Aviation Intelligence Unit
Think Paper #10 - 20 April 2021

EUROCONTROL

Flying the 'perfect green flight': How can we make every journey as environmentally friendly as possible?

European aviation has embarked on its most important trajectory for decades: the goal of achieving the ambitious target of carbon neutrality by 2050. The political will is there, with the European 'Green Deal' showing the way forward: the challenge is to make every journey as environmentally friendly as possible and aim to fly the 'perfect green flight'. This Think Paper takes the reader on a journey, looking at every aspect of a flight before, during and immediately after, to identify the main opportunities to improve aviation sustainability at each stage, the challenges that need to be tackled to get closer to that 'perfect green flight', and what we can do – now and in the medium term – to make that happen.

To identify where the greatest potential for improvement now and in the future lies, we ask:

- Why is it not always possible to fly a 'perfect green flight' today?
- Which measures have the greatest potential to improve the sustainability of aviation now, and in the future?
- What do we need to do to make every single flight greener?

The paper concludes that while various factors make flying 'perfect green flights' very complex, nevertheless a lot can be done now to make flights greener at every stage of a journey, and by every actor involved.

A perfect green flight in big numbers

- **25.8% less CO_2 emissions (4,286kg) per average wider-European area flight (16,632kg) by 2030 using current technology – a saving that will massively increase when emerging developments (electric, hydrogen or hybrid aeroplanes) enter into commercial service**
- **8%** of those reduced CO_2 emissions – **1,331 kg** – are based on **10%** Sustainable Aviation Fuel use – and more would yield even greater benefit
- **8.6-11.2%** of those reduced CO_2 emissions – up to **1,863 kg** – could be delivered by better use of fuel-efficient operational and technological solutions by all European ATM network stakeholders
- **7%** of those reduced CO_2 emissions – up to **1,164 kg** – can be provided by fleet modernisation now based on current types in service; this will increase as new, more fuel and emissions-efficient models are rolled out.

Main findings of this Think Paper

1. **A significant advance towards the "perfect green flight"** can be made by making better use of existing measures, and all actors working together: we estimate that per flight, **up to 4,286kg of CO_2 emissions (25.8%) could be eliminated by 2030 compared to 2019, out of an average 16,632kg of CO_2 for a total flight in the wider European area, and based on current technology.**

2. **Better use of fuel-efficient air traffic management improvements** could deliver 8.6%-11.2% (up to 1,863 kg) of those reduced CO_2 emissions per flight. To realise this benefits pool, accelerating the transition from SESAR R&D to deployment as well as improving the functioning and performance of the network to the greatest extent are crucial. This will require a network-centric cooperative decision-making (CDM) process with all network actors, as set out in the proposed recast Single European Sky (SES) package.

3. **Emerging aircraft technologies in the form of hybrid, fully-electric and hydrogen airplanes will transform aviation over the period 2030-2050, enabling aviation to meet its climate-neutrality goal by 2050. By 2050, these new airplanes will be increasingly prevalent on short to medium haul sectors**; while SAF use will predominate in the long-haul sector, with further upscaling of SAF production seeing 83% of fuel used being SAF, irrespective of any further technological developments.

FIGURE 1: AIRCRAFT TECHNOLOGIES & ENERGY TIMELINE 2021-2050

	Evolutionary tech phase	Breakthrough tech phase	Revolutionary tech phase
Conventional fleet	Growing use of SAF as a % of all fuel: 10% or more (assuming supply increases)	Upscaling of SAF as a % of all fuel to 50%	Further upscaling of SAF (bio and synthetic) as a % of all fuel to 83%
New aircraft technologies	New models with more efficient engines	Emergence of hybrid, fully electric & hydrogen aircraft	Increasing production of hybrid, fully electric & hydrogen aircraft
Timeline	2021 – 2030 (Think Paper scope)	2030 – 2040	2040 – 2050

Source: EUROCONTROL

4. **Sustainable aviation fuel (SAF) is the most promising measure towards aviation decarbonisation right now.** 10% use of SAF by 2030 would deliver 1,331 kg or 8% in CO_2 saving – but today, use stands at just 0.1%. To hit this target, investment in SAF must be ramped up now, and a firm policy support target set incentivising its use. This would accelerate SAF uptake, leading to higher demand and a faster decarbonisation of aviation – permitting **more ambitious target setting** in the future. 20% SAF use by 2030 would represent a colossal challenge to meet – but would potentially deliver up to 16% in CO_2 saving per flight.

5. **Airlines can play a significant role in reducing CO_2 emissions, but greater incentives may be needed to balance economic considerations:**
   - modernising their current fleets to remove less efficient aircraft older than 15 years – which would save 7% or 1,164 kg in emissions; here, the pandemic has prompted an acceleration in fleet renewal, with many older aircraft types unlikely to return;
   - reducing 'economic fuel tankering', whereby aircraft carry more fuel than they need to reduce or avoid refuelling at their destination airport; this could save a further 89 kg or 0.54% of emissions;
   - working with airports to use Ground Power Units rather than aircraft Auxiliary Power Units on the ground, saving 0.3% or 50 kg;
   - optimising the fuel efficiency of their existing fleets, building on a massive 25% improvement over the last 15 years that has seen aviation prove more fuel efficient than cars at 3 to 4 litres per passenger 100km.

