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Environmental impact of aviation


A C-141 Starlifter leaves contrails over Antarctica.

The **environmental impact of aviation** occurs because aircraft engines emit heat, noise, particulates and gases which contribute to climate change[1][2] and global dimming.[3] Airplanes emit particles and gases such as carbon dioxide (CO_2), water vapor, hydrocarbons, carbon monoxide, nitrogen oxides, sulfur oxides, lead, and black carbon which interact among themselves and with the atmosphere.[4]

Despite more fuel-efficient and less polluting turbofan and turboprop engines, the rapid growth of air travel contributes to an increase in total pollution attributable to aviation. From 1992 to 2005, passenger kilometers increased 5.2 percent per year. In the European Union, greenhouse gas emissions from aviation increased by 87 percent between 1990 and 2006.[5]

Comprehensive research shows that despite anticipated efficiency innovations to airframes, engines, aerodynamics and flight operations, there is no end in sight, even many decades out, to rapid growth in CO_2 emissions from air travel and air freight,[6][7] due to projected continual growth in air travel.[8][9] This is because international aviation emissions escaped international regulation until the ICAO triennial conference in 2016 agreed on the CORSIA offset scheme.[10] In addition, due to low or non-existent taxes on aviation fuel, air travel enjoys a competitive advantage over other transportation modes due to lower fares.[11][12] Unless market constraints are put in place, growth in aviation emissions will result in the sector's emissions amounting to all or nearly all of the annual global CO_2 emissions budget by mid-century, if climate change is to be held to a temperature increase of 2 °C or less.[13]

There is an ongoing debate about possible taxation of air travel and the inclusion of aviation in an emissions trading scheme, with a view to ensuring that the total external costs of aviation are taken into account.[14]

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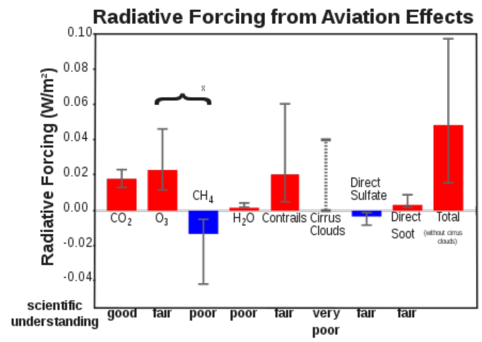
Climate change



Radiative forcings from aviation emissions (gases and aerosols) in 1992 as estimated by the IPCC

Like the majority of human activities involving combustion, most forms of aviation release carbon dioxide (CO_2) and other greenhouse gases into the Earth's atmosphere, contributing to the acceleration of global warming[15] and (in the case of CO_2) ocean acidification.[16] These concerns are highlighted by the present volume of commercial aviation and its rate of growth. Globally, about 8.3 million people flew daily in 2014 (three billion occupied seats per year), twice the total of 1999.[17] In 2018, global commercial operations emitted 918 million tonnes (Mt) of CO2, 2.4% of all CO2 emissions: 747 Mt for passenger transport and 171 Mt for freight operations.[18]

In addition to the CO_2 released by most aircraft in flight through the burning of fuels such as Jet-A (turbine aircraft) or Avgas (piston aircraft), the aviation industry contributes greenhouse gas emissions from ground airport vehicles and those used by passengers and staff to access airports, as well as through emissions generated by the production of energy used in airport buildings, the manufacture of aircraft and the construction of airport infrastructure.[19]

While the principal greenhouse gas emission from powered aircraft in flight is CO_2, other emissions may include nitric oxide and nitrogen dioxide (together termed oxides of nitrogen or NO_x), water vapour and particulates (soot and sulfate particles), sulfur oxides, carbon monoxide (which bonds with oxygen to become CO_2 immediately upon release), incompletely burned hydrocarbons, tetraethyllead (piston aircraft only), and radicals such as hydroxyl, depending on the type of aircraft in use.[20] Emissions weighting factor (EWFs) i.e., the factor by which aviation CO_2 emissions should be multiplied to get the CO_2-equivalent emissions for annual fleet average conditions is in the range 1.3–2.9.[21]

Mechanisms and cumulative effects of aviation on climate

In 1999 the contribution of civil aircraft-in-flight to global CO_2 emissions was estimated to be around two percent.[20] However, in the cases of high-altitude airliners which frequently fly near or in the stratosphere, non-CO_2 altitude-sensitive effects may increase the total impact on anthropogenic (human-made) climate change significantly.[20] A 2007 report from Environmental Change Institute / Oxford University posits a range closer to four percent cumulative effect.[22] Subsonic aircraft-in-flight contribute to climate change[20] in four ways:

Carbon dioxide (CO_2)

CO_2 emissions from aircraft-in-flight are the most significant and best understood[23] element of aviation's total contribution to climate change. The level and effects of CO_2 emissions are broadly the same regardless of altitude (i.e., they have the same atmospheric effects as ground-based emissions). In 1992, emissions of CO_2 from aircraft were estimated at around two percent of all such anthropogenic emissions, and that year the atmospheric concentration of CO_2 attributable to aviation was around one percent of the total anthropogenic increase since the industrial revolution, having accumulated largely over just the last 50 years.[24] Figures from British Airways suggest carbon dioxide emissions of 100 gram per passenger kilometre for large jet airliners (a figure which does not account for the production of other pollutants or condensation trails).[25]

