

GLOBAL AVIATION

CLIMATE CHANGE. AIRPORT AIR QUALITY

CHALLENGES DIAGNOSTICS ACTIONS

This paper is the English translation,
performed by Antoine Berthier (ENV-ISA)
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H.D.R, DR., ENG. **RICHARD RAMAROSON**
Freelance, Environmental Broad Consulting
Ex-"International Outgoing Fellow"(2009-2012) at Harvard
University, Cambridge, MA, USA
Under European Union Marie Curie Program People.



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AVIATION

AND CLIMATE CHANGE

Aviation industry constitutes an indispensable major growth for the world global economy. In the 60's, air traffic experienced an annual increase of 13.5% to stabilize currently at 5% per year. This development of air traffic for the transport of passengers and freight unfortunately led to environmental nuisances: noise and air and

pollution in the vicinity of airports climate change.

Carbon dioxide (CO_2), with lifetime around 100 years, is one of the main greenhouse gases responsible for global warming of the earth planet inducing climate change and retroaction. Air transport (AT) contributes between 2-3% of current global greenhouse gas emissions CO_2 and exhibits increase around 3 to 4% per annum, correlated to a constant growth of air traffic [1], through kerosene consumption.

Other aviation effluents considered as non- CO_2 contribute to these climate effects.

Aircraft contrails contribute to a certain degree to global warming as well as soot (black carbon), alone as an entity, by absorbing visible radiation. However, when acting as initial feed to condensation nuclei, particulate matters participate to cloud formation and may have a cooling or a global warming effect depending on the type of clouds (large uncertainties). Sulfate aerosols and organic compounds emitted by aircraft leads to a cooling effect. Ozone (O_3), a greenhouse gas formed by photochemical reactions between engine effluents and chemical compounds in the atmosphere, contributes to the global warming. But its increase photochemically induces a decrease of methane another powerful greenhouse gas partially offsetting warming effect by ozone.



**OZONE (O_3) GREENHOUSE GAS
FORMED BY PHOTOCHEMICAL
REACTIONS**

GLOBAL AVIATION



REDUCE THE ENVIRONMENTAL IMPACT OF GLOBAL AVIATION AND STABILIZE CO₂ EMISSIONS

Over decades, the aviation industry has been a pioneer in developing innovative technologies for more fuel-efficient and less polluting aircraft engines, using new, higher-performance materials for aircraft, optimizing aerodynamics and flight operations, and developing alternative fuels on a large scale, with or without blending with jet fuel. This technological innovation, coupled with existing regulations, leads to a reduction of overall aviation emissions and environmental impact, but do not fully offset the effects of the steady increase in annual air traffic.

The International Civil Aviation Organization [2] has implemented several measures to reduce the environmental impact of global aviation and stabilize CO₂ emissions. Scenarios of CO₂ emissions from aviation between 2005 and 2050 associated with each of these measures have been developed and are available on the ICAO website (figures and figures). Thus, by 2050, these estimates would lead to a significant reduction in CO₂ emissions while considering the increase in global air traffic (5% per year).

AIRPORT AIR QUALITY AND AIR TRAFFIC

Although noise is a significant regulated nuisance at airports and surrounding areas, all category of emission sources pollutes local and regional air quality.

At airports, emissions are issued from various sources including aircraft under the Landing-Take-Off cycle (LTO) and technical support equipment at the gates, accounting for a large portion.

Fuel storage, airside mobiles in non-public areas and de-icing also contribute to these emissions.

Finally, emissions from ground vehicles for passengers' transportation and other services at the terminals are sources of pollutants.

Depending on the geographic location of airports, other surrounding "non-airport" emission sources contribute to and interact with airport emissions.

These include national roads and highways, local industries, natural forest emissions, agriculture activities, adjacent urban areas, desert areas, oceans and wildfires.

AIRCRAFT OPERATING MODE

1. TAXIING

The movement of aircraft on the ground is divided into several phases called the LTO cycle: at the passenger boarding area, the flight preparation operating embedded auxiliary power units (or APU: "Auxiliary Power Unit"). The taxiing phase is defined by the movement of the aircraft to the take-off runway ends or vice versa to the landing area after landing. During this time, engine thrust is at 7% of power. Take-off and climb to 3000 feet of altitude use maximum engine thrust while the approach (before landing) uses only 30% of engine thrust.

