A roadmap for contrail mitigation in Europe

Current knowledge and remaining challenges to scale up contrail navigational avoidance, and how to start deploying it in Europe in the 2030s.

T&E briefing, based on To70 study
September 2026

T&E

Executive summary

The problem

Contrails warm the planet as much as aviation's CO_2 emissions.

The solution

Contrail navigational avoidance - deviating flights to avoid contrail formation areas - is the most efficient mitigation lever available today.

The challenge

To achieve significant benefits, contrail avoidance must be deployed at large scale, and coordinated across entire regions.

This briefing presents a roadmap to deploy contrail avoidance at scale in Europe in the 2030s

The briefing reviews the **operational reality of contrail navigational avoidance, and how to deploy it at scale in European airspace:**

- Analysis of experience from **flight trials**
- **Remaining operational gaps** in terms of tools, procedures, training and collaboration
- **A roadmap to address those gaps and deploy contrail avoidance in Europe by 2032**

The briefing is based on a To70 study in collaboration with T&E, based on interviews with experts and research.

Table of contents

The why, how and when of contrail mitigation

Contrails warm the planet roughly as much as aviation's CO_2

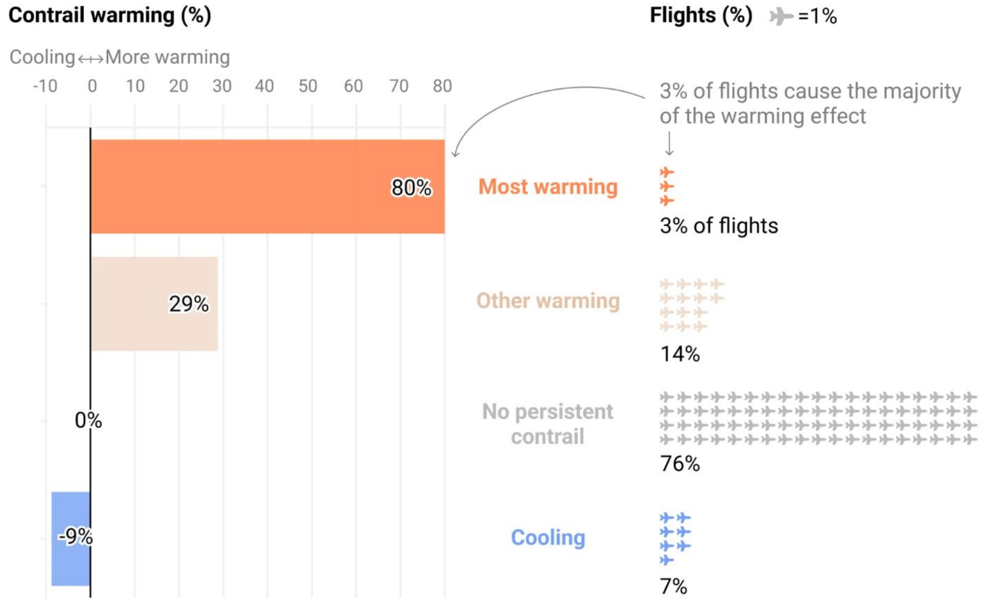
Similar warming to aviation's CO_2

Contrails climate impact is similar to that of its CO_2 emissions, causing **immediate warming**, but it depends strongly on where and when aircraft fly.

3% of flights create 80% of contrail warming

Contrail warming is **highly concentrated**, thus targeting a small number of flights can deliver **large climate benefits**.

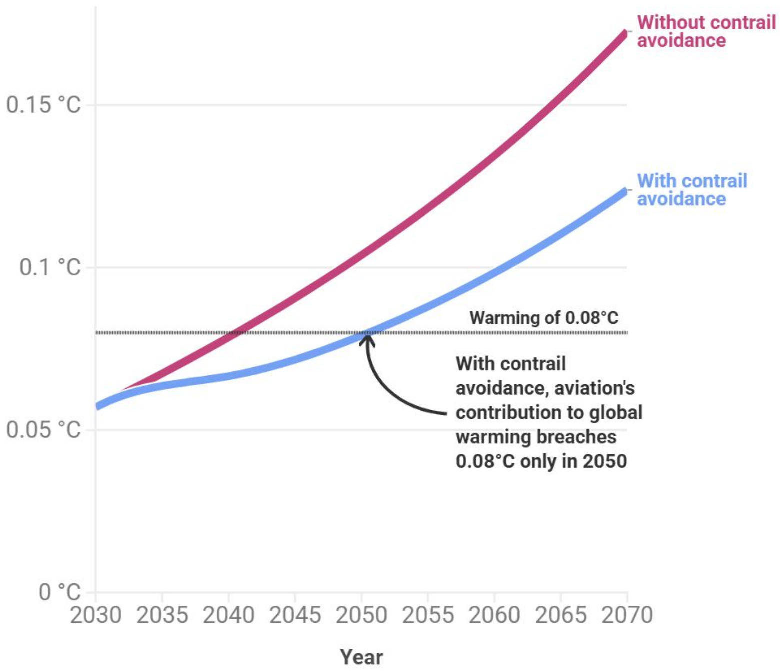
3% of flights cause 80% of global contrail warming



Source: T&E (2026), based on Teoh et al. (2024) for 2019 • The distribution of contrail warming varies by region. In Europe, 5% of departing flights account for 80% of contrail warming.

