Aircraft emissions: focus on *ultrafine particles*

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This presentation

1. Emissions of air pollutants from jet engines
2. Air quality WHO guidelines and Australian standards
3. Measuring aircraft emissions
4. Dispersion of aircraft emissions
5. Evidence of health impacts of the emissions

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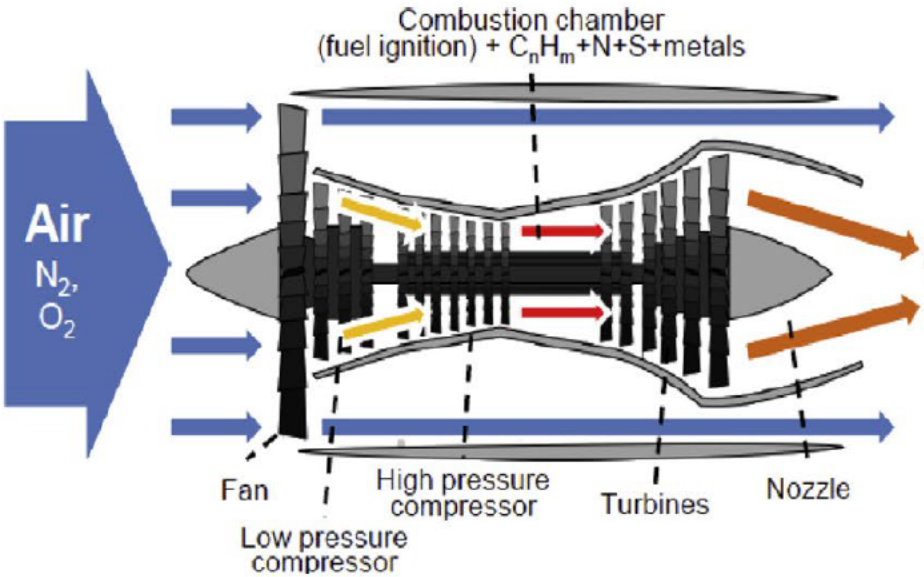
Combustion emissions from jet engines



Ideal complete combustion:
$CO_2+H_2O+N_2$

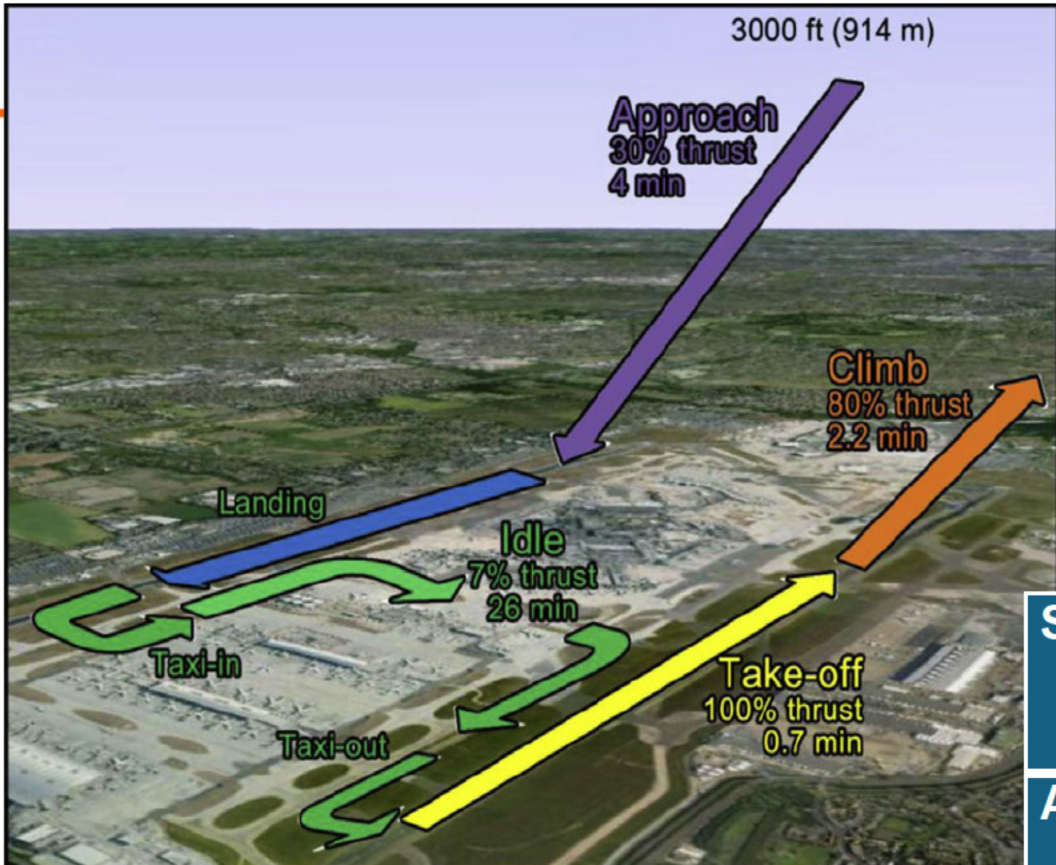
Actual combustion (simplified):
$CO_2+N_2+H_2O+O_2+CO+SO_x+NO_x+HC+$soot