Oxides of nitrogen (NO_x)

At the high altitudes flown by large jet airliners around the tropopause, emissions of NO_x are particularly effective in forming ozone (O_3) in the upper troposphere. High altitude (8–13 km) NO_x emissions result in greater concentrations of O_3 than surface NO_x emissions, and these in turn have a greater global warming effect. The effect of O_3 surface concentrations are regional and local, but it becomes well mixed globally at mid and upper tropospheric levels.[26]

NO_x emissions also reduce ambient levels of methane, another greenhouse gas, resulting in a climate cooling effect. But this effect does not offset the O_3 forming effect of NO_x emissions. It is now believed that aircraft sulfur and water emissions in the stratosphere tend to deplete O_3, partially offsetting the NO_x-induced O_3 increases. These effects have not been quantified.[24] This problem does not apply to aircraft that fly lower in the troposphere, such as light aircraft or many commuter aircraft.

Water vapor (H_2O), and contrails

One of the products of burning hydrocarbons with oxygen is water vapour, a greenhouse gas. Water vapour produced by aircraft engines at high altitude, under certain atmospheric conditions, condenses into droplets to form condensation trails, or "contrails". Contrails are visible line clouds that form in cold, humid atmospheres and are thought to have a global warming effect (though one less significant than either CO_2 emissions or NO_x induced effects).[27] Contrails are uncommon (though by no means rare) from lower-altitude aircraft, or from propeller-driven aircraft or rotorcraft.

Cirrus clouds have been observed to develop after the persistent formation of contrails and have been found to have a global warming effect over-and-above that of contrail formation alone.[28] There is a degree of scientific uncertainty about the contribution of contrail and cirrus cloud formation to global warming, and attempts to estimate aviation's overall climate change contribution do not tend to include its effects on cirrus cloud enhancement.[23] However, a 2015 study found that artificial cloudiness caused by contrail "outbreaks" reduces the difference between daytime and nighttime temperatures. The former are decreased and the latter are increased, in comparison to temperatures the day before and the day after such outbreaks.[29] On days with outbreaks the day versus night temperature difference was diminished by about 3.3 °C (6 °F) in the southern US and 2.8 °C (5 °F) in the US midwest.[30]

Contrails

Particulates

Least significant on a mass basis is the release of soot and sulfate particles. Soot absorbs heat and has a warming effect; sulfate particles reflect radiation and have a small cooling effect. In addition, particles can influence the formation and properties of clouds,[31] including both line-shaped contrails and naturally-occurring cirrus clouds. The impact of "spreading contrails and cirrus clouds that evolve from them—collectively known as contrail cirrus—have a greater radiative forcing (RF) today than all aviation CO_2 emissions since the first powered airplane flight".[32] Of the particles emitted by aircraft engines, the soot particles are thought to be most important for contrail formation since they are large enough to serve as condensation nuclei for water vapor. All aircraft powered by combustion will release some amount of soot; although, recent studies suggest that reducing the aromatic content of jet fuel decreases the amount of soot produced.[33][34][35]

Cirrus cloud formation

CO_2 emissions per passenger kilometre

In 2018, CO_2 emissions totalled 747 million tonnes for passenger transport, for 8.5 trillion revenue passenger kilometres (RPK), giving an average of 88 gram CO_2 per RPK.[18]

Emissions per passenger kilometre vary according to the size and type of aircraft, the altitude, the freight and passenger occupancy rate, the distance flown and the route stops, while the radiative forcing is greater at higher altitudes (see below).

Europe

In Europe, the average airline fuel consumption per passenger in 2017 was 3.4 L/100 km (69 mpg_{-US}), 24% less than in 2005, but as the traffic grew by 60% to 1,643 billion passenger kilometres, CO_2 emissions were up by 16% to 163 million tonnes for 99.8 g/km CO_2 per passenger.[36]

USA

In 2018, the US airlines had a fuel consumption of 58 mpg_{-US} (4.06 L/100 km) per revenue passenger for domestic flights,[37] or 32.5 g of fuel per km, generating 102 g CO_2 / RPK of emissions.