Contrail mitigation brings quick benefits in a climate emergency

0.025 °C less by 2050	As published in T&E's "A way forward for contrail mitigation" study, contrail mitigation starting in 2030, cutting contrail warming by half by 2040, results in an **avoided temperature increase of ~0.025°C in 2050 and ~0.049°C in 2070**.
3-5% contribution to the 2°C budget	Implementing contrail avoidance frees up **3–5 percentage points of the global 2025–2050 temperature budget in a 2°C pathway** that would otherwise be consumed by aviation - an important contribution to meeting the climate goals of the Paris Agreement.



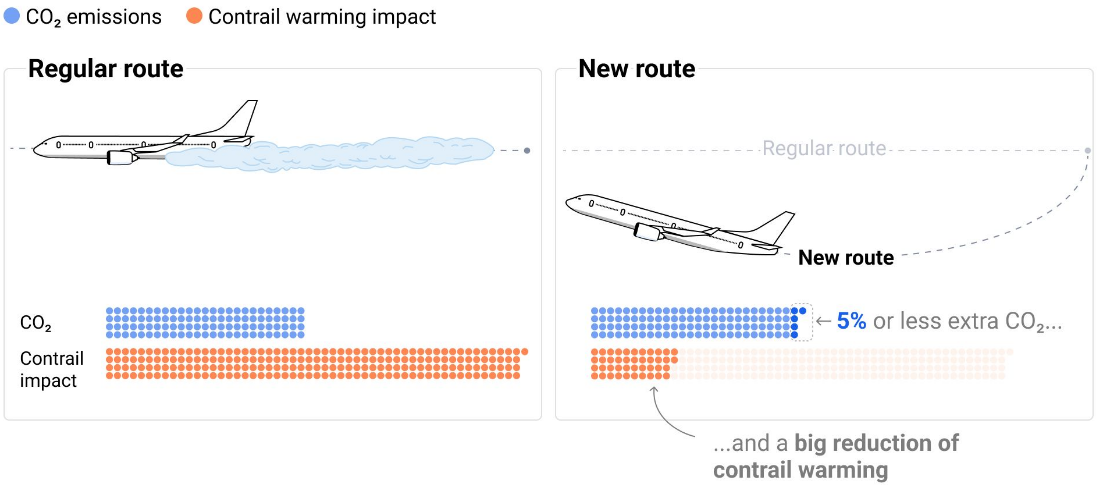
Source: T&E (2026), based on Klima Consulting (2026)

The most promising solution: contrail navigational avoidance

Flight deviations of 4,000 feet or less are enough to reduce contrail warming

Contrails form in cold and humid areas of the atmosphere (ISSRs), which are very thin. 1-2 flight level changes (2,000- 4,000 feet up or down) can avoid the worst contrail forming regions. **Targeting the most warming contrails ensures that <u>the avoided contrail warming far exceeds the possible extra CO_2 emissions</u> from the deviations**.

Net climate benefits of rerouting the most warming flights can be huge



Source: Teoh et al. (2024), Frías et al. (2024), T&E. Note: Simulation of the net climate impact of contrail avoidance for a flight within the 5% of European flights that generate 80% of contrail warming. Assumptions: GWP100 used to compare the climate impact of CO2 and contrails. Contrail warming reduced by 80%. The 5% extra fuel burn is a conservative estimate - extra fuel burn in flight tests and simulations is 2% or lower.

Air traffic management (ATM): the key to contrail navigational avoidance at scale

Going from flight by flight to entire airspaces requires coordinated effort

Air Traffic Management (ATM) holds the key to scaling up contrail avoidance

Trials have proven that flight by flight contrail avoidance is feasible. However, for significant climate benefits, contrail avoidance must be scaled up to entire airspaces. **ATM actors (Air Navigation Service Providers and the Network Manager) will play an essential role** to coordinate flight deviations of hundreds or thousands of flights. ATM actors, **in coordination with airlines (flight dispatchers and pilots)** will need to make sure that the climate impact of flight trajectories, including contrail and CO_2 warming, is reduced, while **safety and capacity** are maintained.

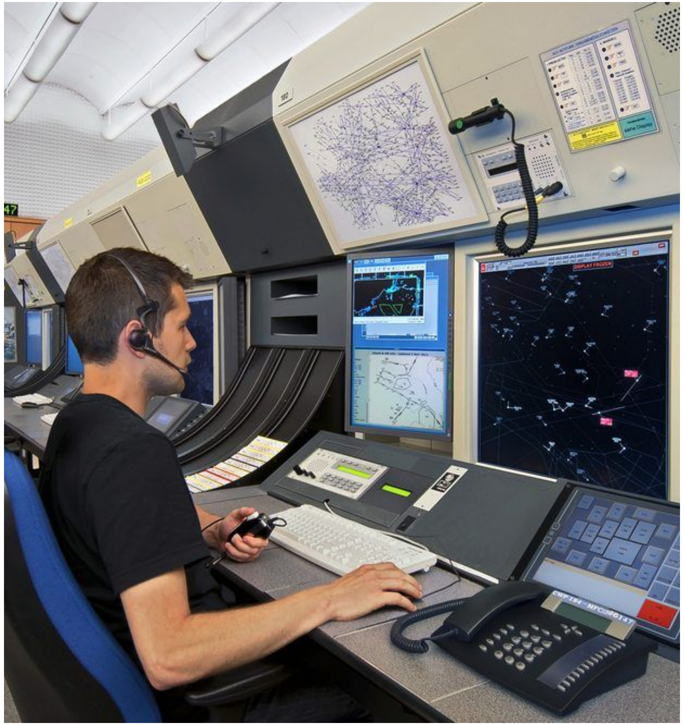
Who is who in ATM - Air navigation service providers (ANSPs)