The actual duration of taxiing depends on airport configuration and the daytime congestion of air traffic; the longer it lasts with the traffic jams at peak hours, the greater the quantity of emissions.

PRIMARY POLLUTANTS



Combustion of kerosene produces so-called primary pollutants emitted at aero-engine nozzle exit, similar to car exhausts. Carbon dioxide (CO_2) and water vapor (H_2O) are the major primary effluents, classified as greenhouse gases inducing climate change. Other minor pollutants are also produced including carbon monoxide (CO), nitrogen oxides (NO_x), a multitude of organic compounds of different volatilities, grouped as VOCs including chemical compounds derived from poor fuel combustion including polycyclic aromatic hydrocarbons (PAHs), and sulfur dioxide (SO_2) and sulfates (Sulfur species is an initial content of any fossil fuel with 0.3% by mass for kerosene for civil aviation).

Solid/liquid particulate matters (PM) are among the minor primary pollutants consisting of aggregates of spherical solid particles potentially coated with other chemicals, and heavy metals. The size distribution of primary particulate spans from around aerodynamic diameter of 5 nm (1 nanometer = 10^{-9} m) to 10 μm (1 μm = 1 micrometer = 10^{-6} m). At the nozzle exit, particles smaller than 100 nm in size (Ultra Fine Particles) largely dominate in number concentration showing 2 peaks at less than 10 nm and more than 40 nm. For comparison, human hair size between is between 50 μm and 100 μm . Unlike cars, no particulate matter filters are embedded in aero-engines.

PRIMARY POLLUTANTS



SIZE DISTRIBUTION, A KEY CHARACTERISTIC FOR PM

Atmospheric particles are classified according to their size distribution, namely their aerodynamic diameter: ultrafine particles (UFP) cover a size range from the smallest possible up to around 100 nm (PM_{0.1}); fine particles (FP) display a size class up to 2.5 µm (PM_{2.5}) and the coarse particles (GP) is between PM_{2.5} and 10 µm (PM₁₀). There is an intermediate size in the particle class that includes particles between 100 nm (UFP) and 1 µm namely PM₁.

PM₁ exhibits two specificities: firstly, they can penetrate more deeply into the respiratory system (alveoli) than can PM_{2.5} and PM₁₀ due to their smaller size and more available surface-area, accumulating more hazardous pollutants, secondly, they are subject to coagulation and condensation and acts as condensation nuclei for cloud formation.

PRIMARY POLLUTANTS



A new standard on CO₂ emissions from aircraft engines has been adopted by ICAO

Primary pollutants emitted by aircraft engines are associated to combustion of kerosene, like for gasoline and diesel engines for CO₂. At maximum and intermediate engine thrusts (for takeoff, cruise and landing), emissions of minor primary pollutants such as NO_x and particulate matters (by mass) exhibit a maximum; SO₂ emissions remain almost constant. During taxiing at less power (7%), engines emit other minority primary pollutants such as carbon monoxide CO and a multitude of VOCs in addition to NO_x, particulate matter and SO₂.

For environmental protection, the International Civil Aviation Organization (ICAO) sets standards and recommendations for certification of aircraft engines for CO₂ emissions and a list of minority pollutants including non-volatile particulates.