6. **More attention needs to be paid to noise and non-CO2 impacts,** such as contrail avoidance.

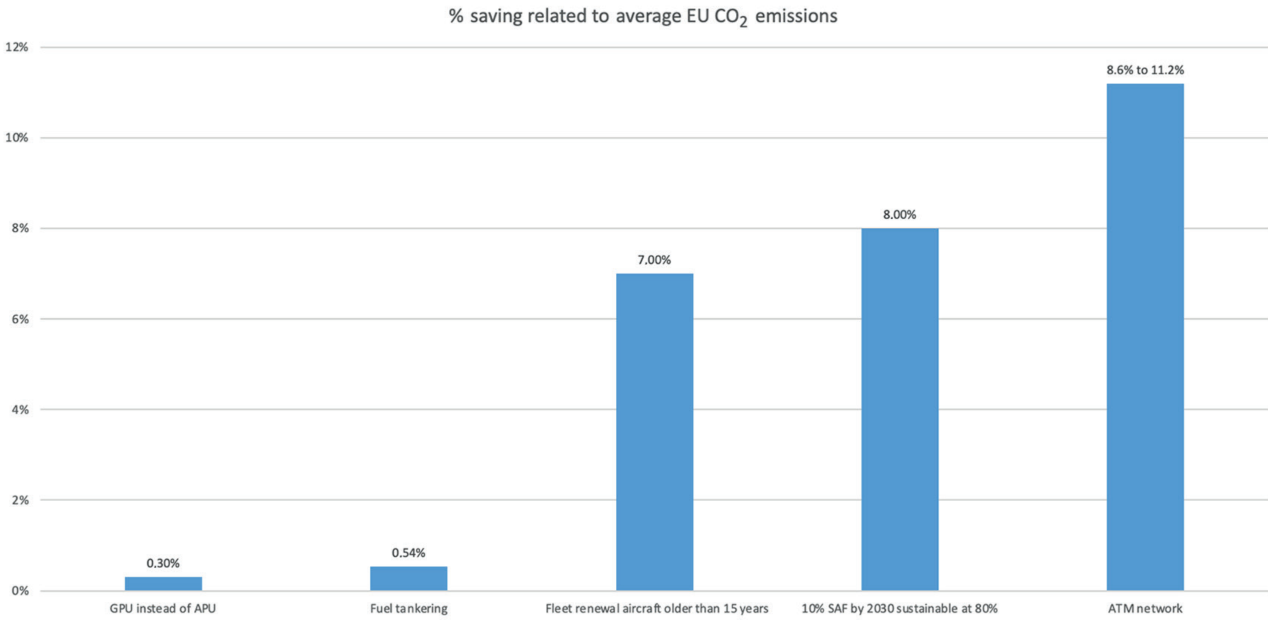
How much potential is there to 'green' every flight already?

Figure 2 summarises the potential savings in terms of CO_2 emissions that could be avoided on average per flight across the wider European (ECAC – European Civil Aviation Conference, 44 States including all 41 EUROCONTROL Member States) area by 2030. It shows that, by using a combination of existing measures more consistently, and without factoring in major technological leaps (e.g. hybrid/fully electric or hybrid/fully hydrogen-powered aircraft), a lot can already be done collectively to reduce CO_2 and non-CO_2 emissions from aviation using current technology.

We estimate that by 2030, up to 4,286kg of CO_2 emissions (25.8%) could be eliminated per flight compared to 2019 out of an average 16,632kg of CO_2 for a total flight in the ECAC area – a significant advance towards the "perfect green flight". And this potential saving is purely based on current aircraft technology: these reductions will massively increase when emerging developments (electric, hydrogen or hybrid aeroplanes) enter into commercial service.

The two most short-term promising fuel/CO_2 savings accelerators are air traffic management improvements including further use of the currently implemented continuous climb and descent operations (CCO/CDO), and Free Route Airspace (FRA), where air navigation service providers (ANSPs), airlines, airports, flight plan service providers and the EUROCONTROL Network Manager have a key role to play (from 8.6% up to 11.2%), and sustainable aviation

FIGURE 2: POTENTIAL CO_2 SAVINGS THAT COULD BE REALISED, KG/FLIGHT ACROSS THE WIDER EUROPEAN AREA



Source: EUROCONTROL

***Note:** Due to interdependencies, the sum of benefits does not always add up.*

fuel (SAF), which could deliver a 8% reduction in emissions based on just 10% use by 2030; this would however increase significantly if SAF were to become more widely used. The proposed recast SES package is central to the faster and wider adoption of these and other emerging solutions.

Next comes the renewal of the airline fleet, with the retirement of older, less fuel-efficient aircraft (over 15 years old) in favour of new, more fuel-efficient models, resulting in savings of **1,164 kg** of CO_2 emissions (7%).

Additional measures that also play their part in reducing CO_2 emissions are tackling the economic-environmental trade-off in "fuel tankering", whereby aircraft often carry more fuel than is needed on economic grounds generating on average 89kg of additional fuel burn (**0.54%** of CO_2 per flight); and the use of Ground Power Units rather than aircraft Auxiliary Power Units at airports (**0.3%** or **50 kg**).