ANSPs: responsible for safely managing the airspace

ANSPs manage aircraft in flight and on the manoeuvring area of airports, and are the legitimate holder of that responsibility. ANSPs also play a key role in determining strategic route availability such as flight paths, permitted flight levels and flight times. The two main roles are:

Air traffic controllers (ATCOs): the main service provided by ANSPs. ATCOs coordinate all air traffic for a safe, efficient operation. They manage aircraft flying at cruise level, but also in the climb and descent phases, and around aerodromes.

Flow managers (FM): they ensure the interface between local ATCOs, airlines and airports, and the network manager, on air traffic flows and capacity management services.

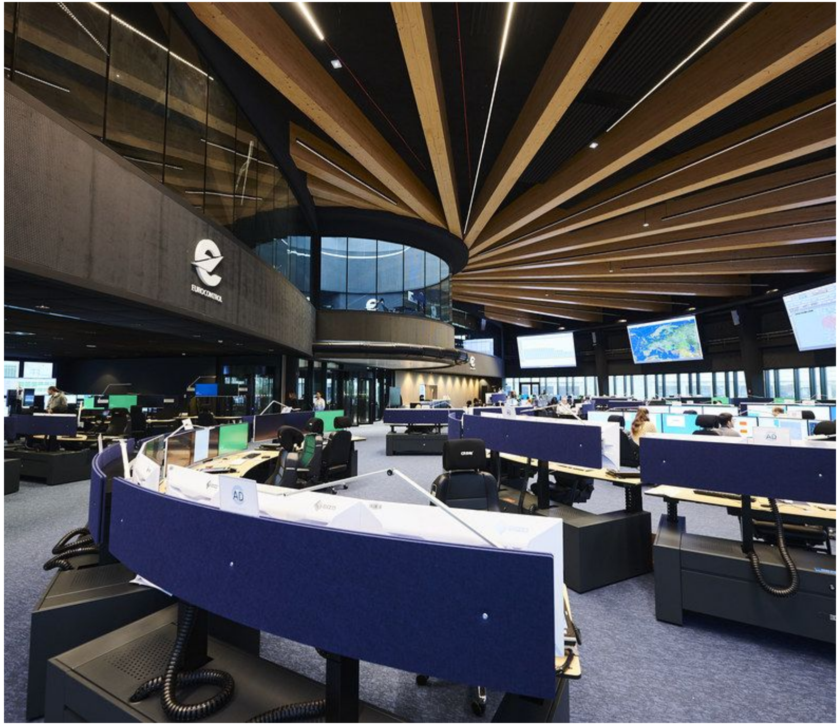


Who is who in ATM - Network manager (NM)

NM: the coordinator across airspaces

The Network manager (NM) provides a coordinating role between national or regional ANSPs, especially in Europe where the airspace is segmented. The NM manages ATM network functions (airspace design, flow management) as well as scarce resources (transponder code allocations, radio frequencies) and cost division. The NM's general objectives are to support the execution of the network functions and to contribute to the continuous improvement of network operations and the overall performance of the network.

Eurocontrol is the network manager in Europe.



T&E

Who is who in ATM - Airlines

Airlines plan and execute the flights

Airlines are responsible for the **initial planning and for the execution of flight routes**. The main actors involved in the ATM process are:

Flight dispatchers: they develop the flight plans for all flights, and coordinate them with the NM and the pilots.

Pilots: they are responsible for the safe execution of the flight. Their responsibility includes the provision of sufficient fuel and avoidance of adverse weather, but also arrival within the allocated time, and communication in the air with air traffic control. They are in control of the routing once the engines are on.

ATM procedures

Continuous coordination between all ATM actors - the NM, ANSPs, airlines - is essential for the correct functioning of the ATM system.

On top of airlines, ANSPs and the network manager, coordinating with other services such as weather services or military airspace managers is crucial for a safe, efficient ATM system.