Particles:
Ultrafine particles (UFP), smaller then 0.1 micrometres

10^{15} to 10^{17} particles are emitted per kg of fuel burnt.

Masiol, M. and Harrison, R.M., 2014. Aircraft engine exhaust emissions and other airport-related contributions to ambient air pollution: A review. *Atmospheric Environment*, *95*, pp.409-455

Landing and Take-Off (LTO) Cycle



A LTO cycle refers to all the operations the aircraft carry out below 3000 ft above field elevation (914 m) which roughly corresponds to the atmospheric mixing height, i.e. the lower part of the troposphere within which pollutants emitted at ground-level mix rapidly.

Stage	Time Duration (min)	Engine Thrust (%)
Approach	4	30
Ground Ops	26	7
Take Off	0.7	100
Climb	2.2	80

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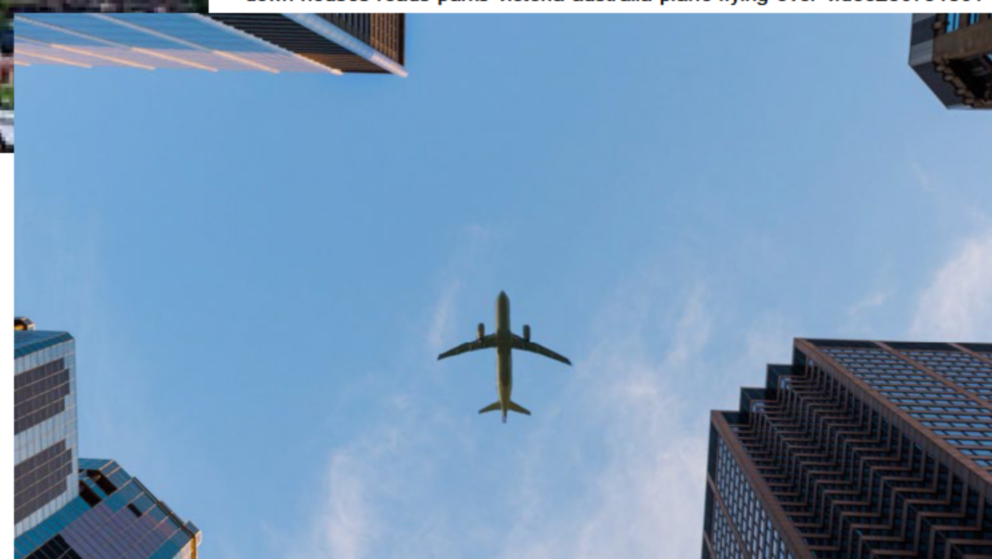
Masiol, M. and Harrison, R.M., 2014. Aircraft engine exhaust emissions and other airport-related contributions to ambient air pollution: A review. *Atmospheric Environment*, *95*, pp.409-455