International

In 2010 about 60 percent of aviation emissions were from international flights.[38] These flights are not covered by the Paris Agreement and its emissions reduction targets: however the International Civil Aviation Organization has set airlines' carbon emissions in 2020 as the upper limit of what carriers are allowed to discharge.[39]

Emissions by passenger class, and effects of seating configuration

In 2013 the World Bank published a study of the effect on CO_2 emissions of its staff's travel in business class or first class, versus using economy class.[40] Among the factors considered was that these premium classes displace proportionately more economy seats for the same total aircraft space capacity, and the associated differing load factors and weight factors. This was not accounted for in prior standard carbon accounting methods. (In addition, premium class travellers have larger baggage allowances, so their luggage takes up more space as well.) The study concluded that when considering respective average load factors (percentage of occupied seats) in each of the seating classes, the carbon footprints of business class and first class are three times and nine times higher than economy class.[40][41][42] A related article by the International Council on Clean Transport notes further regarding the effect of seating configurations on carbon emissions that:[42]

> The A380 is marketed as a "green giant" and one of the most environmentally advanced aircraft out there. But that spin is based on a maximum-capacity aircraft configuration, or about 850 economy passengers. In reality, a typical A380 aircraft has 525 seats. Its fuel performance is comparable to that of a B747-400 ER and even about 15 percent worse than a B777-300ER on a passenger-mile basis (calculated using Piano-5 on a flight from AUH to LHR, assuming an 80 percent passenger load factor, and in-service fleet average seat counts).

Total climate effects

In an attempt to aggregate and quantify the total climate impact of aircraft emissions, the Intergovernmental Panel on Climate Change (IPCC) estimated that aviation's total climate impact is some two to four times that of its direct CO_2 emissions alone (excluding the potential impact of cirrus cloud enhancement).[20] This is measured as radiative forcing. While there is uncertainty about the exact level of impact of NO_x and water vapour, governments have accepted the broad scientific view that they do have an effect. Globally in 2005, aviation contributed "possibly as much as 4.9 percent of radiative forcing."[38] UK government policy statements have stressed the need for aviation to address its total climate change impacts and not simply the impact of CO_2.[43]

The IPCC has estimated that aviation is responsible for around 3.5 percent of anthropogenic climate change, a figure which includes both CO_2 and non-CO_2 induced effects. The IPCC has produced scenarios estimating what this figure could be in 2050. The central case estimate is that aviation's contribution could grow to five percent of the total contribution by 2050 if action is not taken to tackle these emissions, though the highest scenario is 15 percent.[20] Moreover, if other industries achieve significant cuts in their own greenhouse gas emissions, aviation's share as a proportion of the remaining emissions could also rise.

Future emission levels

Even though there have been significant improvements in fuel efficiency through aircraft technology and operational management as described here, these improvements are being continually eclipsed by the increase in air traffic volume.

A December 2015 report finds that aircraft could generate 43 Gt of carbon pollution through to 2050, consuming almost 5 percent of the remaining global climate budget. Without regulation, global aviation emissions may triple by mid-century and could emit more than 3 Gt of carbon annually under a high-growth, business-as-usual scenario. By 2020, global international aviation emissions are projected to be around 70% higher than in 2005.[44] Efforts to bring aviation emissions under an effective global accord have so far largely failed, despite there being a number of technological and operational improvements on offer.[45][46]

Continual increases in travel and freight

From 1992 to 2005, passenger kilometers increased 5.2 percent per year:

> During the first three quarters of 2010, air travel markets expanded at an annualized rate approaching 10%. This is similar to the rate seen in the rapid expansion prior to the recession. November's results mean the annualized rate of growth so far in Q4 drops back to around 6 percent. But this is still in line with long run rates of traffic growth seen historically. The level of international air travel is now 4 percent above the pre-recession peak of early 2008 and the current expansion looks to have further to run.[47]

> Air freight reached a new high point in May (2010) but, following the end of inventory restocking activity, volumes have slipped back to settle at a similar level seen just before the onset of recession. Even so, that means an expansion of air freight during 2010 of 5–6 percent on an annualized basis – close to historical trend. With the stimulus of inventory restocking activity removed, further growth in air freight demand will be driven by end consumer demand for goods which utilize the air transport supply chain .... The end of the inventory cycle does not mean the end of volume expansion but markets are entering a slower growth phase.[47]

In a 2008 presentation[15] and paper [48] Professor Kevin Anderson of the Tyndall Centre for Climate Change Research showed how continued aviation growth in the UK threatens the ability of that nation to meet CO_2 emission reduction goals necessary to contain the century-end temperature increase to even 4° or 6 °C. (See also: the 4 Degrees and Beyond International Climate Conference (2009)[49] and its proceedings.)[50] His charts show the projected domestic aviation carbon emission increase for the UK as growing from 11 MT in 2006 to 17 MT in 2012, at the UK's historic annual emission growth rate of seven percent. Beyond 2012 if the growth rate were reduced to three percent yearly, carbon emissions in 2030 would be 28 MT, which is 70 percent of the UK's entire carbon emissions budget that year for all sectors of society. This work also suggests the foreseeable future which confronts many other nations that have high dependency on aviation. "Hypermobile Travelers",[51] an academic study by Stefan Gössling, et al., (2009) in the book *Climate Change and Aviation*,[52] also points to the dilemma caused by the increasing hypermobility of air travelers both in particular nations and globally.[53]

Scope for improvement

Aircraft efficiency

While late model jet aircraft are significantly more fuel efficient (and thus emit less CO_2 in particular) than the earliest jet airliners,[54][55] new airliner models in the 2000s were barely more efficient on a seat-mile basis than the latest piston-powered airliners of the late-1950s (e.g., Constellation L-1649-A and DC-7C).[55] Claims for a high gain in efficiency for airliners over recent decades (while true in part) has been biased high in most studies, by using the early inefficient models of jet airliners as a baseline. Those aircraft were optimized for increased revenue, including increased speed and cruising altitude, and were quite fuel inefficient in comparison to their piston-powered forerunners.[55]

Today, turboprop aircraft – probably in part because of their lower cruising speeds and altitudes (similar to the earlier piston-powered airliners) compared to jet airliners – play an obvious role in the overall fuel efficiency of major airlines that have regional carrier subsidiaries.[56] For example, although Alaska Airlines scored at the top of a 2011–2012 fuel efficiency ranking, if its large regional carrier – turbo-prop equipped Horizon Air – were dropped from the lumped-in consideration, the airline's ranking would be somewhat lower, as noted in the ranking study.