Flight planning	Network coordination	Flight execution	Supporting Services
File flight plans with proposed times and routes *(Airlines)*	Review flight plans for capacity limits *(Network Manager)*	Oversee take-off and landing sequences *(ANSPs)*	Provide weather and atmospheric data *(Meteorological Services)*
Adjust plans for winds, charges, and constraints *(Airlines)*	Issue departure slots *(Network Manager)*	Manage cross-border air traffic flows *(ANSPs)*	Deliver contrail-forecasting and optimisation tools *(Data & Tool Providers)*
	Coordinate network efficiency and safety *(Network Manager)*	Adjust routes in real time *(Pilots, Airlines, ANSPs)*	Coordinate scheduling *(Airports)*
	Allocate airspace and ensure safe routing *(ANSPs)*	Execute approved flight plans in accordance with clearances *(Pilots)*	Manage restricted or shared airspace *(Military Airspace Managers)*
	Manage national air traffic sectors *(ANSPs)*	Maintain safe separation of aircraft *(ANSPs)*	

New ATM procedures to avoid contrails are being created and tested

Lead	**Pre-tactical** - before the flight departs	**Tactical** - during flight
Airline led - Pilot or dispatcher	The dispatcher prepares a flight plan to avoid contrail areas, and informs the pilot. The flight plan is submitted as usual to NM.	The pilot receives real time information to change route to avoid a contrail area, and requests route change to ATC.
ATM led - ATC, NM or flow manager	The NM integrates contrail areas in their flight planning software, and adjusts flight plans received from dispatchers, who then accept flight plan.	ANSP flow manager restricts airspace in contrail areas, and instructs ATC to avoid those areas. Final decision made based on safety, capacity or economic constraints.
Hybrid - collaborative	The dispatcher prepares a flight plan to avoid contrail areas, and the NM adjusts all flight plans to ensure maximum efficiency at network level.	Both pilot and ATC are informed of the contrail area, and both can request a deviation to avoid it.

Highly specialised tools are an essential part of the ATM system

Airlines

The flight planning software (FPS) is used by airlines to prepare their flight plans, which are then submitted to the NM. The software allows airlines to optimise flight plans based on a range of parameters - generally fuel and time costs, and airspace charges.

Network manager

The Integrated Initial Flight plan Processing System (IFPS) checks if flight plans submitted by airlines comply with airspace constraints, such as altitude or airspace restrictions. Once approved by the system, flight plans are checked by the NM and local flow manager to ensure they fit airspace and airport capacity.

ANSPs (flow managers)

Flow managers work from the NM's Network Operations Plan (NOP), to monitor demand against sector and airport capacities. Where imbalances are identified, flow managers apply Demand and Capacity Balancing measures, coordinated back through the NM and reflected in updated slot allocations for affected flights.

ANSPs (controllers)

Air traffic controllers work from Flight Data Processing Systems (FDPS) integrated with radar/surveillance displays, which present live flight data, conflict alerts and sequencing support tools. They allow controllers to issue and update clearances to maintain separation and optimise traffic flow through their sector in real time.

Contrail avoidance will require an update of ATM tools

Principles to integrate contrails in ATM tools

· Contrail formation areas (ISSRs) can be included in ATM tools as restriction areas, or areas with higher charges.
· Similar models should be used across different ATM tools to align on where contrails may form.

Airlines

Some flight planning softwares (FPS) integrate contrail formation areas, but the use of this functionality is still limited. The contrail functionality within FPS allows airlines to allocate a cost to contrail areas, so that these areas are avoided when the flight is optimised.

NM and ANSP flow managers

NM and flow managers tools can integrate contrail areas in a similar way to how they are integrated in flight planning software. This would allow NMs and flow managers to limit the use of airspaces with likely contrail formation, in a similar way to how airspaces with military flights or adverse weather are managed today.

ANSPs (controllers)

Given the safety-critical nature of the role of air traffic controllers, any changes to their working tools requires extensive testing. This makes the integration of contrails in their systems more complex than in NM/flow managers tools.

Learning by doing: what trials have taught about contrail avoidance

Why flight trials are essential to learn about contrail avoidance

From theory to practice

Contrail avoidance involves many different actors working together. Even though a lot of scientific and theoretical research has been carried out, the ultimate learning comes when aircraft take off and everyone has to put in practice the tools and procedures developed on paper.

Live flight trials involve testing contrail avoidance tools and procedures in real operations. This provides essential real-life experience, and data about feasibility and benefits - for example, through gathering observational data to assess whether contrails formed as predicted by the models.

All the areas where trials advance contrail avoidance knowledge

Reducing scientific uncertainty

Benchmarks weather predictions against real-world observations to clarify trade-offs between contrail warming & fuel burn.

Validating operational feasibility

Measures airspace capacity impact and determines if trajectory changes are best made pre-flight or in-flight.

Systems & standardization

Tests software tools and contributes to the creation of necessary protocols and updated ATM processes.

Building human expertise

Trains flight dispatchers, air traffic controllers, and pilots, ensuring operational readiness for daily implementation.