The rest of this paper looks at each aspect of a flight to identify what measures are already partially or fully in place, and what their potential is to decrease emissions.

The initial findings of this paper will be tested, further harmonised and quantified by EUROCONTROL and partners in the ALBATROSS project,[1] which aims to quantify the benefits of "perfect green flights". A 2-year study launched by the SESAR Joint Undertaking under the EU's Horizon 2020 Research and Innovation programme, ALBATROSS will explore in real conditions the feasibility of implementing the most fuel/CO_2 efficient flights possible by conducting a series of live trials across Europe.

What additional decarbonisation potential will new aircraft technology bring?

The projected emissions savings outlined in this paper are based on existing technology, but we expect the picture to change significantly over the following 20 years up to 2050. New aircraft technologies are expected to accelerate progress and ensure that aviation meets the goal of climate-neutrality by 2050, as per the timeline (Figure 1) on the cover page. Nevertheless, the savings solutions proposed in this paper will still have a significant role to play in the near future in helping aviation decarbonise.

Between 2021 and 2030 only evolutionary technical developments are expected for commercial aviation, although the first hybrid-electric aircraft should be close to market introduction. Further efficiencies will be delivered by enhancements to existing aircraft models, but clearly increased SAF usage remains the most promising and realistic short-term solution for decarbonising aviation. Aircraft are already authorised to fly using 50% SAF, and certification to 100% SAF is expected in the coming years; however, the availability of SAF remains the main constraint in the short term, as this paper underlines with its assumption that SAF could account for 10% or more of all fuel used by 2030.

The picture is set to change significantly in the decade up to 2040, when we expect breakthrough developments via the progressive introduction of hybrid, fully-electric and hydrogen aircraft in the short to medium-haul segments. We expect SAF production to have ramped up, providing 50% of all fuel used by conventional airplanes, with particular relevance for the long-haul segment.

The phase 2041-2050 is what we term the "revolutionary tech phase", with hybrid, fully-electric and hydrogen aircraft predominating in the short to medium-haul segments. In the long-haul sector, further upscaling of SAF (bio and synthetic) production should reach up to 83% of fuel used, irrespective of any technological developments, as predicted in the Destination 2050 report.

Pre-flight: Airlines' business choices are crucial

Airlines need to embed environmental efficiency in their values and operating procedures. Fuel conservation and thus CO_2 reduction should be a priority objective. Every airline should have an ongoing fleet modernisation programme, replacing older models with newer, less fuel-consuming and quieter models, alongside a fuel conservation policy.

Aircraft performance degrades over the airframe lifecycle, requiring a strict fleet maintenance programme[2]. Airbus data indicate that as airframes and engines age, aerodynamic and performance deterioration tends to increase fuel burn and emissions, increasing the drag of an aircraft by up to 2% over 5 years[3]. Airlines should assign aircraft to city-pairs according to the most efficient fuel conservation and load factors.

By analysing the distance flown, fuel consumption, and ageing degradation of engines and airframe of a sample of more than 23,000 aircraft in service in 2019, we find that replacing them with more modern aircraft models would save about 7% of current CO_2 emissions based on replacing aircraft older than 15 years with new models; here, the pandemic has already triggered this. Furthermore, fleet renewal has an additional advantage of helping stabilise average noise levels at today's major airports by 2030. This 7% fleet renewal will provide an additional decarbonisation boost to aviation, complementing natural fleet renewal and fuel efficiency improvements. Here, it is essential to underline that this saving assumes fleet renewal based on current technology, whereas over the next years, ever more fuel and emissions-efficient types will enter into service such as electric, hydrogen and hybrid aircraft.

Airlines should also consider setting up robust flight emissions offsetting programmes, as some major European airlines are already starting to do.

Pre-flight: Passenger choices have an impact

Passengers have their own role to play in greening flights, from how they travel to the airport, to potentially which carrier they use, and in some cases which airport they decide to fly from. Having more accurate, up-to-date information on the environmental performance of aviation, and airlines in particular, would enable passengers to factor this into flight selection, encouraging airlines to develop stronger, more ambitious policies on these issues. The "Environmental Labelling Scheme" that EASA, the European Union Aviation Safety Agency, is committed to developing with Member States, industry and non-governmental organisations should certainly help in this respect.[4]

The passenger's environmental responsibility goes further. Among other things, s/he can select the greenest means of transport to and from airports, travel light, select the class of seat with the lowest environmental share (this however may depend on business choices made by airlines for that specific city-pair: an economy seat has half the environmental impact of a premium seat, 4 times less than a business seat, and 8 times less than a first class seat), or offset his/her own share of the flight climate impact, when the airline does not have a compensation system already in place.

Passengers may not always be able to choose their departure/arrival airports, but where they can, they **should be attentive to their environmental performance.** Significant advances have been made by many European airports: 52 already qualify as carbon-neutral as reported by ACI through its Airport Carbon Accreditation system, and many more are engaged in reducing their environmental footprint. The latest independently verified carbon reduction (2018-2019) achieved by European airports in the Airport Carbon Accreditation programme is 133,621 tonnes of CO_2 – a 7% decrease in emissions under their direct control.[5]

Pre-flight planning: Significant scope for reduced fuel and emissions

Considerable progress has been made by airport operators (AOs), ANSPs and the EUROCONTROL Network Manager (NM) to improve the safe flow of air traffic in all phases of flight, balancing demand and capacity, improving demand accuracy and predictability management, enhancing capacity or congestion management, increasing information exchange, all enabled by cooperative decision-making (CDM).