Aircraft manufacturers are striving for reductions in both CO_2 and NOx emissions with each new generation of design of aircraft and engine.[57] While the introduction of more modern aircraft represents an opportunity to reduce emissions per passenger kilometre flown, aircraft are major investments that endure for many decades, and replacement of the international fleet is therefore a long-term proposition which will greatly delay realizing the climate benefits of many kinds of improvements. Engines can be changed at some point, but nevertheless airframes have a long life. Moreover, rather than being linear from one year to the next the improvements to efficiency tend to diminish over time, as reflected in the histories of both piston and jet powered aircraft.[55]

A 2014 life-cycle assessment of the cradle-to-grave reduction in CO_2 by a carbon-fiber-reinforced polymer (CFRP) airliner such as a Boeing 787—including its manufacture, operations and eventual disposal—has shown that by 2050 such aircraft could reduce the airline industry's CO_2 emissions by 14–15 percent, compared use of conventional airliners.[58] The benefit of CFRP technology is not higher than that amount of reduction, despite the lighter weight and substantially lower fuel consumption of such aircraft, "because of the limited fleet penetration by 2050 and the increased demand for air travel due to lower operating costs" (rebound effect).[58]

Operations efficiency

Research projects such as Boeing's ecoDemonstrator program have sought to identify ways of improving the efficiency of commercial aircraft operations. The U.S. government has encouraged such research through grant programs, including the FAA's Continuous Lower Energy, Emissions and Noise (CLEEN) program, and NASA's Environmentally Responsible Aviation (ERA) Project.

Adding an electric drive to the airplane's nose wheel may improve fuel efficiency during ground handling. This addition would allow taxiing without the use of the main engines.[59][60][61]

Another proposed change is the integrating of an Electromagnetic Aircraft Launch System to the airstrips of airports. Some companies such as Airbus are currently researching this possibility. The adding of EMALS would allow the civilian aircraft to use considerably less fuel (as a lot of fuel is used during take off, in comparison to cruising, when calculated per km flown). The idea is to have the aircraft take off at regular aircraft speed, and only use the catapult for take-off, not for landing.[62][63]

Other opportunities arise from the optimization of airline timetables, route networks and flight frequencies to increase load factors (minimize the number of empty seats flown),[64] together with the optimization of airspace. However, these are each one-time gains, and as these opportunities are successively fulfilled, diminishing returns can be expected from the remaining opportunities.

Another possible reduction of the climate-change impact is the limitation of cruise altitude of aircraft. This would lead to a significant reduction in high-altitude contrails for a marginal trade-off of increased flight time and an estimated 4 percent increase in CO_2 emissions. Drawbacks of this solution include very limited airspace capacity to do this, especially in Europe and North America and increased fuel burn because jet aircraft are less efficient at lower cruise altitudes.[65] The warming effect of contrails can also be reduced by 3/5 by going below or above wide and flat areas of cold, humid weather that cause the cloud cover to form.[66][67][68]

While they are not suitable for long-haul or transoceanic flights, turboprop aircraft used for commuter flights bring two significant benefits: they often burn considerably less fuel per passenger mile, and they typically fly at lower altitudes, well inside the tropopause, where there are no concerns about ozone or contrail production.

Alternative fuels

Some scientists and companies such as GE Aviation and Virgin Fuels are researching biofuel technology for use in jet aircraft.[69] Some aircraft engines, like the Wilksch WAM120 can (being a 2-stroke Diesel engine) run on straight vegetable oil. Also, a number of Lycoming engines run well on ethanol.

In addition, there are also several tests done combining regular petrofuels with a biofuel. For example, as part of this test Virgin Atlantic Airways flew a Boeing 747 from London Heathrow Airport to Amsterdam Schiphol Airport on 24 February 2008, with one engine burning a combination of coconut oil and babassu oil.[69] Greenpeace's chief scientist Doug Parr said that the flight was "high-altitude greenwash" and that producing organic oils to make biofuel could lead to deforestation and a large increase in greenhouse gas emissions.[69] Also, the majority of the world's aircraft are not large jetliners but smaller piston aircraft, and with major modifications many are capable of using ethanol as a fuel.[70] Another consideration is the vast amount of land that would be necessary to provide the biomass feedstock needed to support the needs of aviation, both civil and military.[71]