Evidence-based policy

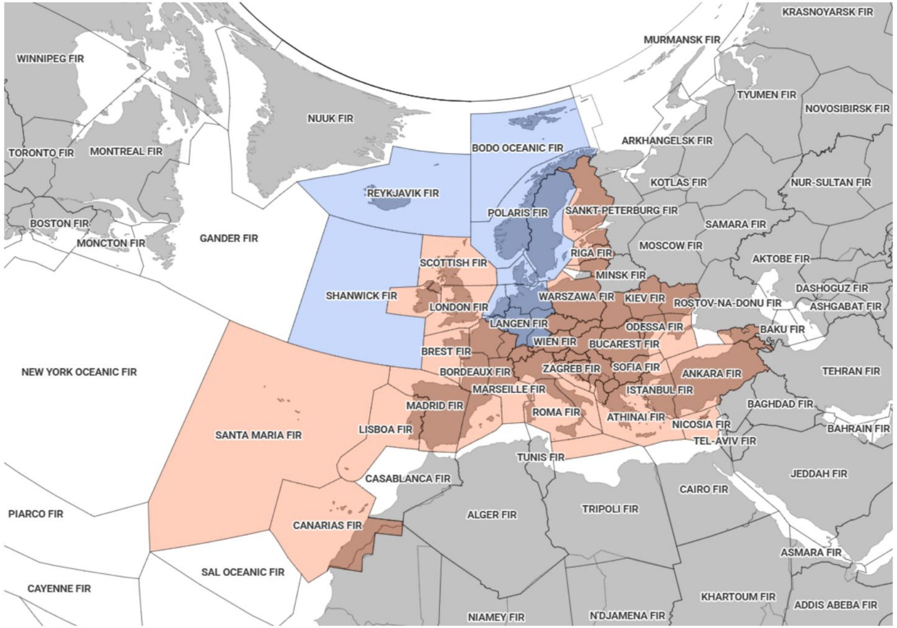
Provides empirical data to refine forecasting models and build the evidence base to inform future climate policies.

Overview of past trials

MUAC & DLR (2021)	Tactical, ATM-led trial targeting night flights. 200 flights rerouted.
MUAC & Google (2024)	Tactical, ATM-led approach similar to 2021's trial, facilitated by a tool developed by Google. 500 flights rerouted.
D-KULT (2024-2025)	Pre-tactical, led by airlines and facilitated by the German ANSP. 108 flights rerouted.
CONCERTO (2024-2026)	Pre-tactical, ATM-led project with shadow trials - no real flights rerouted.
CICONIA (2024-2026)	Both ATM- and airline-led approaches, with more than 50 flights rerouted. Operational and scientific objectives were covered.

Most contrail avoidance trials have taken place in Central & Northern Europe

Lower flight information regions (FIRs) - Eurocontrol FIRs in orange - Eurocontrol FIRs participating in trials in blue



Source: T&E and To70 (2026), based on Eurocontrol and Open Aviation • Using Albers equal-area projection

Scientific lessons: climate benefits in certain situations are clear

· The location of contrail formation areas (ISSRs) is well predicted

· Forecasts are stable up to 24 hours before the flight

· ISSR dimensions tend to be overestimated, and are relatively thin: vertical deviations of 2000 - 4000 feet are in principle sufficient to avoid the areas where the most warming contrails form

· Reliable weather forecasts, and contrail formation models, are essential to guarantee climate benefits of contrail avoidance, and also to ensure engagement from involved actors (dispatchers, pilots, controllers, NM)

· **Current knowledge is enough to act in specific situations (e.g. night flights)**

NOTE: remaining scientific gaps for contrail mitigation, and how to address them are covered in the "A way forward for contrail mitigation" study. **This briefing focuses on operational gaps only**.

Operational lessons: low traffic presents opportunities to avoid contrails

· Tactical trials indicate little capacity impact during low traffic, around 20% capacity reduction during higher traffic

· Pre-tactical contrail avoidance is considered more adequate for medium and high traffic situations

· Automation is key to large scale implementation - current tools require manual, time consuming interventions

· Coordination, data sharing and developing procedures are critical - dispatchers, pilots, air traffic controllers and the network managers should all be informed that a contrail avoidance flight is taking place

· The current policy framework - cost-optimised flight plans, minimum distance KPI for ATM - needs to be adapted for contrail avoidance

· **Contrail avoidance is manageable today in specific situations (e.g. low traffic areas)**

Key learning: deploy contrail avoidance with higher warming and low traffic

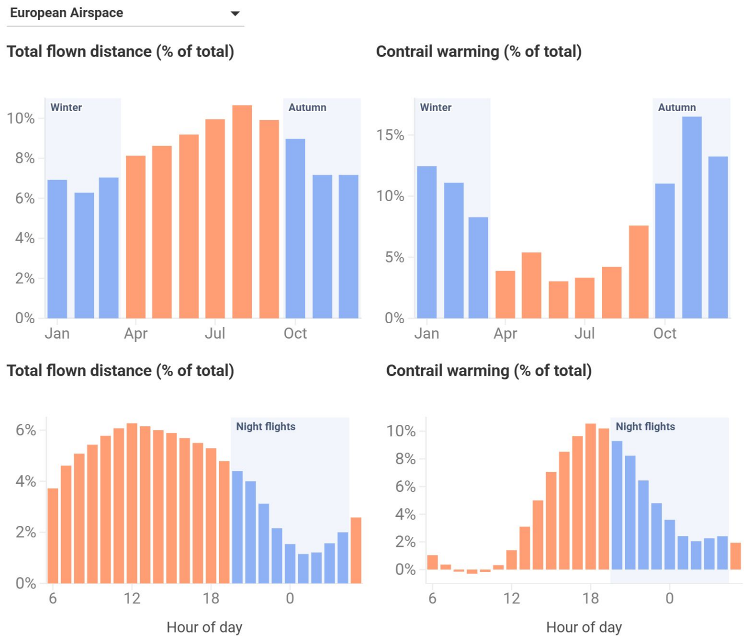
Starting at nights and in winter reduces scientific and operational uncertainties.

