebate per verified avoiding flight, 2030 (£)	500	440	148	500
Running cost (£m)	53.3	53.3	53.3	53.3
Fuel repaid (£m)	19.2	27.2	31.7	3.7
Service charge, 2030 (£ per flight; negative is a credit)	0.57	2.28	2.60	−0.59
Non-avoiding flights: fees paid (£m)	−77.6	−39.1	−20.2	−186.6
Non-avoiding flights: net position, including their service charge (£m)	−78.1	−39.4	−20.3	−184.6
Avoiding flights: rebates and fuel repaid, less fuel burned (£m)	+54.8	+24.6	+6.3	+19.7
Avoiding flights: net position, including their service charge (£m)	+53.8	+23.0	+4.3	+20.0
Net cost to the taxpayer (£m)	0	0	0	0
Net cost to industry (£m)	89.6	100.0	105.0	59.2
Net cost to industry per UK flight (£)	2.76	3.07	3.23	1.82
Resource cost (£ per tonne avoided)	2.15	1.91	1.82	9.06
Value of warming avoided at the shadow price (£m)	882	1,064	1,140	127
Net benefit: value less net cost to industry (£m)	793	964	1,035	68

Table 17: Headline results, 2030–40. Net cost to industry per flight is spread over all UK airspace flights. Resource cost is the running cost plus all avoidance fuel, per tonne avoided; fees, rebates and the service charge are transfers within the industry. Targeted flights paying the fee are those in scenario 2. Avoiding flights are all flights that file an avoidance plan. Non-avoiding flights are those in scenario 2. The service charge is also paid by the large majority of flights that are never flagged. Warming avoided is valued at the model's shadow price, £11/tCO_2e in 2030 rising to £29/tCO_2e in 2040, which is deliberately low.

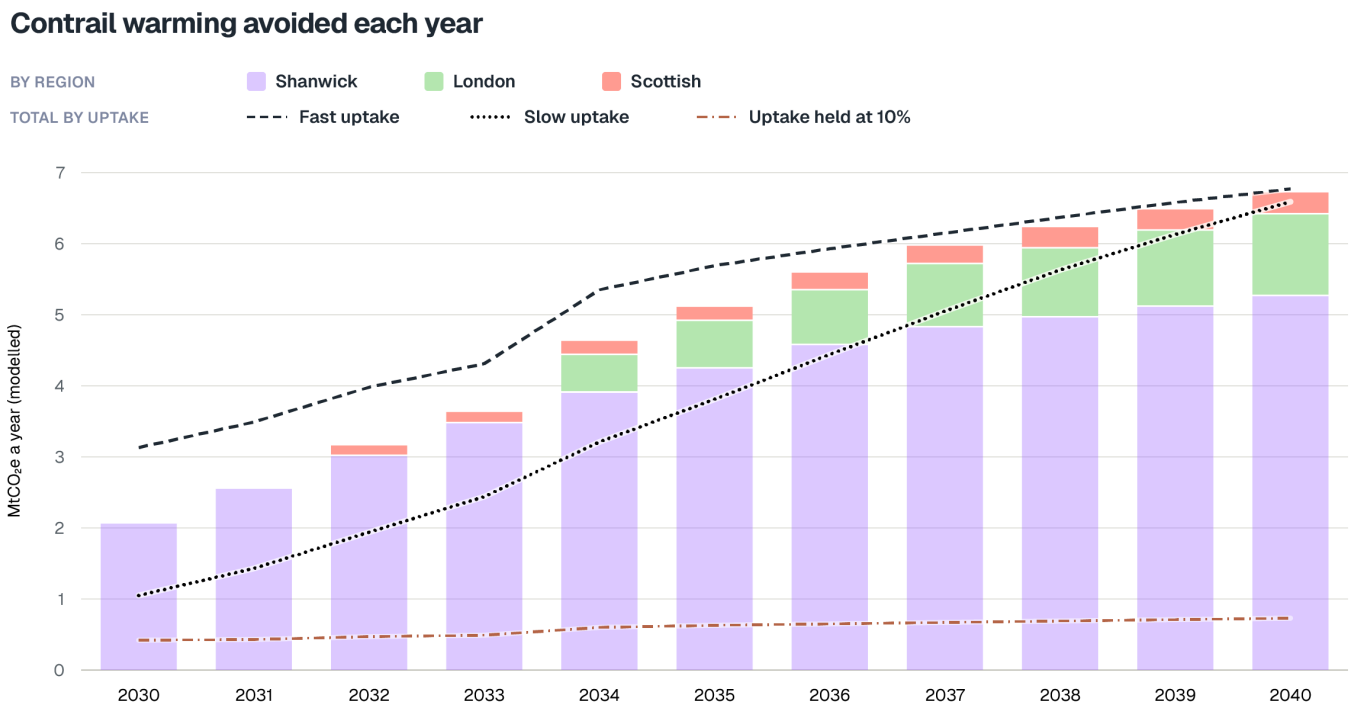


Figure 7: Contrail warming avoided each year: central case by region (bars) and totals for the other cases (lines).

What the cases show. The largest difference is between a scheme that changes behaviour and one that does not: the three active cases avoid 42 to 58 $MtCO_2e$, against 7 $MtCO_2e$ with low uptake. Slow and fast uptake differ by 16 $MtCO_2e$, because all three active cases reach the 95 per cent ceiling by the late 2030s and differ only in the early years. Engagement with operators before launch therefore matters. Shanwick provides about 85 per cent of the benefit. Starting the Scottish and London FIRs in 2032 and 2034, against all three in 2030, reduces the warming avoided over the decade by about 4 $MtCO_2e$ but makes almost no difference by 2040 (Annex B.6).