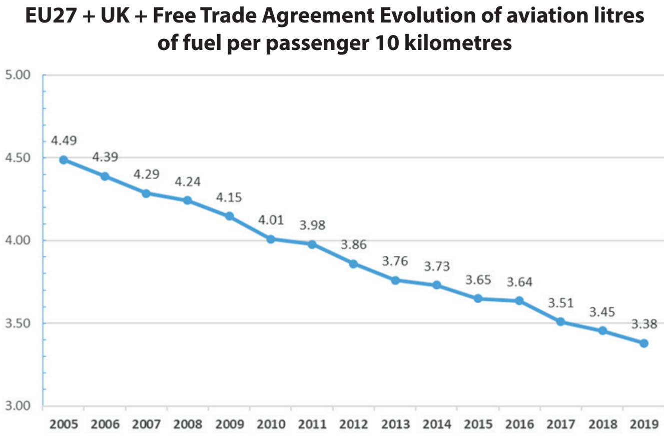
Some airlines already share data with ANSPs and the EUROCONTROL NM to help them optimise their operations. This improves traffic capacity management, increases fuel conservation and lowers the environmental impact in terms of noise and fuel/emissions reductions. This should increase to maximise the potential benefits to aviation.

In a recent fuel efficiency study[6] EUROCONTROL estimated the **fuel inefficiency of the ATM network in 2019 to be between 8.6% and 11.2% from take-off to landing** for flights within Europe.

Carrying unnecessary extra weight increases the quantity of fuel burned in flight, as an ICAO study[7] emphasises: *"The extra fuel burn attributable to additional weight carried on board an aircraft is typically of the order of 2.5 to 4.5 per cent of the additional weight, per hour of flight, depending on the characteristics of the aircraft. For example, 500 kg of extra weight for a ten-hour flight could result in the additional consumption of 125 to 225 kg of fuel and an increase in CO_2 emissions of 390 to 710 kg."* Therefore, it is of the utmost importance to minimise non-essential items on-board, such as paper, water, cups, waste, etc., and ensure necessary items are as light as possible.

Given the above efficiency gains, the payload of each flight (passengers plus cargo) should be maximised to optimise the **fuel-per-passenger ratio, which has steadily improved over the last 15 years** as per Figure 3. **Aviation is now more fuel efficient than cars at 3 to 4 litres per passenger 100km**, reflecting a massive

FIGURE 3: EVOLUTION OF AVIATION LITRES OF FUEL PER PASSENGER 100 KMS



Source: EUROCONTROL

FIGURE 4: NET SAVINGS DUE TO TANKERING VS. EXTRA CO_2 EMITTED

	Extra fuel burnt (tonnes/year)	Cost to transport extra fuel (M€/year)	Extra CO_2 emitted (tonnes/year)	Cost of purchasing CO_2 allowances (M€/year)	Net saving = Tankering saving - [Extra fuel + CO_2 cost] (M€/year)
Full tankering	160,000	88	504,000	10	217
Partial tankering	126,000	69	397,000	8	48
Total tankering	**286,000**	**157**	**901,000**	**18**	**265**

Source: EUROCONTROL Think Paper #1

25% improvement by airlines since 2005. This reflects steadily improving passenger load factors, which pre-pandemic stood at 82.5%[8],rising up to 97% for low-cost airlines.[9]

The fuel needed for a flight depends on the final payload; therefore, refuelling processes should end up close to final load-sheet delivery, in order to minimise any unnecessary additional fuel to be loaded and avoid CO_2 emissions.

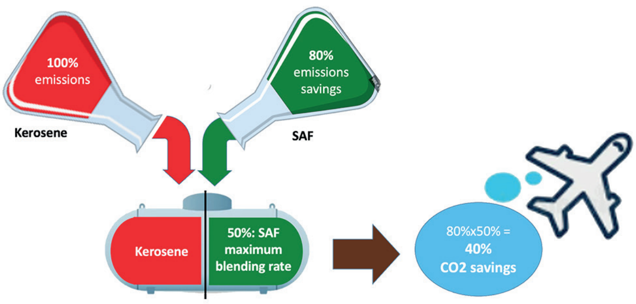
Incentives will need to be put in place to encourage airlines not to practise economic fuel tankering, whereby aircraft carry more fuel than they need for their flight in order to reduce or avoid refuelling at their destination airport, when the negotiated fuel price and the cost of fuel services at the departure airport are significantly lower than at the destination airport.