Contrail warming is more intense at nights and during autumn and winter. This coincides with the periods **when air traffic is lower**, which makes them the perfect starting point to deploy contrail avoidance at scale: **deviating fewer flights addresses more warming**.

Starting at times and areas with low traffic allows the ATM system to test contrail avoidance with less workload. Afterwards, tools and procedures can be refined, and contrail avoidance can be progressively deployed to times and airspaces with more air traffic.

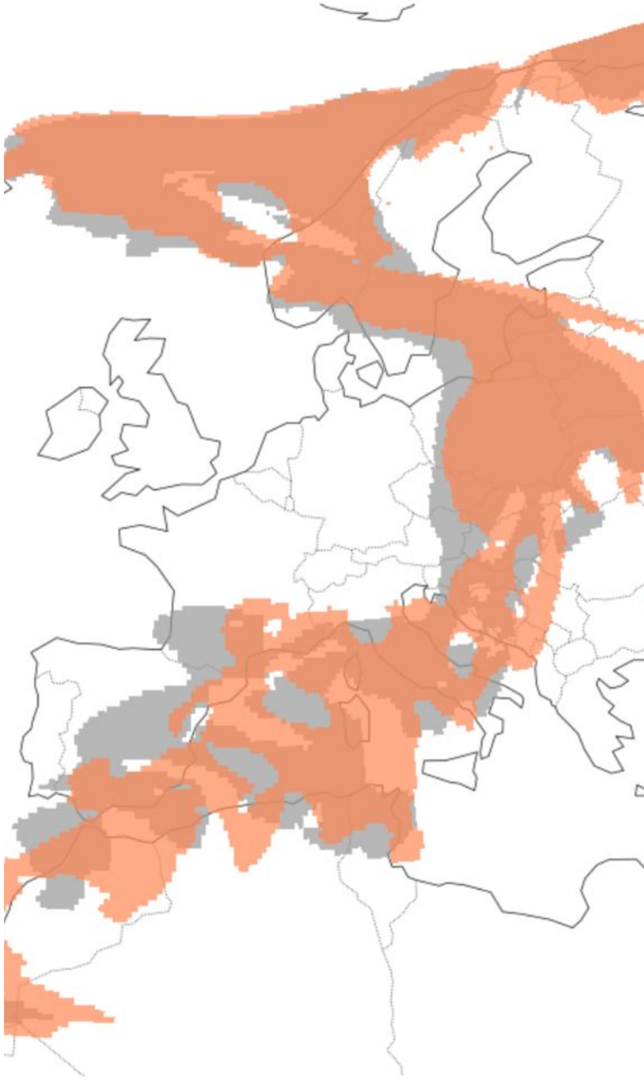
Autumn and winter flights have a disproportionate contrail climate impact

Total flown distance, contrail warming (both share of 2019 European total) and contrail warming per flown distance (share of 2019 European average) by month



Source: T&E (2025), based on Teoh et al. (2024) for the year 2019, re-run by ICL with an updated version of pycontrails (v0.54.8) • Times in UTC.