Cost. The net cost to industry is the running cost plus the extra fuel burned, since fees, rebates and the service charge move money between operators. It rises slightly with uptake, from £90 million in the slow case to £105 million in the fast case, because more avoidance burns more fuel, and it is lowest, at £59 million, if uptake stays at 10 per cent, because little avoidance happens. That total hides who pays. At 10 per cent uptake, flights that do not avoid pay £187 million in fees over the decade; £21 million goes to the few that do, and, because of the rebate cap, £160 million comes back to all flights through the service charge. In the central case they pay £39 million. For an individual operator, not avoiding is always the more expensive choice. Set against what it achieves, the 10 per cent case is also the worst value: £9.06 per tonne avoided against £1.91 in the central case, and a net benefit at the shadow price of £68 million against £964 million. The resource cost averages £1.91 per tonne of warming avoided in the central case, well below the US$5 to US$25 per tonne usually cited for contrail avoidance (Section 2.4) and far below the cost of sustainable aviation fuel. Staff training and engine-cycle costs are not yet included. They will be added on the pattern of the Contrails.org cost model, in which fuel makes up over 90 per cent of the cost.

Air traffic control. Avoidance is modelled as planned before departure. When many flights want the same alternative levels, not all can have them. In the domestic FIRs the plans would be accepted, but the

EUROCONTROL Network Manager would add restrictions to match capacity, causing delay; in Shanwick, fewer flights would receive their filed trajectory at the oceanic boundary. Avoidance plans are checked against the route availability document (RAD) and co-ordinated through the Network Manager like any other flight plan, so many operators planning around the same regions would have a network effect that is not yet well understood. The model represents both with an acceptance rate that falls as uptake rises: from 96 to 94 per cent in Shanwick, 93 to 86 per cent in the London FIR and 95 to 91 per cent in the Scottish FIR. These rates are judgements, to be replaced with NATS data, and neither the cost of delay nor the wider network effect is yet included (Annex B.6).

7.6 Scheme finances

All fee income is used in the year it is collected: as rebates, and to 2034 partly towards running costs. The service charge covers the remaining running cost and the fuel repayment (Figure 8). The scheme needs no reserve: fee income is paid out in the year it is collected, and any gap between the service charge and the costs it covers is corrected two years later.

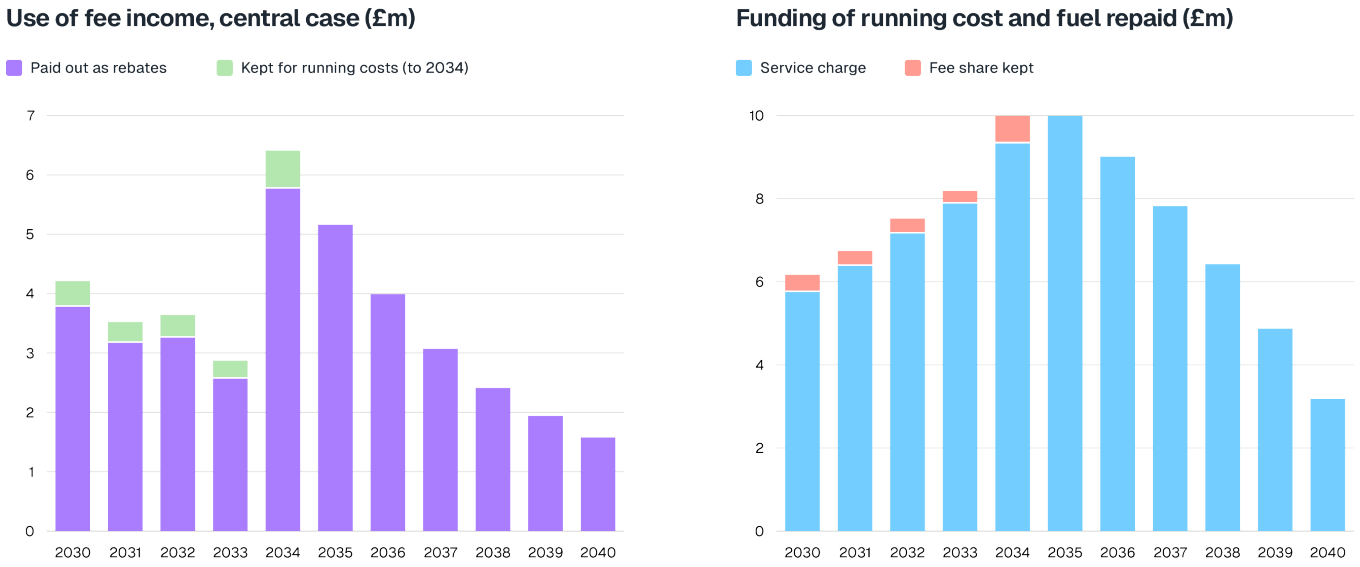


Figure 8: Use of fee income (left) and funding of the running cost and fuel repaid (right), central case.

Uptake held at 10 per cent. If uptake stays at the voluntary level, the scheme collects about £187 million in fees over the decade. It pays £21 million to the few flights that avoid, as capped rebates of £500 rising to about £609, and returns the remaining £160 million to all flights through the service charge, which becomes a small credit. Operators that hold back still pay the fee every time a region is confirmed. The net cost to industry is the running cost and a little fuel, but the climate benefit is small.

Running cost. The model assumes £5 million a year, rising 5 per cent a year to 2034 and falling 10 per cent a year after that as verification is automated. The workshop's first estimate was £50 million a year. NATS considers that too high, and £5 million possibly so, depending on the investment needed by the Met Office and planning-software providers. At £2 million a year the service charge would be about £1.10 per flight in 2030; at £20 million it would be about £8.19 (Annex B.6). A cost estimate split between scheme administration, forecast provision and planning-software changes is a Phase 1 deliverable.

After 2040. The rebate is small and fuel repayment has ended. The fee remains as a standing charge on avoidable warming, with its income still paid out as rebates, and the service charge covers the running cost only. Contrail avoidance at this stage becomes a standard, low-cost part of business-as-usual commercial aviation.