In 2018, as per Figure 4, we estimated that 21% of short and medium-haul flights in Europe were performing fuel tankering, representing a net saving of **265M€** per year to the airlines, but burning **286,000** tonnes of additional fuel burnt (equivalent to **0.54%** of the whole jet fuel used in Europe), or **901,000** tonnes of CO_2 per year (see EUROCONTROL Think Paper #1 for more details). [10]

The most important recent development on the aviation sustainability front is sustainable aviation fuel (SAF). Continuing to burn 100% fossil fuels on every flight should be avoided by replacing part of the standard fossil jet fuel used in aircraft by a sustainably-produced alternative fuel whose carbon impact is reduced by up to 80% over its lifecycle. [11, 12]

For now, SAFs are only certified to account for a maximum of 50% of an aircraft's fuel load[13], although trials are underway to demonstrate that it is already possible and safe to power cargo and commercial flights with 100% SAFs, in the hope of speeding up certification[14]. Therefore, based on a 50% blend, **SAF has the potential to reduce CO_2 emissions from aviation by up to 40%, as Figure 5 shows.**

FIGURE 5: SAF EMISSIONS SAVINGS



Recent "perfect green flight"[15] trials by Braathens,[16] DHL,[17] and KLM[18] show that collaboration between all parties is crucial to achieve maximum savings and substantially reduce CO_2 emissions, by around 46% for the regional flight trial in Sweden compared to standard regional jets. While difficult to draw conclusions in terms of maximum possible fuel savings, these trials clearly show that combining existing operational improvements with fuel-efficient aircraft can deliver real savings. However, they also show that the level of readiness for sustainable SAF is not yet satisfactory.

Using SAF as much as possible would be a considerable step forward towards aviation sustainability and is probably the technical solution that could be deployed most rapidly without modifications to existing systems and aircraft.

However, today SAF accounts for **less than 0.1%** of the roughly 300 million tonnes of EU aviation fuel consumption.[19] **It is vital to ramp up SAF production, and availability at major airport hubs, to reduce the cost of SAFs, currently 3 times higher than fossil jet-A1 fuel, and to incentivise their adoption.** The Destination 2050 report[20] estimates that, with proper incentives, 6% of fuel used could be SAFs by 2030; IEA's Sustainable Development Scenario[21] anticipates around 10% in 2030 and 19% in 2040; while some countries such as Norway and Finland are already targeting up to 30% of SAF by 2030.[22]

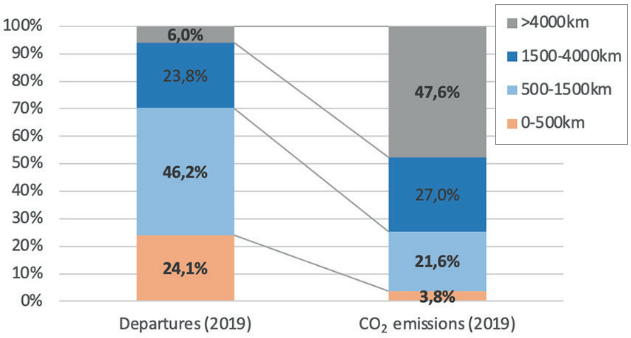
A firm policy support target of 10% SAF by 2030 could lead to higher demand than initially expected and a faster decarbonisation of aviation. This would accelerate SAF uptake, leading to higher demand and speeding up aviation decarbonisation – permitting **more ambitious target setting** in the future. 20% SAF use by 2030 would represent a colossal challenge to meet – but would potentially deliver **16%** in CO_2 saving per flight, leading, with the other measures proposed, to **34%** in CO_2 emissions savings per flight (**5,617kg** of CO_2).

SAFs can also improve aircraft fuel efficiency by 1-3% and can reduce SOx and particulate matter (PM) emissions by 100% and 90% respectively, according to SAF producer SKyNRG,[23] reducing the likelihood of contrail formation.

Rather than flying only the most economically beneficial route, AOs and ATM should also consider the most environmentally friendly route and cruising flight levels, taking into account weather conditions, air traffic constraints but also the possibilities offered by dynamic ATM (such as FUA, the Flexible Use of Airspace, which permits military airspace to be crossed by civil aircraft when not in use).[24] This means balancing delays, fuel burn and route charges.

SAF is also fundamental to reducing long-haul flight (>4,000km) emissions, which account for the bulk of flights in the wider European area, as Figure 6 shows.

FIGURE 6: % OF FLIGHT VERSUS CO_2 EMISSIONS IN 2019



Departures: Scope for improvement

From leaving the gate to taxiing onto the runway, there are a series of measures that could be optimised to make every flight greener.

The first is with passengers. Non-transit passengers arriving late to the gate cause small delays that may add complexity to managing departures. Airlines that opt to speed up en-route flight to compensate for delays and missed slots increase fuel burn and thus emissions.

The second is shared by airlines and airports. Moving an aircraft using its own auxiliary power unit (APU) burns more fuel in most cases than using a mobile GPU (ground power unit) for that purpose. This is non-negligible: according to United Continental,[25] APUs use **150 to 400+ kg** of fuel per hour, while GPUs provided by the airport use less than **20 kg** of fuel per hour. It is estimated that **0.3%** fuel savings could be realised (Destination 2050). APUs also generate more noise, more pollution, and increase aircraft maintenance costs.