In December 2008, an Air New Zealand jet completed the world's first commercial aviation test flight partially using jatropha-based fuel. Jatropha, used for biodiesel, can thrive on marginal agricultural land where many trees and crops won't grow, or would produce only slow growth yields.[72][73] Air New Zealand set several general sustainability criteria for its Jatropha, saying that such biofuels must not compete with food resources, that they must be as good as traditional jet fuels, and that they should be cost competitive with existing fuels.[74]

In January 2009, Continental Airlines used a sustainable biofuel to power a commercial aircraft for the first time in North America. This marks the first sustainable biofuel demonstration flight by a commercial carrier using a twin-engined aircraft, a Boeing 737-800, powered by CFM International CFM56-7B engines. The biofuel blend included components derived from algae and jatropha plants.[75]

One fuel biofuel alternative to avgas that is under development is Swift Fuel. Swift fuel was approved as a test fuel by ASTM International in December 2009, allowing the company to continue their research and to pursue certification testing. Mary Rusek, president and co-owner of Swift Enterprises predicted at that time that "100SF will be comparably priced, environmentally friendlier and more fuel-efficient than other general aviation fuels on the market".[76][77]

As of June 2011, revised international aviation fuel standards officially allow commercial airlines to blend conventional jet fuel with up to 50 percent biofuels. The renewable fuels "can be blended with conventional commercial and military jet fuel through requirements in the newly issued edition of ASTM D7566, Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons".[78]

In December 2011, the FAA announced it is awarding US$7.7 million to eight companies to advance the development of drop-in commercial aviation biofuels, with a special focus on ATJ (alcohol to jet) fuel. As part of its CAAFI (Commercial Aviation Alternative Fuel Initiative) and CLEEN (Continuous Lower Emissions, Energy and Noise) programs, the FAA plans to assist in the development of a sustainable fuel (from alcohols, sugars, biomass, and organic matter such as pyrolysis oils) that can be "dropped in" to aircraft without changing current infrastructure. The grant will also be used to research how the fuels affect engine durability and quality control standards.[79]

By 2020, IAG had invested $400 million to convert waste into sustainable aviation fuel with Velocys.[80]

Finally, liquified natural gas is another fuel that is used in some airplanes. Besides the lower GHG emissions (depending on where the natural gas is obtained), another major benefit to airplane operators is the price, which is far lower than the price for jet fuel.

Electric aircraft

In UK, transport replaced power as the largest emissions source, including aviation for 4%, expanding until 2050, and passenger demand may have to be reduced. For the Committee on Climate Change (CCC) of the UK government, the UK target of an 80% reduction from 1990 to 2050 is still achievable but the Paris Agreement should tighten emissions targets. Their position is that emissions in problematic sectors, like aviation, should be offset by greenhouse gas removal, carbon capture and storage, and reforestation.[81]

For the CCC, huge technology shifts are uncertain, but consultant Roland Berger points to 80 new electric aircraft programmes in the last two years, all-electric for the smaller two-thirds and hybrid for larger aircraft, with forecast commercial service dates in the early 2030s on short-haul routes like London to Paris, with all-electric aircraft not expected before 2045. Berger predicts a 24% CO_2 share for aviation by 2050 if fuel efficiency improves by 1% per year and if there are no electric or hybrid aircraft, dropping to 3–6% if 10-year-old aircraft are replaced by electric or hybrid aircraft due to regulatory constraints, starting in 2030, to reach 70% of the 2050 fleet. This would greatly reduce the value of the existing fleet of aircraft, however.[81]

Limits to the supply of battery cells could hamper their aviation adoption, as they compete with other industries like electric vehicles. Lithium-ion batteries have proven fragile and fire-prone, and their capacity deteriorates with age. However, alternatives are being pursued, such as sodium-ion batteries.[81]

Offsetting

On 1 October 2019, Air France announced it will offset CO_2 emissions on its 450 daily domestic flights for 57,000 passengers from 1 January 2020, through certified projects. The company will also offer its customers to voluntary compensate all their flights and aims to reduce its emissions by 50% per pax/km in 2030 compared to 2005.[82]

Starting in November 2019, UK budget carrier EasyJet decided to offset carbon emissions for all its flights, through investments in atmospheric carbon reduction projects. It claims to be the first major operator to be carbon neutral, at a cost of £25 million for its 2019-20 financial year. Its CO_2 emissions were 77g per passenger in its 2018-19 financial year, down from 78.4g the previous year.[83]

From 1 January 2020, British Airways began offsetting its 75 daily domestic flights emissions through carbon-reduction projects investments. The airline seeks to become carbon neutral by 2050 with fuel-efficient aircraft, sustainable fuels, and operations changes. Passengers flying overseas can offset their flights for £1 to Madrid in economy or £15 to New York in business-class.[80]

US low-cost carrier JetBlue plans to use offsets for its emissions from domestic flights starting in July 2020, the first major US airline to do so. It also plans to use sustainable aviation fuel made from waste by Finnish refiner Neste starting in mid-2020.[84]