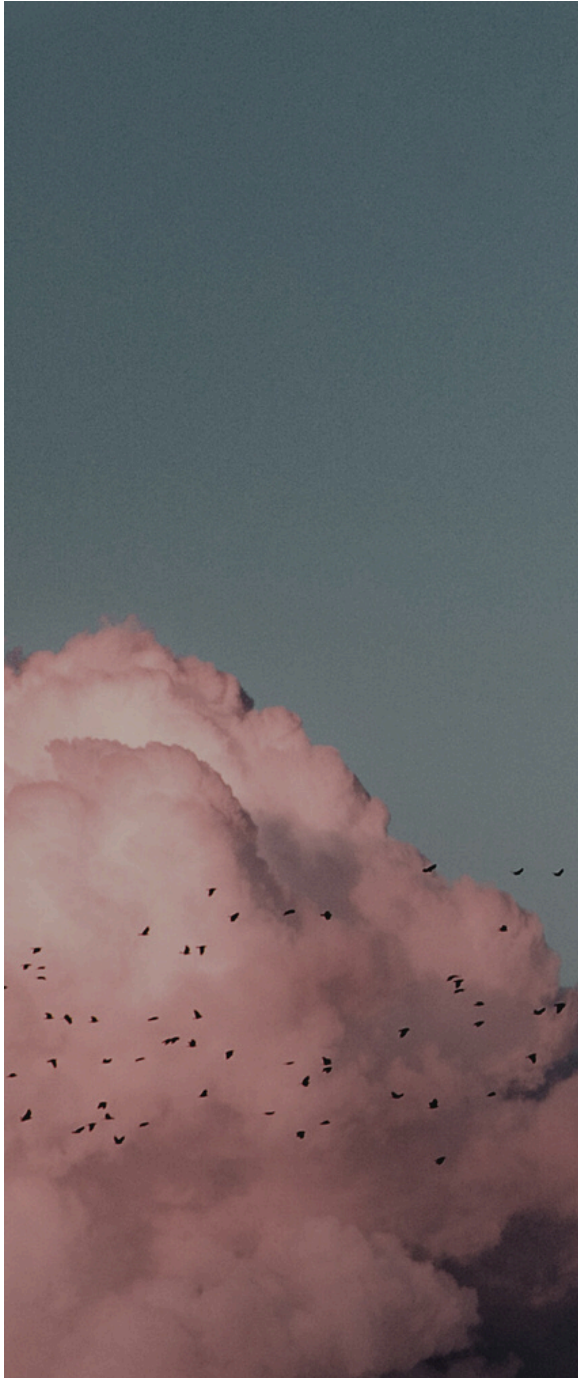
A new standard for CO₂ emissions from aircraft engines has been adopted by ICAO and comes into effect in 2017, applied in 2020 for new aircraft and 2023 for those already in production.

Regarding non-volatile particulate emissions from a certain category of aircraft engines, a new ICAO standard has been adopted for their mass and number and will be applied from 2023. However, certain types of engines and auxiliary power units on board aircraft are not "yet" subject to these standards.

ICAO has a database of exhaust emissions from aero-engines [3], measured according to the protocols defined in Annex 16 Volume II for all engines with a static power greater than 26.7 kN.

SECONDARY POLLUTANTS

AT AIRPORTS



Minor primary effluents trigger physicochemical mechanisms in the ambient air in the short and medium term, through interaction with each other and with other pre-existing pollutants in the environment, all sources combined.

Depending on the seasons, local meteorology, time of day, sunshine and other factors, the so-called secondary pollutants are formed as ozone (O_3), under strong heat and sunshine at visible and near ultraviolet wavelengths (UV) by interaction with NO_x , VOCs and CO. In winter season and autumn, primary nitrogen oxides will remain mostly in the form of nitrogen dioxide NO_2 (less UVA) and ozone production is less important (at lower temperature).

Since their emission from aircraft engines, the evolution of PM in ambient air remains somewhat more complex. Primary PM grows during the day by interaction with other pollutants (gases/liquids/solids) from engines and with other airport sources. These include organic compounds, nitrogen oxides, sulfur dioxide and other species already present in the airport ambient air, such as ammonia, sulfates and nitrates. New particles are formed in the ambient air, in particular in its form of UFP evolving and growing with the time of the day partially to PM₁.

SECONDARY POLLUTANTS

Field measurements have been carried out throughout the world at some major airports to observe aircraft emissions and the concentration of ambient air pollutants.

Among these experiments, as an illustration, the work described in [4] aims at characterizing the gas and primary particle emissions by aeronautical engines. Such experiments explore real operating conditions of aircraft at airports, at the nozzle exit and in the near fields downstream of running engines. Emission indices of PM by mass and by number per fuel consumed have been measured. These observations showed a prompt formation of UFP at 30 m behind the nozzle exit during the cooling and expansion of the hot jet. A maximum in number concentration of particles is observed for 30–40 nm size at 1 m of the nozzle exit; at 30 m the prompt formation of new particles leads to new maxima at around 5–10 nm associated most likely to formation of new UFP (by nucleation) in interaction with sulfuric acid, less or semi-volatile organic compounds, liquid water and nanometric particles. Other measurement campaigns were organized to assess the airport ambient air pollution by deploying primary and secondary pollutant detection devices, including particles at several locations at the airport.