Flight path over residential areas

Photograph: Supplied | Cameron Casey | Pexels.
https://www.timeout.com/sydney/news/new-sydney-flight-paths-we-take-a-look-at-suburbs-that-will-be-affected-021524

https://www.dreamstime.com/plane-flying-over-melbournes-suburbs-cbd-looking-down-houses-roads-parks-victoria-australia-plane-flying-over-video256751061



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Air quality WHO guidelines and Australian standards

WHO 2021 Air Quality Guidelines and Australian standards

Pollutant	Averaging time	2021 AQG level	Australian Standards
$PM_{2.5}$, µg/m^3	Annual	5	8
	24-hour[a]	15	25
PM_{10}, µg/m^3	Annual	15	25
	24-hour[a]	45	50
O_3, µg/m^3	Peak season[b]	60	–
	8-hour[a]	100	128
NO_2, µg/m^3	Annual	10	28
	24-hour[a]	25	–
	1 hour	200	151
SO_2, µg/m^3	24-hour[a]	40	52
CO, mg/m^3	24-hour[a]	4	–
	8 hour	10	10.3

Most of these pollutants are emitted by aircraft

$PM_{2.5}$ and PM_{10} particles smaller than 2.5 and 10 micrometres

WHO AQG 2021: UFP *good practice*

The following daily (24 hours) mean particle number concentration (UFP) can be considered as *typical*:

- Clean environments < 10^3 particles cm^{-3} (not affected by anthropogenic emissions)
- Urban background < 10^4 particles cm^{-3}

In *typical* clean urban microenvironments hourly mean concentrations < $2x10^4$ particles cm^{-3}

UFP are emitted by aircraft

Typical values can serve as a comparative reference to distinguish between low and high PNC to guide decisions on the priorities of UFP source emission control.

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Measuring aircraft emissions

Types of measurements

1. Emissions near runways

2. Airport emissions
   - Landing and taking off planes
   - Ground equipment
   - Airport vehicle traffic

3. In-flight emissions

Mazaheri, M., Bostrom, T.E., Johnson, G.R. and Morawska, L., 2013. Composition and morphology of particle emissions from in-use aircraft during takeoff and landing. *Environmental science & technology*, *47*(10), pp.5235-5242

The most important due to their broader impacts, but the most difficult to measure

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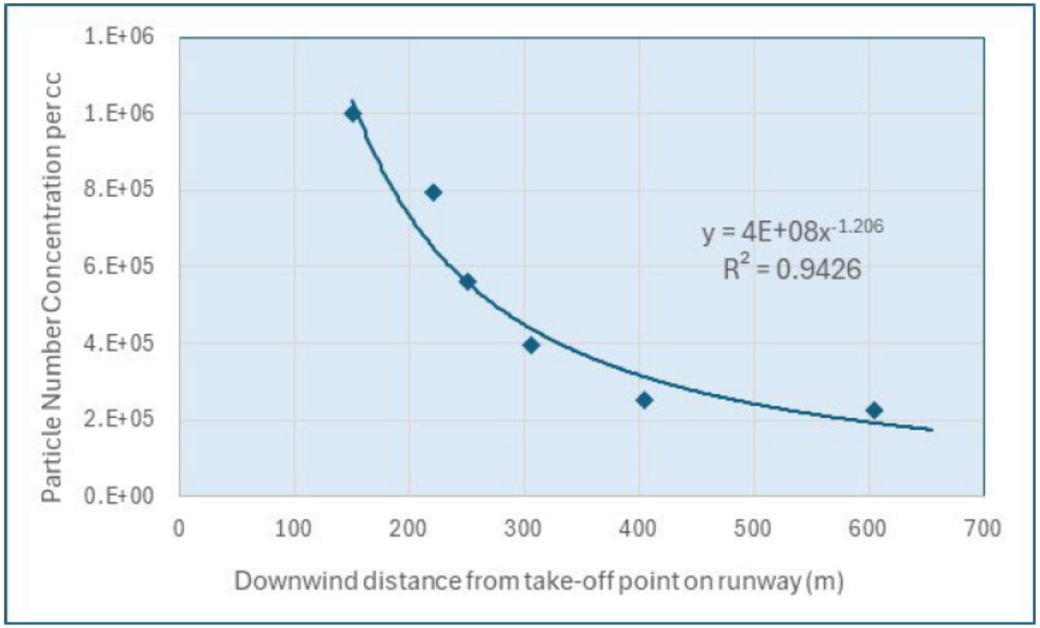
Dispersion of aircraft emissions