Reducing air travel

Personal choices and social pressure

The German video short *The Bill*[85] explores how travel and its impacts are commonly viewed in everyday developed-world life, and the social pressures that are at play. British writer George Marshall has investigated common rationalizations that act as barriers to making personal choices to travel less, or to justify recent trips. In an informal research project, "one you are welcome to join", he says, he deliberately steered conversations with people who are attuned to climate change problems to questions about recent long-distance flights and why the travel was justified. Reflecting on actions contrary to their beliefs, he noted, "(i)ntriguing as their dissonance may be, what is especially revealing is that every one of these people has a career that is predicated on the assumption that information is sufficient to generate change – an assumption that a moment's introspection would show them was deeply flawed."[86]

In Sweden the concept of "flight shame" or "flygskam" has been cited as a cause of falling air travel.[87] Swedish rail company SJ AB reports that twice as many Swedish people chose to travel by train instead of by air in summer 2019 compared with the previous year.[88] Swedish airports operator Swedavia reported 4% fewer passengers across its 10 airports in 2019 compared to the previous year: a 9% drop for domestic passengers and 2% for international passengers;[89]

Reduction of one's carbon footprint for various actions.

Business and professional choices

> With most international conferences having hundreds if not thousands of participants, and the bulk of these usually traveling by plane, conference travel is an area where significant reductions in air-travel-related GHG emissions could be made....This does not mean non-attendance.[90]

For example, by 2003 Access Grid technology has already been successfully used to host several international conferences,[90] and technology has likely progressed substantially since then. The Tyndall Centre for Climate Change Research has been systematically studying means to change common institutional and professional practices that have led to large carbon footprints of travel by research scientists, and issued a report.[91][92][93]

Ending incentives to fly—frequent flyer programs

Over 130 airlines have "frequent flyer programs" based at least in part on miles, kilometers, points or segments for flights taken. Globally, such programs included about 163 million people as reported in 2006.[94] These programs benefit airlines by habituating people to air travel and, through the mechanics of partnerships with credit card companies and other businesses, in which high profit margin revenue streams can amount to selling free seats for a high price.[94] The only part of United Airlines business that was making money when the company filed for bankruptcy in 2002 was its frequent flyer program.[94]

Concerning business travel, "The ease of international air travel and the fact that, for most of us, the costs are met by our employers, means that ... globe trotting conference travel is often regarded as a perk of the job."[90] However, the perk usually is not only the business trip itself, but also the frequent flyer points which the individual accrues by taking the trip, and which can be redeemed later for personal air travel. Thus a conflict of interest is established, whereby bottom-up pressure may be created within a firm or government agency for travel that is really not necessary. Even when such conflict is not a motivation, the perk of frequent flyer miles can be expected to lead in many cases to personal trips that would not be taken if a ticket had to be paid for with personal funds.[95]

By just using an airline-sponsored credit card to pay one's household expenses, personal or business bills, or even expense bills charged to an employer, frequent flyer points can be racked up quickly.[94] Thus, free travel—for which the individual has to pay nothing extra—becomes a reality. Across society, this too can be expected to lead to much air travel—and greenhouse gas emissions—that otherwise would not occur.[96]

Several studies have contemplated the elimination of frequent flyer programmes (FFPs), on the grounds of anti-competitiveness,[97] ethics,[98] conflict with society's overall well-being,[99] or climate effects.[100] There is a record of governments disallowing or banning FFPs and of industry players requesting bans. Denmark did not allow the programs until 1992, then changed its policy because its airlines were disadvantaged.[97] In 2002, Norway banned domestic FFPs in order to promote competition among its airlines.[101] In the U.S. in 1989, a vice president of Braniff "said the government should consider ordering an end to frequent-flyer programs, which he said allow unfair competition."[102]

A Canadian study said that because of competition no airline could unilaterally end its FFP, but that a national government could use its regulatory power to end the programs broadly, which in Canada's case would also require North America-wide cooperation.[99] In further analysis, a Scandinavian study which recommended an end to frequent flyer plans said, "the only possible way of prohibiting FFPs successfully now that they have spread from the US to Europe to the Far East would be to do so on a global basis. The basis exists: it could be done by the World Trade Organization."[97] A 2011 study which surveyed frequent flyers in the U.K. and Norway, looked into behavioral addition to frequent flying and the "flyer's dilemma" of the conflict between "the social and personal benefits of flying and air travel's impact on climate change."[100] It concluded that:

> Continued growth in both frequent flying practices and concern over air travel's climate impacts are in a dynamic relationship and the question of whether one or the other will reach a tipping point cannot yet be determined. Self-regulation, external regulation, social norms, technology and physical resources will continue to co-constitute the balance. An increasing stigmatisation of 'excessive' air travel may (re)frame flying as more open to collective external mitigation.[100]

Potential for governmental constraints on demand

One means for reducing the environmental impact of aviation is to constrain demand for air travel, through increased fares in place of expanded airport capacity. Several studies have explored this:

- The UK study *Predict and Decide – Aviation, climate change and UK policy*, notes that a 10

percent increase in fares generates a 5–15 percent reduction in demand, and recommends that the British government should manage demand rather than provide for it.[103] This would be accomplished via a strategy that presumes "… against the expansion of UK airport capacity" and constrains demand by the use of economic instruments to price air travel less attractively.[104]
- A study published by the campaign group Aviation Environment Federation (AEF) concludes that by levying £9 billion of additional taxes, the annual rate of growth in demand in the UK for air travel would be reduced to two percent.[105]
- The ninth report of the House of Commons Environmental Audit Select Committee, published in July 2006, recommends that the British government rethink its airport expansion policy and considers ways, particularly via increased taxation, in which future demand can be managed in line with industry performance in achieving fuel efficiencies, so that emissions are not allowed to increase in absolute terms.[106]

International regulation of air travel GHG emissions

Kyoto Protocol 2005

Greenhouse gas emissions from fuel consumption in international aviation, in contrast to those from domestic aviation and from energy use by airports, are excluded from the scope of the first period (2008–2012) of the Kyoto Protocol, as are the non-CO_2 climate effects. Instead, governments agreed to work through the International Civil Aviation Organization (ICAO) to limit or reduce emissions and to find a solution to the allocation of emissions from international aviation in time for the second period of the Kyoto Protocol starting from 2009; however, the Copenhagen climate conference failed to reach an agreement.[107]

Recent research points to this failure as a substantial obstacle to global policy including a CO_2 emissions reduction pathway that would avoid dangerous climate change by keeping the increase in the average global temperature below a 2 °C rise.[108][109][110]

Approaches toward emissions trading

As part of that process the ICAO has endorsed the adoption of an open emissions trading system to meet CO_2 emissions reduction objectives. Guidelines for the adoption and implementation of a global scheme are currently being developed, and were to be presented to the ICAO Assembly in 2007,[111] although the prospects of a comprehensive inter-governmental agreement on the adoption of such a scheme are uncertain.

Within the European Union, however, the European Commission has resolved to incorporate aviation in the European Union Emissions Trading Scheme (ETS).[112] A new directive was adopted by the European Parliament in July 2008 and approved by the Council in October 2008. It became effective on 1 January 2012.[113]

Researchers at the Overseas Development Institute investigated the possible effects on Small Island Developing States (SIDS) of the European Union's decision to limit the supply of Certified Emission Reductions (CERs) to its ETS market to Least Developed Countries (LDCs) from 2013.[114] Most SIDS are highly vulnerable to the effects of climate change and rely heavily on tourism as a basis for their economies, so this decision could place them at some disadvantage. The researchers therefore highlight the need to ensure that any regulatory frameworks put in place to tackle climate change take into account the development needs of the most vulnerable countries affected.

A report published by researchers at the Centre for Aviation, Transport and Environment at Manchester Metropolitan University found that the only way to have a significant impact on emissions was to put a price on carbon and to use a market-based measure (MBM), such as the EU Emissions Trading Scheme (ETS).[115]

International Civil Aviation Organization agreement 2016

In October 2016 the UN agency International Civil Aviation Organization (ICAO) finalized an agreement among its 191 member nations to address the more than 458 Mt (2010)[116] of carbon dioxide emitted annually by international passenger and cargo flights. The agreement will use an offsetting scheme called CORSIA (the Carbon Offsetting and Reduction Scheme for International Aviation) under which forestry and other carbon-reducing activities are directly funded, amounting to about two percent of annual revenues for the sector. Rules against "double counting" should ensure that existing forest protection efforts are not recycled. The scheme does not take effect until 2021 and will be voluntary until 2027, but many countries, including the US and China, have promised to begin at its 2020 inception date. Under the agreement, the global aviation emissions target is a 50 percent reduction by 2050 relative to 2005.[117] NGO reaction to the deal was mixed.[118]

The agreement has critics. It is not aligned with the 2015 Paris climate agreement, which set the objective of restricting global warming to 1.5 to 2 °C. A late draft of the agreement would have required the air transport industry to assess its share of global carbon budgeting to meet that objective, but the text was removed in the agreed version.[119][120] CORSIA will regulate only about 25 percent of aviation's international emissions, since it grandfather's all emissions below the 2020 level, allowing unregulated growth until then.[121] Only 65 nations will participate in the initial voluntary period, not including significant emitters Russia, India and perhaps Brazil. The agreement does not cover domestic emissions, which are 40 percent of the global industry's overall emissions.[120] One observer of the ICAO convention made this summary, "Airline claims that flying will now be green are a myth. Taking a plane is the fastest and cheapest way to fry the planet and this deal won't reduce demand for jet fuel one drop. Instead offsetting aims to cut emissions in other industries,..." Another critic called it "a timid step in the right direction."[122]

Effects of climate change on aviation

Increased turbulence

A report published in the science journal *Nature Climate Change* forecasts that increasing CO_2 levels will result in a significant increase in in-flight turbulence experienced by transatlantic airline flights by the middle of the 21st century. The lead author of the study, Paul Williams, a researcher at the National Center for Atmospheric Science, at the University of Reading stated, "air turbulence does more than just interrupt the service of in-flight drinks. It injures hundreds of passengers and aircrew every year – sometimes fatally. It also causes delays and damage to planes."[123]

Pandemics

See Health hazards of air travel#Infection

Noise

Aircraft noise is seen by advocacy groups as being very hard to get attention and action on. The fundamental issues are increased traffic at larger airports and airport expansion at smaller and regional airports.[124] Aviation authorities and airlines have developed Continuous Descent Approach procedures [125] to reduce noise footprint. Current applicable noise standards effective since 2014 are FAA Stage 4 and (equivalent) EASA Chapter 4.[126] Aircraft with lower standards are restricted to a time window or, on many airports, banned completely. Stage 5 will become effective between 2017–2020. Quantification and comparison of noise effects per seat-distance takes into account that noise from cruise levels usually does not reach the earth surface (as opposed to surface-transportation) but is concentrated on and in proximity of airports.