7.7 Validating the scheme

The design in Sections 7.1 to 7.6 rests on claims that can be tested: that the reference forecast flags the right flights, that refiled plans clear the regions they were meant to clear, that the fee changes filing behaviour at the rate assumed, and that the warming avoided is what the model says it is. Validation is therefore built into the scheme, in four parts.

Success criteria fixed before launch. The Phase 2 demonstrations define, and the Phase 3 decision adopts, the criteria the scheme must meet: a minimum verified avoidance rate for refiled flights, a maximum false-alarm rate for the reference forecast, a minimum net climate benefit per avoiding flight and an expected uptake rate. The criteria are registered before launch so that they cannot be adjusted to fit the result.

Published verification statistics. For each FIR and each charging period, the numbers of flights flagged, refiled, confirmed and cleared, and the shares falling into each scenario of Table 15, are published. These figures feed the three-yearly review of the warming calculation method and allow any party to check that fees and rebates match verified outcomes.

Independent evaluation. An evaluation independent of NERL and of the scheme's administrator reports on warming avoided, on uptake against the modelled cases in Section 7.5 and on leakage (Section 7.4), timed so that its findings feed the three-yearly review of the fee multiple and the service charge. The model takes uptake as an input, so the evaluation's first task is to establish whether the fee produces the response assumed.

An open benchmark for skill. Forecast skill and detection skill are judged against the open verification standard adopted in Phase 1 (such as ContrailBench), so that the warming calculation method and the capability standard (Building block 2) move with measured performance and not with the claims of any one provider. The portfolio-level approach is consistent with the model-based verification practice of the EU's non-CO_2 MRV regime (Section 2.5), which a linked scheme would in any case need to match.

8 What government should do now

Contrail avoidance is ready to move from trials to routine operation, and the UK is well placed to go first. We recommend that government takes seven steps in 2027 and 2028.

#	Action	What it involves	By when
1	Name one owner.	Give the Department for Transport or the Civil Aviation Authority a clear mandate to lead on contrail avoidance and to co-ordinate the Met Office, NATS and airlines.	2027
2	Put contrail forecasts in standard aviation weather data.	Ask the Met Office, through its sponsoring department and the Public Weather Service agreement, to supply forecasts of contrail-forming regions to all airlines, dispatchers and air traffic controllers.	Next refresh of the 2025–30 agreement
3	Keep the charging option open in NR28.	Ask the CAA to include a provision in the next NATS price control allowing a contrail charge variation to be introduced within the control period, after consultation with airspace users.	Late 2027
4	Commission the legal opinion.	Confirm how a fee and rebate attached to route charges sits with Article 15 of the Chicago Convention, ICAO's charging policies and the EUROCONTROL charging principles.	2027
5	Start the planning-software standard.	Ask the CAA to work with flight-planning providers on a voluntary standard for contrail-aware planning, with a published list of compliant providers.	2027–28
6	Fund the evidence.	Support upper-air humidity observations and the independent evaluation of Operation Blue Skies, and agree in principle to a follow-on demonstration in Shanwick and	2027–28

#	Action	What it involves	By when
		then domestic airspace if the trial shows a clear benefit.	
7	Open talks with partners.	Brief Ireland, Canada and the European Commission on the approach, and raise it at the ICAO North Atlantic Systems Planning Group.	2027

Table 18: Seven steps for government in 2027 and 2028.

None of these steps commits government to a feebate. Together they cost little, use existing institutions, and keep a 2030 start possible while Operation Blue Skies reports.

Annex A. Roadblocks and mitigations

The following risks could halt the policy entirely if not designed against. Each is paired with the mitigation built into this roadmap. Drawn from the AIA policy analysis.

Roadblock	Mechanism	How the design avoids it
Net-harm / overcorrection attack	Critics argue extra CO_2 from diversions could exceed the contrail benefit.	Build a net-benefit safeguard into the design; target the flights with the most warming so the benefit always dominates.
Individual-flight attribution impossible at scale	Opponents demand per-flight proof that current observation modalities cannot deliver at scale.	Use aggregate, fleet-level metrics from the outset, supplemented by individual flight modelling; do not promise single-flight observational attribution.
Legal basis for route charging (ICAO / Chicago Convention)	A UK-only rule could be challenged as inconsistent with ICAO or as distorting competition.	A revenue-neutral variation of an existing navigation charge, at modest levels, that meets the four ICAO Doc 9082 principles (paragraph 1.3) [19]: non-discrimination, cost-relatedness, transparency and consultation with users. The EUROCONTROL principles may need an exception for the domestic FIRs. A legal opinion commissioned by the Department for Transport is a Phase 1 deliverable (Section 7.3).
Safety-primacy veto	The regulator can veto anything seen to compromise safety.	Performance-based design, explicit infeasibility allowances, and no unsafe tactical mandates.
Wait-for-the-science deferral trap	Calls to wait for mature science or governance can postpone action indefinitely.	Adaptive regulation that acts on today's capability and tightens over time in line with the policy guardrails (see *Technical guardrails for contrails policy development*).
Distributed-responsibility deadlock	With responsibility split across many bodies, no one owns delivery.	Designate a single co-ordinating owner (DfT or CAA) with a clear mandate.

Roadblock	Mechanism	How the design avoids it
Met Office governance constraint	It is unclear whether the government can direct the Met Office's commercial aero-met operations.	Map the Met Office governance and commercial route first, via the CSA renewal, before relying on it.

Table 19: Principal roadblocks to contrail mitigation policy and proposed mitigations.

A.1 Bottlenecks

These risks slow or weaken the policy without stopping it. They are the priority investment targets for Phase 1.