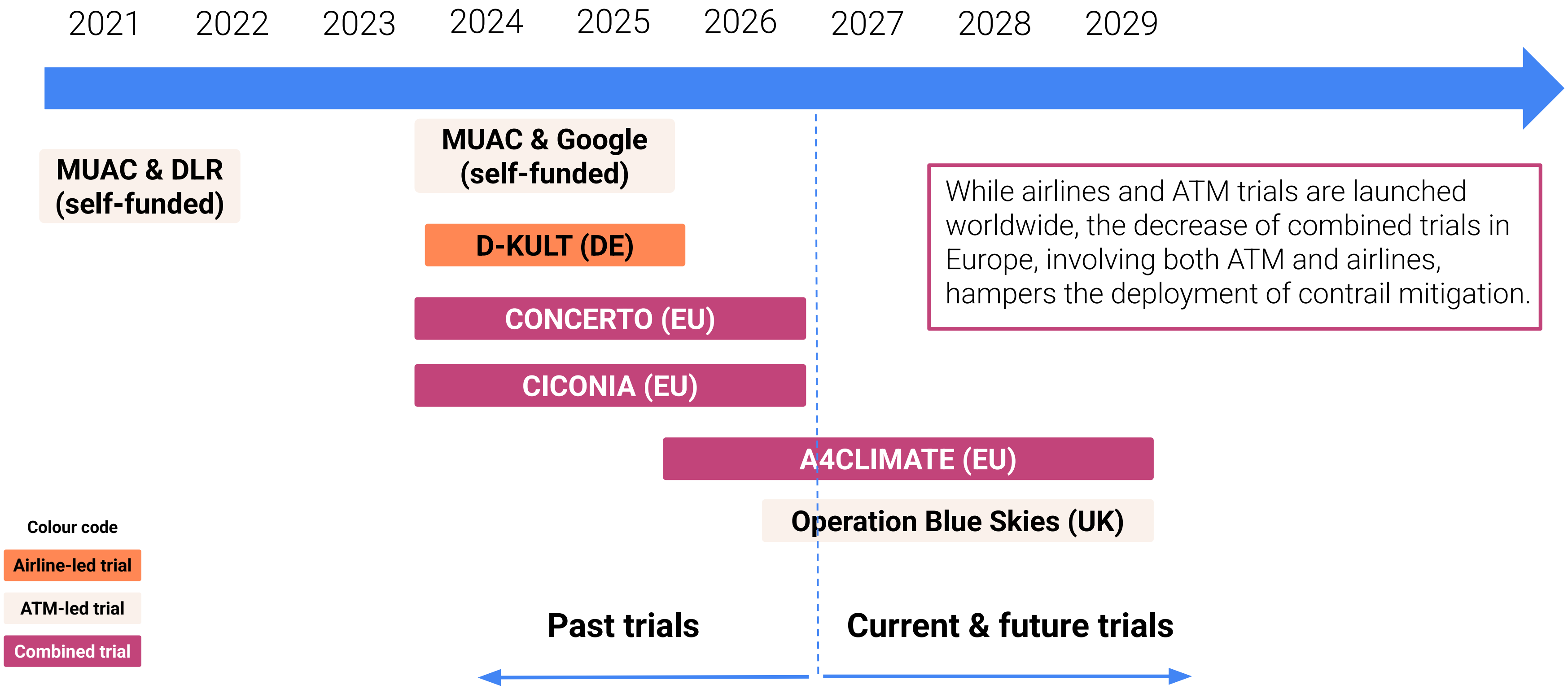
Remaining operational challenges, and how to close them



Operational challenges remain…

	Tooling	Procedures
ATM challenges	· No integration of contrail avoidance in ATM tools implies heavy manual workload · Upgrading ATC tools used by controllers can be challenging	· Lack of standardised ATM procedures integrated into existing procedures · Lack of staff training - very little awareness about contrails and contrail avoidance among most staff
Airline challenges	· No, or limited integration of contrail avoidance in flight planning software tools implies heavy manual workload.	· Lack of standardised dispatcher and pilot procedures integrated into existing procedures · Lack of staff training - very little awareness about contrails and contrail avoidance among most staff · Potential extra fuel burn
Coordination challenges	Lack of interoperable contrail avoidance tooling based on similar: · CO_2 / CO_2e tradeoffs · Weather data · Models and metrics	· Communication and common procedures between airlines (dispatchers, pilots) and ATM (ANSPs, controllers, network manager) · Very fragmented coordination during trials so far, with ATM actors unaware of airline-led trials, and, likewise, airlines unaware of ATM-led trials

...while very few European trials are planned in the near future



Public funding should prioritise combined trials

What effective trials look like

Airline-led trials

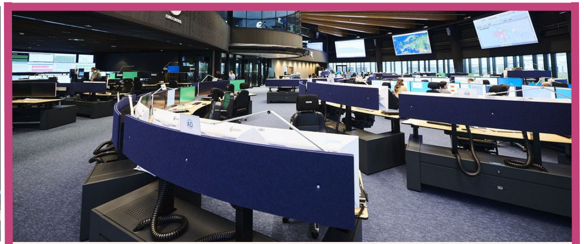
Main goals: develop the airline side of contrail mitigation (airline tools, dispatcher and pilot procedures).

Estimated costs: 0.5-1 M€ per airline, driven by staff and fuel costs. Sometimes self-funded by industry.

ANSP-led trials

Main goals: develop ANSP contrail avoidance capabilities (ANSP tools, procedures).

Estimated costs: up to 4-7 M€, driven by development of ANSP tools (one-off cost for each ANSP). Sometimes self-funded by industry.



Combined trials

Main goals: coordination of all actors, including NM.

Estimated costs: up to 10-15 M€, driven by development of ANSP and NM tools (one-off for each ANSP and for the NM) and fuel costs. Rarely self-funded, so **this should be the priority of public funding**.

Roadmap to contrail mitigation in Europe

T&E

How to deploy contrail avoidance (I): speed up trials to boost our scientific and operational knowledge

2026 to 2029

100 M€ for 10-15 medium-sized trials, prioritising combined trials involving ATM and airlines

· Prioritise combined trials with ANSPs, airlines and Network Manager
· Each trial should involve at least hundreds of flights
· Part of the funds should be used in one-off development costs of ATM tools and procedures, paving the way for large scale trials and operational deployment