The third lies with air traffic control (ATC). Each minute taxiing with engine on burns 3 to 10kg of fuel,[26] so ATC should prioritise minimising ground delays for aircraft with engines already running and facilitate engine-off taxi solutions. Some ATC and airport processes significantly influence the performance of the aircraft from the very beginning of the flight. From best practices for stand allocation, the use of Fixed Electrical Ground Power and Pre-Conditioned Air, to the flexible use of taxiways to minimise taxi time, the use of A-CDM[27] to avoid long queues at the holding points, to the optimisation of runway throughput to avoid delays. When A-CDM was implemented at 17 airports in Europe, over 102,700 tonnes of CO_2 per annum was saved, on top of over 2.2 million minutes of taxiing time and €26.7 million in fuel.[28]

The fourth is using at airports semi or fully electrical aircraft towing systems. These can be hooked or mounted onto the front wheel of the aircraft and used to tow the aircraft between the gate and the runway. This brings immediate environmental benefits: **delaying engine start-up can reduce fuel consumption during taxiing by 50-85%.**[29] Where this is not possible for logistical reasons, where airports have limited manoeuvring areas or budgets, and only when safety permits, "reduced engine taxi" is the best option for reducing fuel burn and noise.

Finally, ATC may be able to grant access to use a runway that minimises flight time, where local current conditions permit, as well as optimising the taxi route from stand to runway.

Take-off: Optimising Continuous Climb Operations can make a significant contribution to emissions

The take-off phase offers a number of potential improvements that can be followed by air traffic controllers (ATCOs) and airlines, of which CCO – Continuous Climb Operations – brings the most important environmental benefit.

ATCOs should, as far as possible, clear flights to climb, avoid unnecessary level-offs and permit CCOs which are more fuel-efficient. A 2018 EUROCONTROL study showed that optimising the climb and descent (CCO and CDO) phases could deliver fuel savings of up to **350,000 tonnes** per year for airlines. This corresponds to over **a million tonnes of CO_2** and **€150 million in fuel costs**. Another EUROCONTROL study carried out during COVID-19 has shown that the average time in level during descent has been reduced by 33%, suggesting that a 30% CDO target could be reasonable once traffic returns to normal.[30]

Fuel saving measures implemented during the departure, take-off, landing and arrival phases also minimise aviation's impact on local air pollution resulting from the emission of several non-CO_2 species.

Rolling take-offs save fuel, so ATCOs should try to seamlessly deliver take-off clearances to avoid aircraft stopping on the runway. Using the shortest departure route (SID) also minimises track miles flown.

In this flight phase, it is necessary to find the right trade-off between **noise impact** and fuel/emissions savings. As long as noise limits are not exceeded, the crew should be able to choose the best Noise Abatement Departure Procedure (NADP) to fly according to the aircraft, weight and weather conditions of the day. NADP 2 will save fuel while not significantly increasing noise in some sensitive areas. NADP 1 reduces noise for areas close to the departure end of the runway by delaying the acceleration climb speed until 3,000 feet is reached. For example, Boeing claims[31] that the fuel saved by flying a NADP2 procedure vs a NADP1 procedure is 67 kg , about 1%, on a Boeing 737-800 with winglets, and 197 kg on a Boeing 777-200ER, about 0.3%.

Ideally, flights should take off in optimum configuration using minimum flaps to save fuel, while following a balanced approach to avoid increasing the level of noise over the sensitive areas that may surround an airport. Reduced flap take-off improves fuel consumption by reducing drag, for example saving between 10kg (737-800wl) and 70kg (747-400) on take-off according to Boeing.[32]

En-route: the flight phase with the greatest impact on fuel consumption/CO_2

Cruising is typically the longest flight phase and has the greatest impact on fuel consumption/CO_2. Here, there are **a number of measures that can be taken to make flights greener.**

It is a common misconception that aircraft could always fly the most direct route between two airports, minimising fuel consumption by following an optimised flight profile, with unrestricted climb, fuel-efficient airspeeds, optimum cruise levels, uninterrupted descent profiles, and so on. In reality, other factors intrude, such as economic considerations, weather and safety considerations (aircraft have to take off and land with a headwind, as well as en-route weather considerations). There may be a lack of airport infrastructure or airspace capacity constraints (whether on holiday or on business trips, everyone wants to leave at the same time). Airspace fragmentation reduces efficiency; not all aircraft have equally modern equipment; air traffic in en-route areas and especially in the terminal manoeuvring areas (TMAs) close to airports may be complex, and military zones may need to be avoided, increasing flight time and fuel consumption.

There is also the natural complexity of a European network that, pre-COVID, saw on average 25-35,000 flights every day, with the all-time record of 37,228 flights set on 3 July 2019 – creating bottlenecks that often require re-routings to ease capacity constraints.

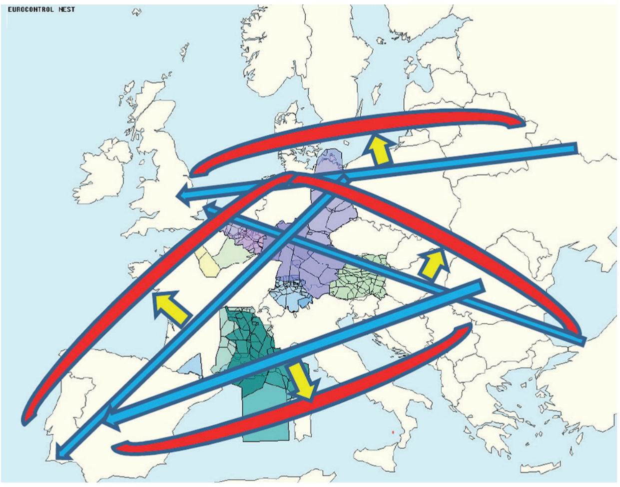
Nevertheless, there are a series of improvements that can be made. On-board systems like the Flight Management System (FMS) ensure that the crew can aim to **fly using the optimum values of speed and cruise level**. FMS's should be updated with the latest wind and atmospheric condition information, and the crew should fly at a speed corresponding to the best Specific Range (maximising the distance flown for a given amount of fuel), on minimal drag configuration whenever possible, and strive to maintain an optimum altitude.