Bottleneck	How the design responds
Upper-tropospheric humidity observation gap (the single largest tractable bottleneck)	Fund sensors, observation campaigns and benchmarking to close the gap.
Flight-planning providers push back against contrail capability	Make contrail routing a near-zero-effort default via standards, procurement, and demand coalitions.
Constrained re-routing envelope in congested airspace	Set network-level performance targets and account for CO_2 trade-offs.
Tactical avoidance raises controller workload	Favour pre-tactical avoidance and longer minimum segment lengths.
NAV CANADA / North Atlantic track interdependency	Open a dedicated NAV CANADA engagement workstream early (Phase 2).
Doing nothing is cheaper for airlines	Price the externality so avoidance pays; reinforce with behavioural nudges. Because the fee is added to the route charge, flight-planning systems that already choose routes by weighing fuel, time and charges (with the cost index setting the balance between fuel and time) will weigh the expected fee in the same way, so the cheapest plan becomes the contrail-avoiding one without a separate decision by the dispatcher. Building block 2 requires compliant software to do this.
NERL performance measures disincentivise facilitation of avoidance	NERL's licence already includes a financial incentive for environmental performance, the three-dimensional insight (3Di) flight-efficiency metric. But 3Di measures only fuel and CO_2 efficiency. Because contrail avoidance typically adds a small fuel penalty, it can count against NERL under the current scheme. Consequently, regulatory engagement will be required

Bottleneck	How the design responds
	to augment existing environmental incentives with contrail-specific instruments. One such instrument is a reporting requirement: NERL clears each contrail-avoiding plan or records why it could not (Section 7.3)

Table 20: Key implementation bottlenecks and Phase 1 responses.

Annex B. Roadmap modelling

B.1 Assumptions and sources

Parameter	Value	Source and notes
Global contrail warming, 2030	265.5 $MtCO_2e$ a year	0.30 × 885 $MtCO_2$ global aviation CO_2 (Teoh et al. 2024 contrail GWP100 factor). Grows 3% a year in line with IATA projections.
Share of global contrail warming by FIR	Shanwick 5%; London 1.2%; Scottish 0.3%	Shanwick: working figure from Operation Blue Skies (Contrails.org, 2026) [24], citing Teoh et al. (2024), which gives 11% for the North Atlantic as a whole; Transport & Environment (T&E) (2026) [25] gives 3.3%, tested in B.6. London and Scottish: T&E (2026) [25]
UK warming pool, 2030	17.26 $MtCO_2e$ a year	Sum of the three FIR shares.
Share of flights targeted	Shanwick 12%; London and Scottish 2%	Flights causing 80% of contrail warming. Shanwick: Teoh et al. (2022), North Atlantic. Domestic: Teoh et al. (2024), global figure; no UK-domestic estimate exists. Tested in B.6.
Share of warming from targeted flights	80%	Teoh et al. (2022, 2024).
Average warming per targeted flight	242 / 70 / 90 tCO_2e	Shanwick / London / Scottish: FIR warming pool × 80% ÷ targeted flights. To be checked against Operation Blue Skies results.
Forecast availability	90%	Share of days the pre-departure forecast service is available.
Forecast precision	66%	Share of forecast contrail regions confirmed by reanalysis. Thompson et al. 2024 [26]: 0.66 (S-WRF), 0.62 (IFS), near zero (GFS). Applied to warming avoided, because refiling for a false alarm avoids nothing.

Parameter	Value	Source and notes
Execution success	70%	Share of refiled flights that avoid a real region. Placeholder from avoidance trials; to be replaced with Operation Blue Skies data.
Start year	Shanwick 2030; Scottish 2032; London 2034	Follows the sequence in Section 6. Each FIR starts at the launch uptake for its case. All three from 2030 tested in B.6.
Uptake	25% / 50% / 75% in the first year in each FIR, rising to 95%; or 10% throughout	Share of flagged flights refiled, weighted by flights, not operators. See B.3.
Plan acceptance	Shanwick 96%→94%; London 93%→86%; Scottish 95%→91%	Acceptance starts near assumed 95% at low uptake, allowing for the normal reasons a plan is not flown as filed. It is set slightly higher in Shanwick, where oceanic airspace has more spare levels, especially at night, and lower in the London FIR, where dense terminal traffic and existing route restrictions limit level changes. It falls as uptake rises because avoiding flights compete for the same levels, most in London, consistent with EUROCONTROL's 2023 simulation finding that holding levels clear in moderate traffic cut capacity by at least 20%. These are judgements, to be replaced with NATS data.
Fee	5 × fuel cost of avoiding (£325 in 2030 at the modelled average, rising 2% a year to £396 in 2040)	Flat; charged in scenarios 2 and 7 where modelled warming exceeds 10 tCO_2e. Multiple reviewed every three years; four and ten times tested in B.6.
Fee share kept for running costs	10% of fee income, 2030–34; none from 2035	Following the Swedish NOx charge, in which administration is met from revenue before refund. 0% and 20% tested in B.6.

Parameter	Value	Source and notes
Rebate	Remaining fee income shared equally among verified avoiding flights, capped at £500 per flight in 2030 rising with the fuel price	Paid in the same year. Cannot exceed fee income. Income above the cap lowers the service charge for all flights.
Service charge	Running cost plus fuel repayment, less the fee share kept, per flight in UK-administered airspace	About £2.28 per flight in 2030 in the central case. Charged across all three FIRs from 2030; charging only where the scheme runs is tested in B.6. Set each autumn from forecasts, with a correction two years later; the model shows the outturn value.
Avoidance fuel	100 kg per refiled flight at £0.65/kg in 2030, rising 2% a year (2026 prices)	A working average across aircraft types. Provisional, benchmarked against published results (Smith et al. 2026; the 2023 American Airlines and Google trial, ~2% on avoiding flights; Contrails.org, 0.1 to 0.5% fleet-wide). Operation Blue Skies will give measured figures for Shanwick, which will set the starting point. A higher figure will raise the fee, rebate and service charge in proportion but does not change the warming avoided.
Fuel repayment	100% to 2035; 80/60/40/20% in 2036–39; zero from 2040	So that the cost of avoidance becomes part of normal operations.
Running cost	£5 million in 2030, +5% a year to 2034, then –10% a year	Working figure; tested at £2 million and £20 million in B.6.