Observations were carried out continuously during several weeks for two different seasons focusing on moving aircraft plumes at the ground, air pollutants along runways and taxiways and at aprons. Results are reported in references [5] and [6].

These field campaigns at airports observe again the prompt formation of new UFP within aircraft plumes as observed by [4] and their daily ubiquity in the airport ambient air, with a weak decrease in concentration at night whatever the season of observations is. These campaigns have also highlighted the importance of the role of aircraft emissions, especially NO_x and VOCs and other effluents, on the concentration of secondary air pollutants such as O₃. The characteristics of fine and ultrafine particles have been especially explored by measuring their number and mass concentration as well as their chemical composition and morphology, showing irregular soot aggregation.

Measurements show that particulate matters have different volatilities and are ubiquitous in the airport atmosphere. The number and mass concentration of fine and ultrafine particles were also measured hourly. UFP exhibit a maximum in number inside younger aircraft plumes and remain almost constant in the air throughout the day, with a close correlation to air traffic diurnal variation.

IMPACT

The synergy between climate change and ambient air pollution remains obvious. As a consequence, the protection of human health and the environment should be in line with climate change impact assessment and any decision-making related with.

Climate change may lead to environmental situation under which adverse impacts on human health are reinforced. These include extreme temperatures, air pollution, flooding, drought, increased disease-carrying vectors (ticks, mosquitoes), water pollution, infections via degraded food quality, etc. (for more information, see the detailed reports of [7]).

At airports, in non-public and the surrounding areas, air pollutants have the same adverse effects on human health as they do in urban environments of the same nature and at same concentration. The short-term exposure of the population concerned, from one hour to one week, is defined as acute during high pollution episodes, while the long-term exposure of the population to background pollution is classified as chronic.

Ozone, nitrogen dioxide, sulfur dioxide, and volatile organic compounds have an adverse impact on the entire respiratory system from the upper airways to the alveoli, on tissues and on other organs. According to these criteria, the detailed description of the impact of the different air pollutants on human health and vegetation and the resulting regulations can be consulted on the official websites of the air quality associations and the public administration.

The World Health Organization [8] establishes a list of recommendations for air pollutants threatening the human health, including PM_{2.5}. At the European level, regulations set limit values that are adopted by the Member States.

IMPORTANCE OF UFP AND FP

ON HUMAN HEALTH

For airborne particles, whether primary or secondary, their effects on health are complex in nature, especially for ufp where detailed and in-depth knowledge of associated pathologies is still very limited and requires to be multiplied. During many years, toxicological and epidemiological studies, in vivo (with rats) and in vitro experiments have been carried out throughout the world for the effects of PM10, PM2.5 and more recently of PM0.1.

Results are regularly published in the scientific literature. Among these works, references [9] and [10] establish a rather detailed and complete review of these scientific research outcomes showing statistically consistent main conclusions for most of the experiments conducted. These studies were conducted in urbanized areas worldwide but not necessarily at airports, thus constituting a general case of scientific reviews.

Whether population exposures concerned are long term (chronic) or short term (acute) for all classes of particles, it appears that cardiovascular diseases are the most frequently observed in the cohort and represent by far, in mortality rate, 2/3 of the samples.

Inside alveoli and the internal walls of the blood vessels, several mechanisms are triggered by the presence of particles, linked to the immune reactions of the organism, either at the cellular level or at the blood level. Atherosclerosis problems and the development of heart attacks have been observed in particular in the case of acute exposure to PM10, PM2.5 and UFP.