Water pollution

Fuel and chemical spills

Airports can generate significant water pollution due to their extensive use and handling of jet fuel, lubricants and other chemicals. Airports install spill control structures and related equipment (e.g., vacuum trucks, portable berms, absorbents) to prevent chemical spills, and mitigate the impacts of spills that do occur.[127]

Aircraft deicing. Excess deicing fluid may contaminate nearby water bodies, if not properly recovered.

Deicing chemicals

In cold climates, the use of deicing fluids can also cause water pollution, as most of the fluids applied to aircraft subsequently fall to the ground and can be carried via stormwater runoff to nearby streams, rivers or coastal waters.[128]:101 Airlines use deicing fluids based on ethylene glycol or propylene glycol as the active ingredient.[128]:4 Airports also use chemical deicers on runways, taxiways and other paved surfaces, which tend to run off to nearby water bodies. Pavement deicers may contain potassium acetate, glycol compounds, sodium acetate, urea or other chemicals.[128]:42

Ethylene glycol and propylene glycol are known to exert high levels of biochemical oxygen demand (BOD) during degradation in surface waters. This process can adversely affect aquatic life by consuming oxygen needed by aquatic organisms for survival. Large quantities of dissolved oxygen (DO) in the water column are consumed when microbial populations decompose propylene glycol.[129]:2–23

Sufficient dissolved oxygen levels in surface waters are critical for the survival of fish, macroinvertebrates, and other aquatic organisms. If oxygen concentrations drop below a minimum level, organisms emigrate, if able and possible, to areas with higher oxygen levels or eventually die. This effect can drastically reduce the amount of usable aquatic habitat. Reductions in DO levels can reduce or eliminate bottom feeder populations, create conditions that favor a change in a community's species profile, or alter critical food-web interactions.[129]:2–30

Air quality

Particulate emissions

Ultrafine particles (UFPs) are emitted by aircraft engines during near-surface level operations including taxi, takeoff, climb, descent, and landing, as well as idling at gates and on taxiways. Other sources of UFPs include ground support equipment operating around the terminal areas. In 2014, an air quality study found the area impacted by ultrafine particles from the takeoffs and landings downwind of Los Angeles International Airport to be much larger than previously thought.[130] Typical UFP emissions during takeoff are on the order of 10^{15}–10^{17} particles emitted per kilogram of fuel burned. Non-volatile soot particle emissions are 10^{14}–10^{16} particles per kilogram fuel on a number basis and 0.1–1 gram per kilogram fuel on a mass basis, depending on the engine and fuel characteristics.[131][132][133][134][135]

Lead emissions

Some 167,000 piston engine aircraft—about three-quarters of private planes in the United States—release lead (Pb) into the air due to leaded aviation fuel.[136] From 1970 to 2007, general aviation aircraft emitted about 34,000 tons of lead into the atmosphere according to the Environmental Protection Agency.[137] Lead is recognized as a serious environmental threat by the Federal Aviation Administration if inhaled or ingested leading to adverse effects on the nervous system, red blood cells and cardiovascular and immune systems with infants and young children especially sensitive to even low levels of lead, which may contribute to behavioral and learning problems, lower IQ[138] and autism.[139]

Radiation exposure

Flying 12 kilometres (39,000 ft) high, passengers and crews of jet airliners are exposed to at least 10 times the cosmic ray dose that people at sea level receive. Every few years, a geomagnetic storm permits a solar particle event to penetrate down to jetliner altitudes. Aircraft flying polar routes near the geomagnetic poles are at particular risk.[140][141][142][143]

Land use for infrastructure

Airport buildings, taxiways and runways occupy part of the local ecosystem. Most of aircraft movement however is in air at altitude and so is away from direct interaction with sensitive natural surface features or human detection. This is different from roads, railways and canals, which are very significant in use of land and the dividing of ecological zones.

See also

- Aviation Environment Federation, UK-focused non-profit direct action group
- Aviation taxation and subsidies
- Chemtrail conspiracy theory
- Continuous descent approach
- Electric aircraft
- Energy efficiency in transport
- European Green Deal
- Environmental impact of aviation in the United Kingdom
- Environmental impact of transport
- Flying Matters, pro-aviation coalition in the United Kingdom
- Hydrogen powered aircraft
- Hypermobility (travel)
- Individual action on climate change
- Plane Mad (direct action group)

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