2029 to 2032+

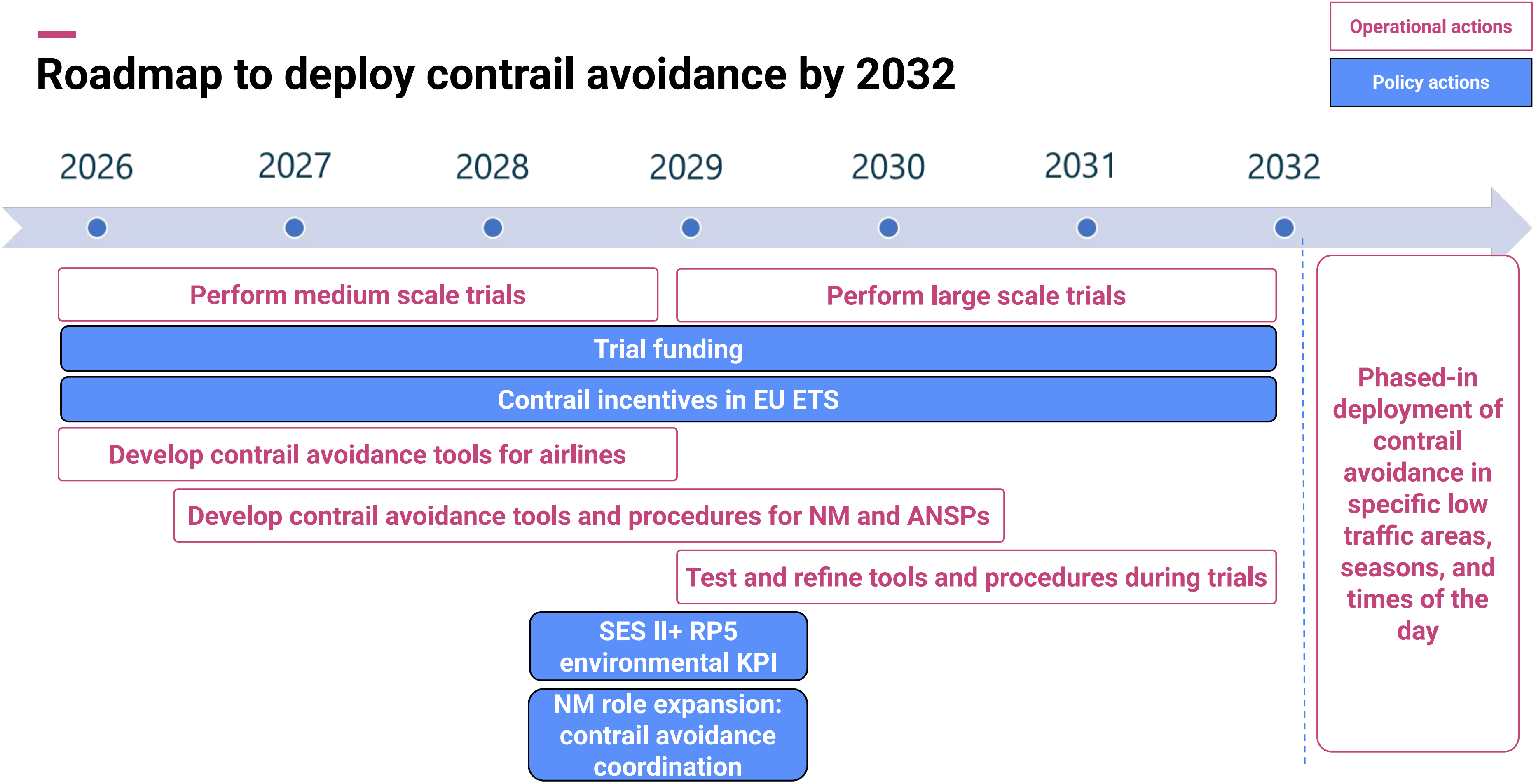
Launch large scale trials to test operational procedures and close remaining scientific gaps

· Trials would involve thousands of flights, across all seasons
· The aim should be to get as close as a real life operational deployment as possible

How to deploy contrail avoidance (II): create the policy framework to launch contrail avoidance at scale in the 2030s

2026 to 2029	**Prepare the policy framework for the deployment of contrail avoidance** · Aviation strategy: recognise contrail avoidance as one of the key climate mitigation levers for aviation in the upcoming aviation strategy, including the announcement of flight trials · ATM policy: consider contrails and non-CO_2 effects in the design of the upcoming environmental and climate KPI for the next Reference Period 5 of Single European Sky 2+, and develop standard procedures for contrail avoidance · NM: expand the mandate of the next NM to contrail avoidance coordination · EU ETS: create incentives for airlines to equip and use contrail avoidance tools, and to engage in trials
2029 to 2032+	**Integration and scaling of contrail avoidance in ATM policy** · EU ETS: rollout incentives for contrail avoidance · After 2032: deploy contrail avoidance in selected airspaces during specific periods. Progressively expand contrail avoidance to busier airspaces or time periods as technologies and science mature further

Roadmap to deploy contrail avoidance by 2032



Acknowledgements

Briefing published: September 2026

Contributors: Carlos López de la Osa García, Vincent de Haes, Diane Vitry, Jérôme du Boucher, Erin Vera

Responsible editor: William Todts, Executive Director

To cite this briefing

T&E (2026). Briefing on To70's report "Contrail avoidance roadmap"

Acknowledgements

The findings and views put forward in this publication are the sole responsibility of the authors listed above.

Further information

Carlos López de la Osa
carlos.lopez@transportenvironment.org

www.transportenvironment.org | Bluesky | LinkedIn