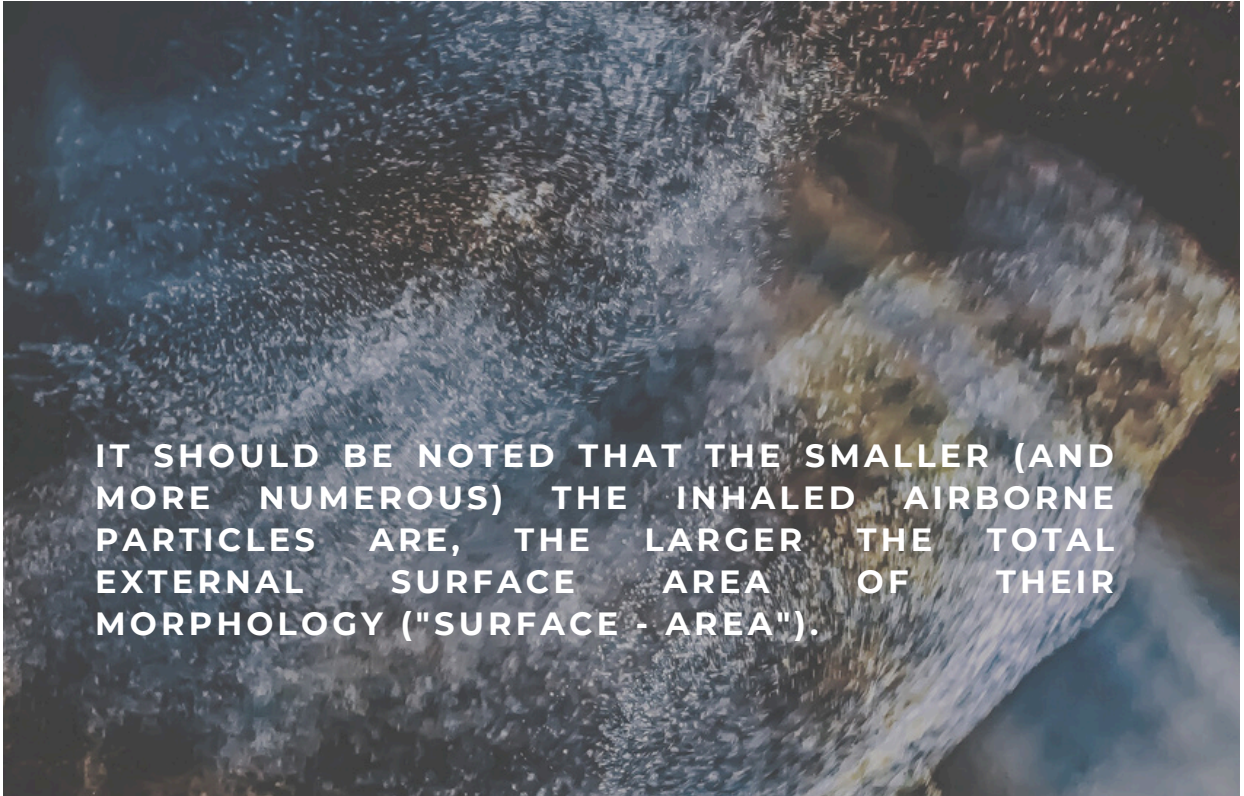
Respiratory diseases are the second most common cause in the upper, lower and alveolar lung branches. PM triggers tissue inflammation, oxidative stress (for more details on this point see [12]), causes asthma, chronic obstructive pulmonary disease (COPD), pneumonitis, bronchitis and bronchiolitis.

The third place is held by cerebrovascular diseases. However, the findings show that the mechanisms of the link between pathologies such as stroke and all PM are far from being understood. Studies show that UFP can also pass into the brain area via olfactory bulbs at the nasal level and are likely to bypass the blood-brain barrier.

Although there are contradictions between the various results of studies on pathologies associated with PM, including UFP, it would seem that they are triggered and exacerbated by the condition of patients, especially diabetics, and their age.

Cancers are also part of the risks associated with the inhalation of particles, mainly the UFP. Indeed, the size classes of inhaled particles and the ease or not of adsorbed and absorbed chemical compounds to be deposited on the walls of the respiratory system according to their solubility and by diffusion, very often dictate their fate until they deeply accumulate in the deepest organs such as the alveoli.

SURFACE-AREA



IT SHOULD BE NOTED THAT THE SMALLER (AND MORE NUMEROUS) THE INHALED AIRBORNE PARTICLES ARE, THE LARGER THE TOTAL EXTERNAL SURFACE AREA OF THEIR MORPHOLOGY ("SURFACE - AREA").

Because of this larger contact area, UFP (and PM1) are more likely to capture/attach toxic chemicals from the air than their PM2.5 and PM10 counterparts. The latter two are rather characterized by their mass with less surface area.