In defining an optimal trajectory, ATC can help by offering a **better optimisation of the 4D trajectory** (horizontally and vertically) and **minimising the adoption of hard ATM constraints** such as permanent RAD restrictions[33] that affect the AOs. Where there is an unavoidable need to set such hard constraints, consideration should be taken to apply more flexible solutions such as dynamic RAD constraints that can be lifted depending on the traffic situation. Flying the 4D commercial trajectory selected also ensures optimal capacity management for the network as a whole. It is important to note that the greenest option is not always the most direct route: flights can be planned using wind-assisted routes, and a direct route would move the aircraft away from these benefits.

Key to efficient capacity management is **Free Route Airspace** (FRA), including cross-border FRA. Since its introduction in 2014, FRA is estimated to have saved airlines more than **2.6 million tonnes** of CO_2, around 0.5% of total aviation emissions.[34] FRA projects are now in place across 3/4 of European airspace, bringing the region's flight efficiency targets within grasp. EUROCONTROL estimates that accelerating the use of FRA, particularly in the core area of Europe, could lead to huge emissions savings, cutting fuel burned by **3,000 tonnes of fuel/day**, and reducing CO_2 by **10,000 tonnes/day**, resulting in more efficient routings of up to **500,000 nautical miles** and **€3 million** less in fuel costs.[35] FRA helps overcome efficiency, capacity and environmental challenges by helping reduce fuel consumption and emissions, while improving flight efficiency. At the same time, it paves the way for further enhanced airspace design and ATM operational concepts.

FIGURE 7: AO CONSIDERATIONS ON THE WARSAW (EPWA)-ROME (LIRF) ROUTE

FIGURE 8: eNM SHIFTING OF TRAFFIC FLOWS TO OFFLOAD CONGESTED ACCs



In many cases, ATC could also facilitate a "more" optimum trajectory by **allowing the available capabilities of the aircraft to play a role.** For example, only the aircraft's FMS will be aware of the optimum 'top of descent' point, which can be downloaded to ATC by datalink. This will avoid the need for inefficient early descents, and is currently being researched by SESAR.

A new and promising area of research into making flying greener is **contrail avoidance**. Depending on ambient atmospheric conditions, in particular under low temperatures and when the air is moist enough, flight contrails can evolve into contrail-cirrus clouds. **Recent scientific publications attribute more than 50% of aviation's contribution to global climate change to non-CO_2 emissions, with the biggest factor being contrail and contrail-induced cirrus clouds.**[36] It is foreseen that ATCOs could implement avoidance measures especially when the additional fuel burn and the corresponding CO_2 emissions remain within acceptable limits. Live trials are underway at EUROCONTROL MUAC to assess the reliability of detecting these areas.

However, there are also a number of factors that make it more difficult for aircraft to fly as 'greenly' as possible. Financial considerations can lead airlines to deviate from the shortest constrained route (SCR), as Figure 7 shows, when a less direct route (in red) is cheaper to fly due to cheaper airspace route charges. In the example, the SCR route (in green) would have shaved off 15 nautical miles and 115kg less fuel (3.6%) compared to the less direct route flown – but the flight planned, which was actually flown, cost €109 less.

Capacity and scalability issues across the network also pose problems for delivering greener flights. Pre-pandemic, capacity had become an increasing issue, leading the EUROCONTROL NM to ramp up cooperation with all partners to find solutions. Summer 2019 saw the eNM/S19 initiative (Enhanced NM/ANSP Network Measures for summer 2019), which deployed a number of capacity-enhancing measures, shifting traffic flows to offload congested ACCs as per Figure 8[37]. Reroutings or level caps to alleviate constrained area control centres, or tactical measures, such as to reduce the impact of unexpected bad weather, all reduced en-route delay by around 12% between 2018 and October 2019 across the European network, increasing predictability and punctuality. Without the eNM measures, en-route delay per flight in summer 2019 could have reached twice the level of 2018 – but at the same time, saw an additional tonnes 16,000 of CO_2 emissions[38], with an impact on fuel burn on the city pairs affected by the RAD measures since the start of the summer.

Here, the recast SES package, which includes the idea of mechanisms to modulate route charges at Union-wide level as a means of improving environmental performance, will clearly support improvements in environmental performance and incentivise greener flights.

Another constraint to flying 'greener' is that airlines may also choose to burn fuel faster by speeding up to make up for accumulated delays before take-off, unless they have a clearly defined policy.