Examples

Aircraft emissions, how far do they go?



Assuming this model of decrease with distance (without considering increasing dilution and dispersion due to winds), **the distance at which the plume will reach the background concentration is about 33 km.**

Zhu, Y., Fanning, E., Yu, R.C., Zhang, Q. and Froines, J.R., 2011. Aircraft emissions and local air quality impacts from takeoff activities at a large International Airport. *Atmospheric Environment*, *45*(36), pp.6526-6533

Aircraft emissions: examples 1

Hu et al (2009) at a regional airport of Santa Monica, observed that spikes in UFP related to the take-off phase **were 440 times elevated above background and reached 2.2 x10^6 particles cm^{-3}.**

Hu, S., Fruin, S., Kozawa, K., Mara, S., Winer, A.M. and Paulson, S.E., 2009. Aircraft emission impacts in a neighborhood adjacent to a general aviation airport in Southern California. *Environmental Science & Technology*, *43*(21), pp.8039-8045

Hsu et al (2013) measured UFP from aircraft departures and arrivals at LAX airport. LTO activity contributed a median **UFP concentration of approximately 1.5x10^5 particles/cm^3 at the end of the departure runway, versus 1.9x10^4 particles/cm^3 and 1.7x10^4 particles/cm^3 at 250 m and 500 m further downwind, respectively**. E.g., UFP contributions from aircraft decreased by 90% in the first 500 m downwind.

Hsu, H.H., Adamkiewicz, G., Houseman, E.A., Zarubiak, D., Spengler, J.D. and Levy, J.I., 2013. Contributions of aircraft arrivals and departures to ultrafine particle counts near Los Angeles International Airport. *Science of the Total Environment*, *444*, pp.347-355

Aircraft emissions: examples 2

Environmental Pollution 345 (2024) 123390

Contents lists available at ScienceDirect

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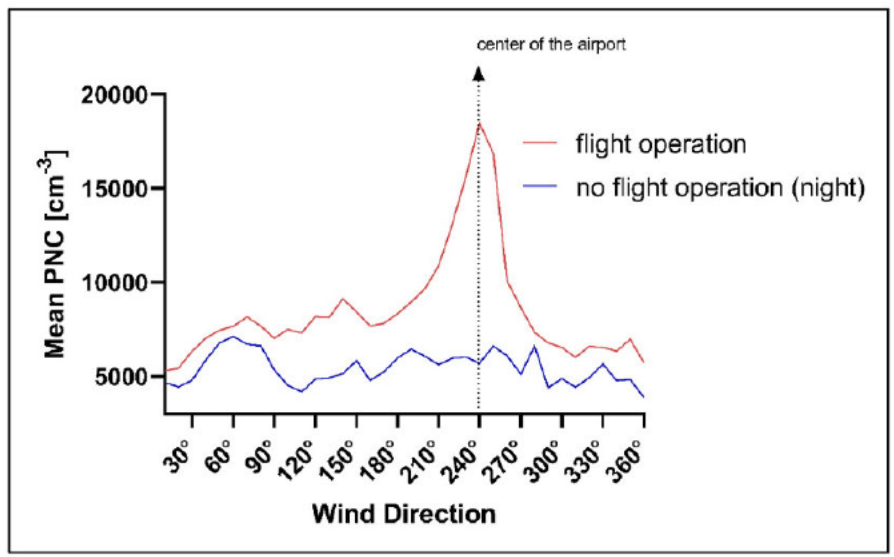
journal homepage: www.elsevier.com/locate/envpol