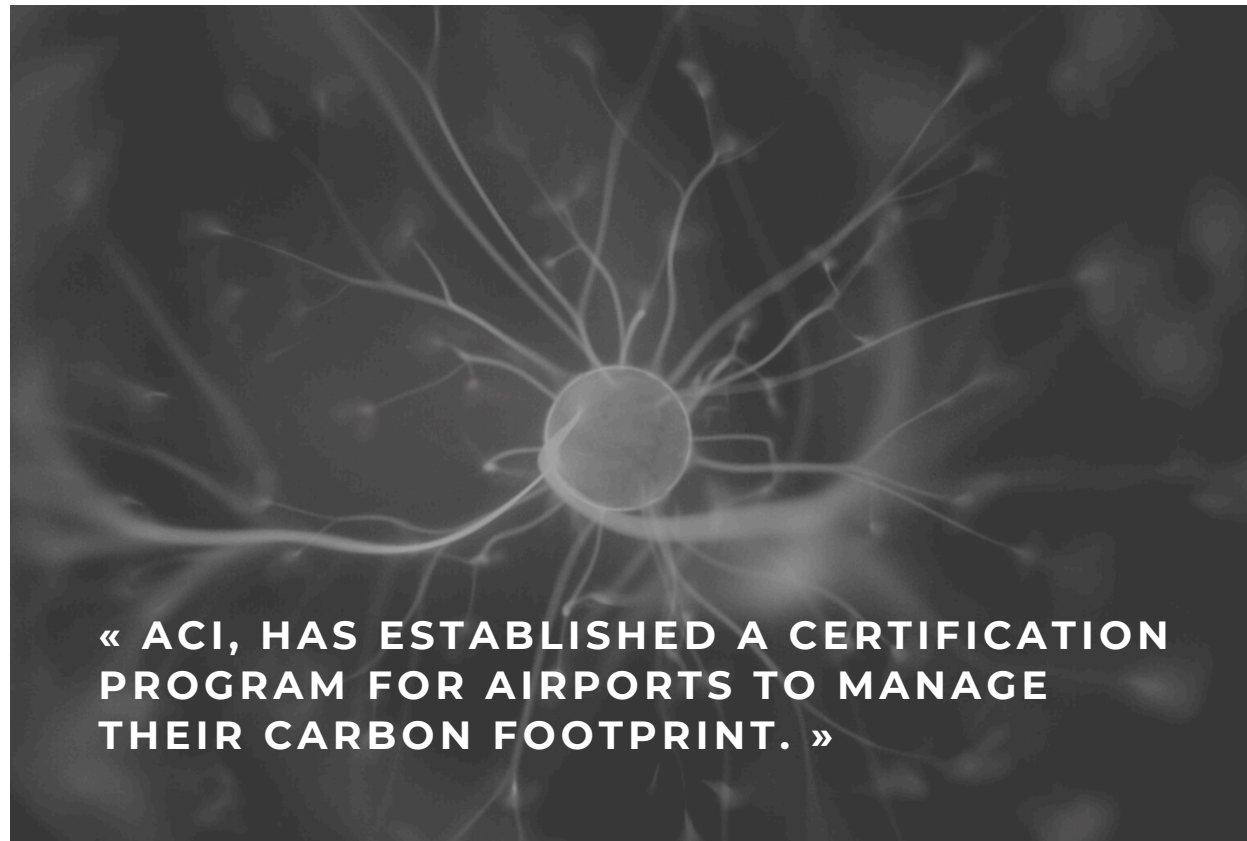
Some chemical compounds resulting from combustion (in general) like the PAH family are carcinogenic; these are quite likely to be adsorbed by UFP.

The International Agency for Research on Cancer (IARC) of the World Health Organization underlines the carcinogenic character of the particles and the chemical compounds accompanying them.

Because of the very limited current knowledge of pathologies associated with the inhalation of UFP on human health, they are the subject of an in-depth research strategy (health sciences-environmental sciences-associated industrial technologies) and of concertation at the level of the world scientific community.

A consensus on a solid basis for their detailed physico-chemical characterization is essential for a better understanding of their effects on global public health.

ESTABLISH A DIAGNOSIS. REDUCE. INNOVATE



In order to better quantify the contribution of global aviation and airport hubs to climate change and local air pollution, solid scientific assessment and innovation studies, carried out in concerted EU projects and programs, are an indispensable pillar.