New ideas could also help make flights greener. In Oceanic airspace, having two aircraft flying in formation envisaged in Airbus' innovative **Fello'Fly project** is a promising concept from Airbus that **could save between 5 to 10% of fuel for the rear flight of each pair of flights.**[39]

Terminal Manoeuvre Area (TMA) – a potential source of significant environmental improvements

The **TMA**, which is at the convergence of arrival and departure flows, **may be a source of significant flight inefficiencies,** particularly in dense and complex TMAs serving one or more large airports, where traffic flows have to be strategically separated to ensure the highest possible level of safety. This may also be the case for TMAs subject to many airspace and environmental constraints, typically when located within the "core" European airspace. A 2015 NATS study[40] showed that **80% of remaining inefficiencies are within 40 nm of airports.** A current EUROCONTROL study indicates that in the TMAs of Europe's 27 major airports, excess flight time exceeds **33 hours** in 2019, equivalent roughly to **100 tonnes** of fuel or **315 tonnes** of CO_2.[41]

Another source of inefficiency arises from the need to optimise ground infrastructure, in particular runways. For airports with high traffic demand, runway capacity may constitute the main bottleneck, and in some cases, operations have been developed over years to ensure maximum pressure is guaranteed, and avoid losing any slots (e.g. arrival aircraft holding).

In the 1990s the introduction of performance-based navigation (PBN) enabled more efficient design of the route structure in the TMA, facilitating shorter routes, segregation of flows, and avoiding densely populated areas. Arrival managers (AMAN and recently extended AMAN) help ATC to meter arrival traffic by speed adjustments in upstream sectors prior to entering the TMA, which significantly reduces extra transit time and holding. ATC should facilitate CDO thanks to S-shape vectoring with distance-to-go or point merge, to optimise vertical profiles and avoid long level-offs at low altitudes. As with the cruise segment, the crew needs to have the information available to update FMS calculations to have a better chance to land on the shortest arrival procedure (STAR); implement a CDO, with a potential 10% fuel saving and 40% noise reduction; and land on the optimal runway with minimum flap configuration,[42] if landing distance permits. Reverse thrust should be limited to safety cases.

New initiatives continue to improve the situation. "Dynamic TMA" enables an agile adaptation to variation in traffic demand by activating the appropriate set of route structure designed for a given level of traffic. The systematic use of target time at metering points and on arrival also reduces extra time in the TMA, involving the flight crew more actively. Other possible trade-offs between maximising runway pressure and minimising flight inefficiency can also be explored.

Landing – room for more efficiency

More efficient taxi-in during ground operations means, as for departures, minimising the use of engine thrust and brakes, choosing the shortest route, using reduced engine taxi techniques such as using a single engine on arrival, delaying the start of the APU, and shutting it off as soon as possible. Stand allocation, Arrival Manager, A-CDM and green airport processes can also reduce emissions in this final flight phase.

Conclusion

Raising awareness on sustainability is essential at all levels and involves all actors combining forces. At EUROCONTROL, we actively promote sustainability solutions, helping actors reduce noise, CO_2 and non-CO_2 emissions, with particular focus on accelerating the implementation of innovative solutions through the SESAR programme, and supported by our operational services. Through our unique applications/models (IMPACT, Open-ALAQS, R-NEST), we assess the impact of aviation on the environment at all levels; we train aviation actors on environmental concerns, operations, and assessments; and we raise awareness via Think Papers and Aviation Sustainability Briefings.

In this Think Paper, we identify solutions that exist and can be optimised immediately to accelerate aviation's journey towards carbon neutrality at every stage of a journey. All can contribute, and all require continued cooperation between the various aviation actors – which include passengers and policy-makers as well as airports, airlines, aircraft, manufacturers and ANSPs. Every flight can aim to be as green as possible, and every flight can become greener by following the various measures detailed in this Paper.

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Main findings

1. Making better use of existing measures can take a significant advance towards the "perfect green flight", which could save up to 4,286kg of CO_2 emissions (25.8%) per flight out of an average 16,632kg of CO_2 for a total flight in the wider European area (ECAC). This is based on existing aircraft technology, and would significantly increase with the uptake of emerging technological solutions.

2. Better use of fuel-efficient air traffic management improvements through increased collaboration between all actors, and speedier implementation of SESAR solutions, could deliver 8.6%-11.2% (or 1,863 kg) of those reduced CO_2 emissions per flight. A more effectively functioning European network, as the recast SES legislation intends, should trigger airspace optimisation and boost the uptake of much required ATM solutions.

3. Emerging aircraft technologies in the form of hybrid, fully-electric and hydrogen airplanes will transform aviation over the period 2030-2050, enabling aviation to meet its climate-neutrality goal by 2050. By 2050, these new airplanes will be increasingly prevalent on short to medium haul sectors; while SAF use will predominate in the long-haul sector, with further upscaling of SAF production seeing 83% of fuel used being SAF, irrespective of any further technological developments.

4. Sustainable aviation fuel (SAF) is the most promising measure towards aviation decarbonisation right now. 10% use of SAF by 2030 would deliver 1,331 kg or 8% of that CO_2 saving. 20% SAF would deliver itself a huge 16% or 2,661kg – but major challenges need to be tackled to ramp up use from today's 0.1%.

5. Airlines can play a significant role in reducing CO_2 emissions by modernising their fleets, reducing 'economic fuel tankering', working with airports to use Ground Power Units rather than aircraft Auxiliary Power Units, and optimising the fuel efficiency of their existing fleets; here, greater incentives may be needed to balance economic considerations in some cases.

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