Table 21: Assumptions and sources.

B.2 Formulae

For each Flight Information Region (FIR) and year y, where:

→ v = forecast availability,

→ u = operational uptake,

→ g = plan acceptance rate,

→ p = forecast precision,

→ e = execution success rate,

→ k = share of fee revenue retained.

$$\text{Pool}_y = \text{Pool}_{2030} \times 1.03^{(y-2030)} \tag{1}$$

$$u_y = \begin{cases} 0, & y < s \\ \text{case ramp from year } & s, y \geq s \end{cases} \tag{2}$$

where uptake begins in start year s at 25%, 50% or 75% (depending on the case) and rises to 95%.

$$\text{Targeted Flights}_y = \text{Flights}_y \times \text{Targeted Share} \tag{3}$$

where the targeted share is 12% for Shanwick and 2% for London and Scottish FIRs.

$$\text{Fee Flights}_y = \text{Targeted Flights}_y \times v \times (1 - u_y) \times p \quad \text{(Scenario 2)} \tag{4}$$

$$\text{Rebate Flights}_y = \text{Targeted Flights}_y \times v \times u_y \times g \times p \times e \quad \text{(Scenario 5)} \tag{5}$$

$$\text{Exempt Flights}_y = \text{Targeted Flights}_y \times v \times u_y \times (1 - g) \quad \text{(Scenario 3)} \tag{6}$$

$$\text{Fee per Flight}_y = £325 \times 1.02^{(y-2030)} \tag{7}$$

since:

$$£325 = 5 \times 100\,\text{kg} \times £0.65 \tag{8}$$

$$\text{Fees}_y = \text{Fee Flights}_y \times \text{Fee per Flight}_y \tag{9}$$

$$k_y = \begin{cases} 10\%, 2030 \leq y \leq 2034 \\ 0, \quad y \geq 2035 \end{cases} \tag{10}$$

$$\text{Cap}_y = £500 \times 1.02^{(y-2030)} \tag{11}$$

$$\text{Rebate per Flight}_y = \min\left(\text{Cap}_y, \frac{\text{Fees}_y(1 - k_y)}{\sum_{\text{FIR}} \text{Rebate Flights}_y}\right) \tag{12}$$

with the rebate calculated across all three FIRs.

$$\text{Excess}_y = \text{Fees}_y(1 - k_y) - \text{Rebate per Flight}_y \times \text{Rebate Flights}_y \tag{13}$$

$$\begin{aligned} \text{Fuel Repaid}_y = \text{Targeted Flights}_y \times v \times u_y \times g \times 100\,\text{kg} \\ \times £0.65 \times 1.02^{(y-2030)} \times \text{Repayment Share}_y \end{aligned} \tag{14}$$

$$\text{Service Charge per Flight}_y = \frac{\text{Running Cost}_y + \text{Fuel Repaid}_y - \text{Fees}_y k_y - \text{Excess}_y}{\text{Flights}_y} \tag{15}$$

A negative value represents a credit.

$$\text{Warming Avoided}_y = \text{Pool}_y \times 0.80 \times v \times u_y \times g \times p \times e \tag{16}$$

$$\text{Net Cost to Taxpayer}_y = \text{Running Cost}_y + \text{Rebates}_y + \text{Fuel Repaid}_y - \text{Fees}_y - \text{Service Charge Income}_y = 0 \tag{17}$$

$$\text{Net Cost to Industry}_y = \text{Running Cost}_y + \text{Fuel Burned}_y \tag{18}$$

Additional assumptions

→ The proportion of flagged flights that are false alarms is fixed at **30.6%**, derived from **90% forecast availability × 34% false-positive rate**.

→ As uptake increases, false alarms shift from **Scenario 1** (non-participating flights) to **Scenario 4** (participating flights).

→ **Scenario 7** is not modelled separately and is assumed to occur only rarely.

B.3 Adoption: evidence for the ramp and the ceiling

Adoption is the share of targeted flights, flight-weighted, whose operator files an amended pre-departure plan when flagged. It is not a share of operators: around 200 airlines use Shanwick but movements are dominated by a handful of majors, so 95 per cent of flights may represent only 20–30 per cent of operators.

It is the largest unevidenced driver in the model, so four cases are carried rather than a single ramp. The three active cases start at 25, 50 and 75 per cent and reach the 95 per cent ceiling six to eleven years after the scheme starts in a FIR; in Shanwick, in 2040, 2037 and 2035 respectively. A fourth holds adoption at 10 per cent throughout as a counterfactual, drawing on the upper end of voluntary adoption seen in previous demonstrations (eg, the American Airlines and Google randomised trial). At the high end, mandatory aviation compliance regimes run at effectively 100 per cent from the first year, though those are reporting obligations rather than behaviour.

The adoption ceiling is set at 95 per cent to allow for residual air traffic control restrictions. Opt-in is a one-off dispatch-system integration rather than a continuing investment, and the incentive is strong: a non-avoiding flight pays £325, against about £65 of fuel to avoid, which is itself repaid in full until 2035. Where fees apply regardless of opt-in, non-adoption is a capability failure rather than a choice, and the residual is flights that cannot fly lower at maximum payload, plus ad-hoc, charter and non-integrated foreign operators.