These assessments enable stakeholders, including the aviation industry, airport operators and airlines, to use innovative and novel solutions to reduce: 1) their carbon footprint for climate impact and 2) their pollutant emissions for air quality related to human health and environmental protection.

ICAO certifications and standards for aircraft engines and air quality monitoring regulations help address the challenges of climate and air pollution issues.

On the other hand, the Airports Council International (ACI), European branch [15], has established a certification program for airports to manage their carbon footprint (climate impact objective) according to 6 criteria:

mapping, reduction, optimization, neutrality, and recently transformation and transition.

This program is offered to all airports for a non-binding commitment. It includes global passenger and cargo aviation as well as all other hub activities, and results in the independent issuance of a climate impact certificate (ACA certificate).



PARTICIPATION

Horizon 2020 is a research and innovation program of the European Union focused on 3 priorities: scientific excellence, industrial leadership and societal challenges. HORIZON 2020 is funded by the period 2014–2020.

RAPTOR (Scientific Research in Aviation and Particulate Matter Technology: Modelling and Regulation) is one of the EU-funded projects under HORIZON 2020, whose mission is to provide a better understanding of the impact of aircraft emissions on public health with a focus on aeronautical particles, including UFP in particular. This mission should make it possible to establish a bridge between the various existing EU projects and actors and a better coordination of research at state level in the field.

The objectives of the project are developed on a few main axes: to improve knowledge of the link between aircraft engine technology and particulate emissions as well as the interdependence of other pollutants such as NO_x and noise pollution; to provide an in-depth overview of particle measurement techniques, to evaluate numerical modelling tools of their internal engine training, provide an overview of existing dispersion models for airports and establish a more complete understanding of particulate emissions from aircraft engines not subject to ICAO standards.

ENVISA coordinates the RAPTOR project and participates in most of the technical tasks including the WP5 batch dealing with particulate emissions from aeronautical engines, particularly particulate matter.

ENVISA also ensures the link between the EU, which finances the project, and the dissemination of the results for the community. For the technical aspect, ENVISA contributed to the tasks dedicated to the achievement of these objectives (WP5/RAPTOR lot). Recommendations on future standards for volatile particulate matter emissions not yet subject to ICAO certification are proposed by the project team.

In terms of emission impact studies on human health, although ENVISA's technical team does not have the competence, the coordination of the project allows it to have the knowledge in this area.

The RAPTOR project carried out (lot WP6/RAPTOR): on the one hand, a detailed review of the existing research results on the effects of particles on human health and on the other hand, in vivo tests (with rats) for toxicological studies of aeronautical particles sampled on coupled test benches, in vitro experiments using human cells taken from the bronchi for the same purposes.

Two types of fuels were used: civil aviation kerosene (Jet A-1) of fossil origin and biofuel from so-called H.E.F.A. oils. A notable difference between the effects of the two fuels was observed: one acting for cytotoxicity and the other for inflammation.

for

The objectives of the project are mainly focused on the development of innovative/innovative actions to achieve carbon neutrality including logistics, the use of non-polluting electric energy, passenger mobility and assessments of environmental issues related to air quality. To these is added the study of the integration of infrastructures for the use of sustainable alternative fuels. The project lasts 60 months.



EXPERTISE

TECHNICAL SUPPORT AT AIRPORTS

At the national level, ENV-ISA provides technical support to airport operators, under the aegis of the Directorate General of Civil Aviation (DGAC) [13], for the establishment of pollutant emission inventories, numerical modelling of the fate of effluents and the assessment of the degradation of air quality and studies of the potential impact of pollutants on public health.

In terms of inventories, all emission sources are processed by ENV-ISA both at airport platforms and on cruise flights. In addition, the company has recently implemented a European software (COPERT) [14] for the establishment of emission inventories and cadaster of access roads to airports and motorways/national roads nearby.

In terms of modelling the dispersion of pollutants, ENV-ISA uses and improves the LASPORT software that takes into account, as input, emissions and average meteorological parameters to establish/calculate the evolution of the distribution map of a set of pollutants at the platform level according to the seasons and emission evolution scenarios. ENV-ISA has also supported several international airports for their application for ACA certification: an article will soon be dedicated to this theme.

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