Influence of a large commercial airport on the ultrafine particle number concentration in a distant residential area under different wind conditions and the impact of the COVID-19 pandemic☆

Janis Dröge *, Doris Klingelhöfer, Markus Braun, David A. Groneberg

Goethe University Frankfurt, Institute of Occupational, Social and Environmental Medicine, Frankfurt am Main, Germany

UFP measured 7 km away from Frankfurt Airport



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Dröge, J., Klingelhöfer, D., Braun, M. and Groneberg, D.A., 2024. Influence of a large commercial airport on the ultrafine particle number concentration in a distant residential area under different wind conditions and the impact of the COVID-19 pandemic. *Environmental Pollution*, *345*, p.123390

Aircraft emissions: where do they go?

Major runways are generally **aligned with prevailing wind directions** and the aircraft take-off facing the wind, so the exhausted **plume is most likely to travel along the trajectory of the runway**.

Zhu, Y., Fanning, E., Yu, R.C., Zhang, Q. and Froines, J.R., 2011. Aircraft emissions and local air quality impacts from takeoff activities at a large International Airport. *Atmospheric Environment*, *45*(36), pp.6526-6533

The two runways at Brisbane Airport run NE-SW.

As with many major airports, **BNE has a large urban community immediately downwind**, so the population affected by near-field aircraft-related pollution can be large.

Additional information

There is a relatively rapid downward transport of in-flight aircraft-emitted UFPs due to a combination of large-scale daytime, convective velocities of up to 1 m/s, and local-scale wingtip vortices that can extend vertically downward for several hundred meters at similar, superimposed velocities. This results in plumes from the descending aircraft during the daytime reaching the ground level in approximately a few minutes near the airport and up to 15 to 20 min at 15 km downwind from the airport.

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Austin, E., Xiang, J., Gould, T.R., Shirai, J.H., Yun, S., Yost, M.G., Larson, T.V. and Seto, E., 2021. Distinct ultrafine particle profiles associated with aircraft and roadway traffic. *Environmental Science & Technology*, *55*(5), pp.2847-2858

Additional information

The differences in the spatial extent of the aircraft versus roadway traffic UFPs are important to consider from a population impact perspective. Austin et al observed concentrations of total PNCs (10–1000 nm sized particles) to be higher near roadways compared to near-airport transects. However, most people spend a relatively small proportion of their time on a major roadway (e.g., during commuting), and because of the relatively short distances over which the roadway PNC decays downwind of major roadways, the roadway PNC would affect only a narrow swath of near-roadway residences and other buildings.

In contrast, the affected areas experiencing elevated aircraft PNCs tend to be more diffuse with consistently elevated concentrations occurring in locations below the direct path of the aircraft. Therefore, there is the potential for more people to be affected by PNCs from aircraft than from roadway sources, albeit at lower concentrations. Moreover, those living within the area affected by landing aircraft emissions may be exposed to relatively higher concentrations of smaller sized UFPs. There is an urgent need to address this problem.