B.4 Main model, central case

Year	Pool (Mt)	Uptake	Accepted	Fee %	Rebate %	Exempt %	Avoided (Mt)
2030	17.26	50%	94.9%	29.7	19.7	2.3	2.10
2031	17.78	60%	94.7%	23.8	23.6	2.8	2.59
2032	18.31	66%	94.3%	20.0	26.0	3.4	3.19

Year	Pool (Mt)	Uptake	Accepted	Fee %	Rebate %	Exempt %	Avoided (Mt)
2033	18.86	75%	94.1%	15.1	29.2	3.9	3.67
2034	19.42	69%	92.0%	18.6	26.4	4.6	4.66
2035	20.01	76%	91.6%	14.3	29.1	5.4	5.16
2036	20.61	82%	91.3%	10.5	31.4	6.2	5.62
2037	21.22	87%	91.0%	7.7	33.0	6.8	5.99
2038	21.86	90%	90.8%	5.8	34.1	7.3	6.26
2039	22.52	93%	90.6%	4.5	34.9	7.7	6.51
2040	23.19	94%	90.5%	3.5	35.4	8.0	6.75
2030–40							52.48

Table 22: Pool and warming avoided in $MtCO_2e$. Accepted is the share of avoidance plans cleared and flown. Uptake is weighted by flights across the FIRs where the scheme is live; the pool covers all three FIRs. Fee, rebate and exempt are shares of targeted flights (scenarios 2, 5 and 3). They do not add to 100 per cent, because scenarios 1, 4 and 6 carry no fee or rebate and forecasts are modelled as unavailable on 10 per cent of days.

B.5 Money table, central case

Year	Fees (£m)	Kept for running costs (£m)	Rebate per flight (£)	Fuel repaid (£m)	Running cost (£m)	Service charge (£/flight)	Industry net cost (£m)
2030	4.2	0.4	440	1.2	5.0	2.28	6.2
2031	3.6	0.4	300	1.5	5.2	2.46	6.8
2032	3.7	0.4	234	2.1	5.5	2.68	7.6
2033	2.9	0.3	160	2.4	5.8	2.86	8.2
2034	6.4	0.6	223	4.0	6.1	3.28	10.0
2035	5.2	0.0	176	4.6	5.5	3.41	10.0
2036	4.0	0.0	123	4.1	4.9	2.99	10.1
2037	3.1	0.0	87	3.4	4.4	2.52	10.2
2038	2.4	0.0	65	2.5	4.0	2.01	10.2
2039	2.0	0.0	50	1.3	3.6	1.49	10.3
2040	1.6	0.0	39	0.0	3.2	0.95	10.4
2030–40	39.1	2.1		27.2	53.3		100.0

Table 23: Money flows, central case. The net cost to the taxpayer is zero in every year. Fees not kept for running costs are paid out as rebates. The industry's net cost is the running cost plus all avoidance fuel burned.

B.6 Sensitivities

Test	Change	Warming avoided 2030–40 (Mt)	Rebate 2030 (£)	Service charge 2030 (£/flight)	Industry net cost (£m)
Central case	—	52.5	440	2.28	100.0
Fee multiple	4 × (£260 in 2030)	52.5	352	2.31	100.0
Fee multiple	10 × (£650 in 2030)	52.5	500	0.82	100.0
Fee share kept, 2030–34	0%	52.5	489	2.45	100.0
Fee share kept, 2030–34	20%	52.5	391	2.11	100.0
Fuel price	Flat at £0.65/kg	52.5	440	2.28	94.4
Start years	All three FIRs from 2030	56.8	452	2.57	108.9
Service charge base	Only FIRs where the scheme runs	52.5	440	15.84	100.0
Running cost	£2m a year	52.5	440	1.10	68.1
Running cost	£20m a year	52.5	440	8.19	259.8
Shanwick share of global warming	3.3% (T&E)	37.4	440	2.28	100.0
Shanwick flights targeted	2%	52.5	440	2.02	75.9
Plan acceptance	No fall with uptake	53.8	440	2.28	100.0

Table 24: Sensitivity tests, central case. Each changes one assumption.

Fee multiple. The multiple does not change the warming avoided in the model, because uptake is an input; instead, it changes the size of the rebate. Against £440 at five times, the 2030 rebate is about £352 at four times (£260). At ten times (£650) it reaches the £500 cap, and the fee income above the cap lowers the 2030 service charge from £2.28 to about £0.82 per flight.

Fee share kept. Keeping no fee income for running costs raises the 2030 rebate to about £489 and the 2030 service charge to £2.45 per flight. Keeping 20% lowers them to £391 and £2.11. The choice moves money between avoiding flights and all flights, and does not change the industry's net cost.

Start years. Starting all three FIRs in 2030 would avoid 56.8 $MtCO_2e$ over the decade, against 52.5 with the staged start, at an industry cost of £109 million against £100 million. By 2040 the two are within 0.02 $MtCO_2e$ a year, because every FIR reaches the 95 per cent ceiling.

Service charge base. If the service charge applied only to flights in FIRs where the scheme runs, Shanwick flights would pay about £15.84 each in 2030 and £9.33 in 2032 when the Scottish FIR joins, falling to the all-airspace level from 2034. The total collected is the same; only who pays changes.

Running cost. The running cost not met from fees is paid through the service charge, so it does not affect the public purse or the rebate. At £2 million a year the service charge in 2030 is about £1.10 per flight and the industry's net cost over the decade is £68 million; at £20 million it is about £8.19 per flight and £260 million.

Shanwick's share of global warming. Using T&E's 3.3 per cent [25] instead of 5 per cent reduces the warming avoided by about a quarter, to 37.4 $MtCO_2e$, because Shanwick provides most of the benefit. This is the largest single uncertainty in the climate result, and Operation Blue Skies should settle it.

Share of Shanwick flights targeted. Targeting 2 per cent instead of 12 per cent of Shanwick flights does not change the warming avoided, because the model shares a fixed pool of warming among the targeted flights. It changes the money: fewer flights pay the fee and fewer receive a rebate, and the industry's net cost falls to £76 million because fewer flights burn extra fuel. Operation Blue Skies data on how many flights are flagged are needed before rates are set.

Plan acceptance. If acceptance did not fall as uptake rises, the warming avoided would be 53.8 $MtCO_2e$, against 52.5: competition for levels costs about 3 per cent of the benefit by 2040. Acceptance and execution success are the two operational assumptions to replace first with trial data.

Re-routing. For a flagged flight, routing around UK-charged airspace pays only if the detour costs less than the expected fee (66 per cent of the fee, the chance that the region is confirmed) plus the Shanwick charge saved (about £100). Table 25 gives the break-even detour for a wide-body aircraft at £15 to £25 per extra nautical mile. The estimate leaves out Icelandic and Danish North Atlantic charges on northern detours, so it overstates the exposure. NATS data on the number of flights routing near the Shanwick boundary are needed to turn it into a share of traffic.

Fee per non-avoiding flight	Break-even detour (nm)
£260	11–18
£325	13–21
£650	21–35
£1,300	38–64

Fee per non-avoiding flight	Break-even detour (nm)
£2,500	70–117

Table 25: Detour below which routing around UK-charged airspace would pay, by fee level.

Annex C. Concept of operations (outline)

This annex sets out, in outline, the sequence of events for a flagged flight under the Phase 3 scheme, from forecast to bill, and the party responsible at each step. It is the frame for the full concept of operations, which is a Phase 1 deliverable. Timings are indicative and are to be set with the Met Office, NATS and operators during Phase 1 and tested in the Phase 2 demonstrations.

Step	Timing	Responsible	What happens
1. Reference forecast issued	Each forecast cycle, ahead of the planning window (lead time to be set)	Met Office (Building block 1)	Forecast of contrail-forming regions by level and time, in the standard aeronautical meteorological packet, reaching airlines, dispatchers, pilots, ANSPs and planning-software providers. This is the reference forecast that defines the flagged set.
2. Normal plan generated	At the operator's normal planning time	Operator (dispatch), using compliant planning software (Building block 2)	The cost-optimised plan is produced before any contrail information is applied; the planning system's audit record evidences the sequence (Section 7.1).
3. Flight flagged	On generation of the normal plan	Planning software, against the reference forecast	The normal plan is tested against the reference forecast. A flight whose route crosses a forecast region with modelled warming above the threshold is flagged; unflagged flights are out of scope.
4. Contrail assessment and refiling decision	Before filing	Operator (dispatch)	The planning system offers a contrail-avoiding alternative, a change of level within the lateral route, with its fuel and time cost. The operator

Step	Timing	Responsible	What happens
			either files the normal plan, accepting the fee if the region is confirmed, or files the avoiding plan. Only the plan to be flown is filed; the normal plan is kept with the audit record and supplied to the verifier.
5. Filing and clearance	Filing to departure	Operator; EUROCONTROL Network Manager and NATS (domestic FIRs); NATS Prestwick (Shanwick)	Plans are filed in the ordinary way and processed by the Network Manager, which checks them against the Route Availability Document and applies any capacity measures. A contrail-avoiding plan is badged so that air traffic control can see the climate purpose of the requested level. Safety-critical instructions take precedence throughout (Section 4.1).
6. Flight	Departure to arrival	Flight crew; air traffic control	The flight is flown as cleared. A tactical instruction that moves a flight off its avoiding level is recorded, and the operator is not penalised for it (scenario 3). A deviation the airline makes without an ATC or safety reason is recorded as scenario 7.
7. Verification	After the flight, on receipt of reanalysis data (interval to be set)	NERL verification function, automated	Normal and flown trajectories (ADS-B or GPS) are re-run through reanalysis weather data

Step	Timing	Responsible	What happens
			to establish whether the region was real and whether the flown route cleared it. The verifier assigns the flight to a scenario in Table 15. On a sample basis the verifier may call for recorded fuel data (QAR or flight data monitoring) for refiled flights, to check planned fuel differences against actual burn (Section 7.1).
8. Settlement	Monthly invoice, after verification	NERL (Shanwick); EUROCONTROL Central Route Charges Office (CRCO) from the NERL verification file (domestic FIRs)	Fees, fuel repayments and an interim rebate of 80% of the forecast annual rate are netted on the operator's route-charge invoice for a later month, once verification is complete; a final rebate adjustment follows after the year ends; the service charge is added to every flight's route charge.
9. Appeals	Within a set period after the bill (to be set)	NERL in the first instance; CAA on reference	An operator may contest the scenario assigned to a flight against the audit record and the verification data. The verification statistics for the period are published (Section 7.7).
10. Rate setting	Each autumn for the following year; fee multiple reviewed every three years	NERL under CAA direction	The fee multiple, the fee share kept for running costs, the service charge, the reference fuel price and the fuel benchmarks are confirmed and

Step	Timing	Responsible	What happens
			notified to operators (Section 7.3).

Table 26: Outline concept of operations for a flagged flight.

Two matters are left to the full concept of operations: the forecast lead time at which the flagged set is fixed, since a flag that moved between forecast cycles would leave operators unable to plan against it; and the treatment of flights re-planned after departure for reasons unrelated to contrails.

References

[1] J. R. Smith *et al.*, "The climate opportunities and risks of contrail avoidance," *Nature Communications*, vol. 17, no. 1, p. 2092, Jan. 2026, doi: 10.1038/s41467-026-68784-8.