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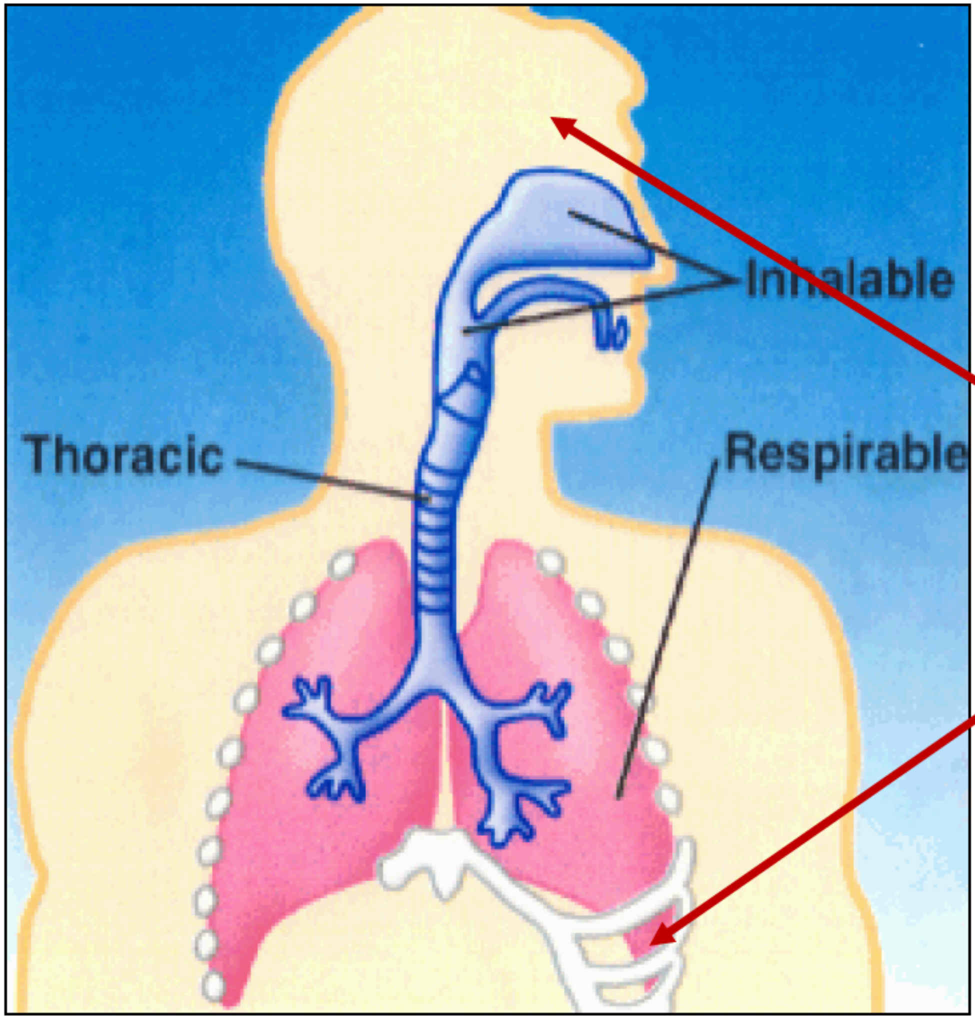
Austin, E., Xiang, J., Gould, T.R., Shirai, J.H., Yun, S., Yost, M.G., Larson, T.V. and Seto, E., 2021. Distinct ultrafine particle profiles associated with aircraft and roadway traffic. *Environmental Science & Technology*, *55*(5), pp.2847-2858

Health impacts

Particle deposition in respiratory tract



UFP reach the deepest part of the respiratory tract due to their small size and directly to the brain through the olfactory system

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Health impact of aircraft emitted UFP: example 1

A population-based cohort study of all mothers who gave birth from 2008 through 2016 while living within 15 km of LAX found that *in utero exposure to aircraft-origin UFPs was positively associated with pre-term birth* independent of the effects of traffic-related exposures.