[2] Aviation Impact Accelerator, "Technical guardrails for contrails policy development: Principles, constraints, and tradeoffs," Cambridge, UK, Report, Nov. 2026. [Online]. Available: https://aiazero.org/docs/technical-guardrails-for-contrails-policy-development.pdf

[3] "AIM § 4-6-6: Guidance on Severe Turbulence and Mountain Wave Activity (MWA)." [Online]. Available: https://faraim.org/faa/aim/chapter-4/section-4-6-6.html

[4] ICAO, "Flight Safety and Volcanic Ash: Risk management of flight operations with known or forecast volcanic ash contamination," Montréal, ICAO Guidance Document Doc 9974 (AN/487), 2012. [Online]. Available: https://www.icao.int/publications/doc-9974

[5] EUROCONTROL, "EUROCONTROL and European Commission release enhanced NEATS platform to improve monitoring of the non-CO2 climate impacts of aviation." [Online]. Available: https://www.eurocontrol.int/press-release/eurocontrol-and-european-commission-release-enhanced-neats-platform-improve

[6] Roland Berger, "Contrails: A solvable problem?," Munich, technical report, Jun. 2025. [Online]. Available: https://www.rolandberger.com/en/Insights/Publications/Contrails-A-solvable-problem.html

[7] C. Elkin and D. Sanekommu, "How AI is helping airlines mitigate the climate impact of contrails." [Online]. Available: https://blog.google/innovation-and-ai/technology/ai/ai-airlines-contrails-climate-change/

[8] M. Shapiro, "The cost of contrail management." [Online]. Available: https://notebook.contrails.org/the-cost-of-contrail-management/

[9] C. López de la Osa and K. Hencz, "Contrail avoidance: aviation's climate opportunity of the decade." [Online]. Available: https://www.transportenvironment.org/articles/contrail-avoidance

[10] Department for Transport, "Transport and growth update: airport expansion and transition to greener aviation." [Online]. Available: https://www.gov.uk/government/speeches/transport-and-growth-update-airport-expansion-and-transition-to-greener-aviation

[11] OECD, "The Swedish tax on nitrogen oxide emissions: Lessons in environmental policy reform," Paris, technical report 2, 2013. doi: 10.1787/5k3tpspfqgzt-en.

[12] X. D'Haultfœuille, P. Givord, and X. Boutin, "The environmental effect of green taxation: The case of the French bonus/malus," *The Economic Journal*, vol. 124, no. 578, pp. F444–F480, 2014, [Online]. Available: http://www.jstor.org/stable/42919227

[13] Z. Yang, "Practical lessons in vehicle efficiency policy: The 10-year evolution of France's CO2-based bonus-malus (feebate) system." [Online]. Available: https://theicct.org/practical-lessons-in-vehicle-efficiency-policy-the-10-year-evolution-of-frances-co2-based-bonus-malus-feebate-system/

[14] "Commission Implementing Regulation (EU) 2019/317 of 11 February 2019 laying down a performance and charging scheme in the single European sky and repealing Implementing Regulations (EU) No 390/2013 and (EU) No 391/2013 (Text with EEA relevance.)." Accessed: Nov. 16, 2026. [Online]. Available: http://data.europa.eu/eli/reg_impl/2019/317/oj

[15] NATS, "Annual report and accounts 2025," technical report, 2025. [Online]. Available: https://www.nats.aero/wp-content/uploads/2025/06/NATS11377_AnnualReport-2025-Full.pdf

[16] NATS, "Busiest year for flights since the pandemic." [Online]. Available: https://www.nats.aero/news/busiest-year-for-flights-since-the-pandemic/

[17] R. Teoh *et al.*, "Aviation contrail climate effects in the North Atlantic from 2016 to 2021," *Atmospheric Chemistry and Physics*, vol. 22, no. 16, pp. 10919–10935, Aug. 2022, doi: 10.5194/acp-22-10919-2022.

[18] R. Teoh *et al.*, "Global aviation contrail climate effects from 2019 to 2021," *Atmospheric Chemistry and Physics*, vol. 24, no. 10, pp. 6071–6093, May 2024, doi: 10.5194/acp-24-6071-2024.

[19] International Civil Aviation Organization (ICAO), “ICAO’s Policies on Charges for Airports and Air Navigation Services,” Montréal, technical report Doc 9082, 2024.

[20] Gold Standard, “Contrail prevention to reduce aviation’s Non-CO2 climate impacts,” technical report GS4GG PAA M400-11, Version 1.0, Jul. 2026. Accessed: Nov. 16, 2026. [Online]. Available: https://globalgoals.goldstandard.org/463_paa-m400-11-contrail-prevention-to-reduce-aviations-non-co2-climate-impacts/

[21] EUROCONTROL, “Principles for Establishing the Cost-Base for En-Route Charges and the Calculation of the Unit Rates,” Route Charging Reference Document Doc. N° 20.60.01, Jan. 2020. Accessed: Nov. 16, 2026. [Online]. Available: https://www.eurocontrol.int/publication/principles-establishing-cost-base-en-route-charges-and-calculation-unit-rates

[22] Civil Aviation Authority (CAA), “The Civil Aviation Authority (Navigation Services Charges) Specification 2026,” London, Specification OR7 115, Jan. 2026. Accessed: Nov. 16, 2026. [Online]. Available: https://www.caa.co.uk/data-and-publications/publications/documents/content/or7-115/

[23] “Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation) (Text with EEA relevance).” Accessed: Nov. 16, 2026. [Online]. Available: http://data.europa.eu/eli/reg/2023/2405/oj

[24] P. Hazlehurst and E. Mitchison, “Operation Blue Skies: Contrail Avoidance at Airspace Scale.” Accessed: Nov. 16, 2026. [Online]. Available: https://notebook.contrails.org/operation-blue-skies-launch/

[25] Transport & Environment, “How to scale up contrail avoidance in Europe?,” technical report, Jan. 2026. Accessed: Sep. 17, 2026. [Online]. Available: https://www.transportenvironment.org/articles/scale_up_contrail_avoidance

[26] G. Thompson *et al.*, “On the fidelity of high-resolution numerical weather forecasts of contrail-favorable conditions,” *Atmospheric Research*, vol. 311, p. 107663, Dec. 2024, doi: 10.1016/j.atmosres.2024.107663.

aiazero.org

© 2026 University of Cambridge | Aviation Impact Accelerator