Wing, S.E., Larson, T.V., Hudda, N., Boonyarattaphan, S., Fruin, S. and Ritz, B., 2020. Preterm birth among infants exposed to in utero ultrafine particles from aircraft emissions. *Environmental Health Perspectives*, *128*(4), p.047002

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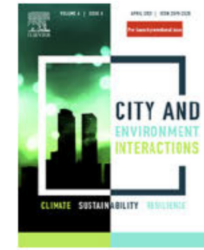

Review Articles

A systematic review of the impact of commercial aircraft activity on air quality near airports

Karie Riley [a], Rich Cook [b,*], Edward Carr [a], Bryan Manning [b]

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Keywords:
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ABSTRACT

Commercial airport activity can adversely impact air quality in the vicinity of airports, and millions of people live close to major airports in the United States. Because of these potential impacts, a systematic literature review was conducted to identify peer reviewed literature on air quality near commercial airports and assess the quality of the studies. The systematic review included reference database searches in PubMed, Web of Science, and Google Scholar, inclusive of years 2000 through 2020. We identified 3,301 articles, and based on the inclusion and exclusion criteria developed, seventy studies were identified for extraction and evaluation using a combination of supervised machine learning and manual screening techniques. These studies consistently showed that ultrafine particulate matter (UFP) is elevated in and around airports. Furthermore, many studies show elevated levels of particulate matter under 2.5 μm in diameter ($PM_{2.5}$), black carbon, criteria pollutants, and polycyclic aromatic hydrocarbons as well. Finally, the systematic review, while not focused on health effects, identified a limited number of on-topic references reporting adverse health effects impacts, including increased rates of premature death, pre-term births, decreased lung function, oxidative DNA damage and childhood leukemia. More research is needed linking particle size distributions to specific airport activities, and proximity to airports, characterizing relationships between different pollutants, evaluating long-term impacts, and improving our understanding of health effects.

Airports represented in the systematic review

	City	Airport	Locid
CA	Burbank	Bob Hope	BUR
CA	Los Angeles	Los Angeles International	LAX
CA	San Francisco	San Francisco International	SFO
CA	San Jose	Norman Y Mineta San Jose International	SJC
CA	Santa Monica	Santa Monica Municipal	SMO
CT	Hartford	Hartford-Brainard	HFD
GA	Atlanta	Hartsfield-Jackson Atlanta International	ATL
MA	Boston	General Edward Lawrence Logan International	BOS
NJ	Teterboro	Teterboro	TEB
NV	Las Vegas	McCarran International	LAS
NY	Albany	Albany International	ALB
NY	New York	Laguardia	LGA
RI	Providence	Theodore Francis Green State	PVD
TX	Dallas-Fort Worth	Dallas-Fort Worth International	DFW
VA	Roanoke	Roanoke-Blacksburg Regional/Woodrum Field	ROA

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Riley, K., Cook, R., Carr, E. and Manning, B., 2021. A systematic review of the impact of commercial aircraft activity on air quality near airports. *City and environment interactions*, *11*, p.100066

Main conclusions from the review

The studies reviewed consistently demonstrated **that UFP concentrations are elevated in and around airports**.

In addition, many studies also showed **elevated levels of $PM_{2.5}$, black carbon (soot), criteria pollutants, and polycyclic aromatic hydrocarbons.**

Finally, the systematic review, while not focused on health effects, identified a number of references reporting adverse health effects impacts, including **increased rates of premature death, pre-term births, decreased lung function, oxidative DNA damage and childhood leukemia.**

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References

1. Austin, E., Xiang, J., Gould, T.R., Shirai, J.H., Yun, S., Yost, M.G., Larson, T.V. and Seto, E., 2021. Distinct ultrafine particle profiles associated with aircraft and roadway traffic. *Environmental Science & Technology*, *55*(5), pp.2847-2858
2. Dröge, J., Klingelhöfer, D., Braun, M. and Groneberg, D.A., 2024. Influence of a large commercial airport on the ultrafine particle number concentration in a distant residential area under different wind conditions and the impact of the COVID-19 pandemic. *Environmental Pollution*, *345*, p.123390
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