Basel-Mulhouse Airport and Air Quality - part III: Immission by ultrafine particles *–analysis and determination of the potential hazard to the residents*

Authors
Jürgen Fingerle*, Oswald Rottmann[§], Wolfgang Herrmann[§], and Beat Freiermuth[#]
*BISF - Bürgerinitiative Südbadischer Flughafenanrainer - Postfach 21 D-79564 Weil am Rhein - info@euroairport-laerm.de
[§]BV Freising e.V. - Bürgerverein Freising e.V.- Graf-Moy-Str. 4 D-85356 Freising - kontakt@bv-freising.de
[#]ADRA - Association de Défense des Riverains de l'Aéroport de Bâle-Mulhouse -16 Rue de Leymen - F-68300 SAINT-LOUIS - info.adra@laposte.net

Corresponding author: Jürgen Fingerle
E-mail address: info@euroairport-laerm.de

Abstract
Ultrafine particles or **UFP**s are generated by the combustion of kerosene in modern jet engines in high numbers. Nanoparticles enter the human body and living cells exhibiting a considerable health hazard. In contrast to many other airports no assessment of the UVP situation has been carried out at the Basel-Mulhouse airport We thus took advantage of modern hand-held devices to elucidate this yet undetermined potential hazard generated by the airport beyond noise, classical pollutants and CO_2.
We found UFPs emitted by aircraft jets and distinguished them from industrial soot or diesel car emissions. We can show very high concentrations of UFPs at the perimeter of the airport. Our measurements are intended to alert the airport and the responsible authorities to introduce an UFP monitoring into the pollution assessment of the airport. We do not claim to have quantitatively and reproducibly assessed the ultrafine particle burden generated by the airport. However, we can establish with the use of simple means that data can be provided to identify the likelihood of health thread for people living near the airport.

Introduction
Ultrafine particles generated by combustion processes like diesel engines or kerosene jet engines are recognized as a specific health hazard[1-17].
In contrast to the particles classically measured as PM10 or PM2.5, UFPs are so small that they are not blocked in the airway or the lungs, but cross the pulmonary alveolus easily and enter the blood stream followed by deposition in bodies periphery. As a consequence of the toxic chemical nature of UFPs derived from kerosene combustion, these particles elicit a significant and specific health hazard.

PM10 smaller 10 µm	PM2.5 smaller 2.5 µm	PM1 smaller 1 µm,	UFP smaller 0.1 µm =100nm

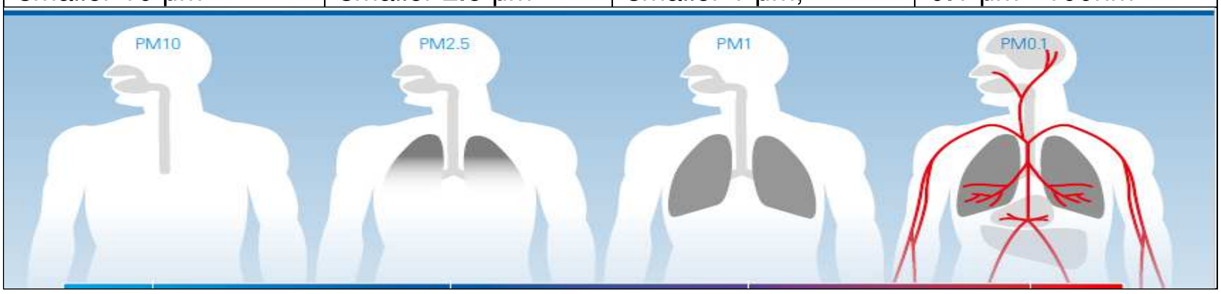

Fig. 1: Penetration depth of particles from https://www.afprofilters.com/particulate-matter-air-filters/

Their small size provokes the additional difficulty of quantification. While PM10 or PM2.5 particles are large enough to be retained on conventional filters and measured by their weight, ultrafine particles are smaller than 100 nm and too light to be determined accurately by their mass. For comparison, the diameter of UFPs is more than 500 fold smaller than a human hair. Thus UFP burden is assessed by their concentration as particles per volume. The count rate of the measuring devices is influenced by the lower size detection limit, typically around 5-30 nm. Furthermore temperature, humidity and sunlight have a major impact on pollutants and influence both the particle formation as well as their detectability. These technical difficulties have to be considered if data from different sources are compared[18].

Especially for diesel cars the health issues caused by UFPs are now recognized by the authorities and begin to influence the legislation at least. The newer rules for European cars demand for the first time a limit for such small particles. To acknowledge the measuring challenges, the sizes considered are 28-100 nm. According to the Euro 6 regulations for example passenger car engines, diesel or petrol, can't emit more than $6x10^{11}$ such UFPs per km which, for diesel cars compares to roughly 1,6 $x10^{12}$ UFPs per liter fuel (EU regulations 692/2008 and 459/2012).
These emission values sound enormously high. For comparison, normal air harbors some thousand UFPs per cm^3 and ultraclean air in high altitude has 1000 UFPs per cm^3. The question remains to how many particles do these emissions translate in the air we breathe in the vicinity of airports and what level of health hazard does result from this contamination. The technical issues around the accurate determination of UFPs as well as some political pressure by the air traffic lobby has prevented the authorities so far to issue a threshold value for UFPs jet engine aircrafts.
Nevertheless, the health hazards caused by UFPs are well described. The WHO commission IARC (international agency for research on cancer) judges UFP in conjunction with PM2.5 to be carcinogenic. The WHO even emphasizes that there is no lower limit where health hazards by UFPs can be excluded with certainty[19].

A further peculiarity of civil jet aircraft emitted UFPs is their even smaller size as compared to diesel car UFPs. Moreover, jets emit much higher numbers. It is well known and documented[20] that modern jet engines emit particularly small particles with a mean diameter of only 13 nm. The size is however somewhat dependent on the respective thrust levels. The difference in size between jet-UFP and those derived from industry soot, furnaces or cars allow an elegant separation of the respective UFP source.
As far as 20 km from airports increased UFP concentrations can be measured, whereas UFP-concentrations fall already to background level at a distance of some 100 m from a highway road.

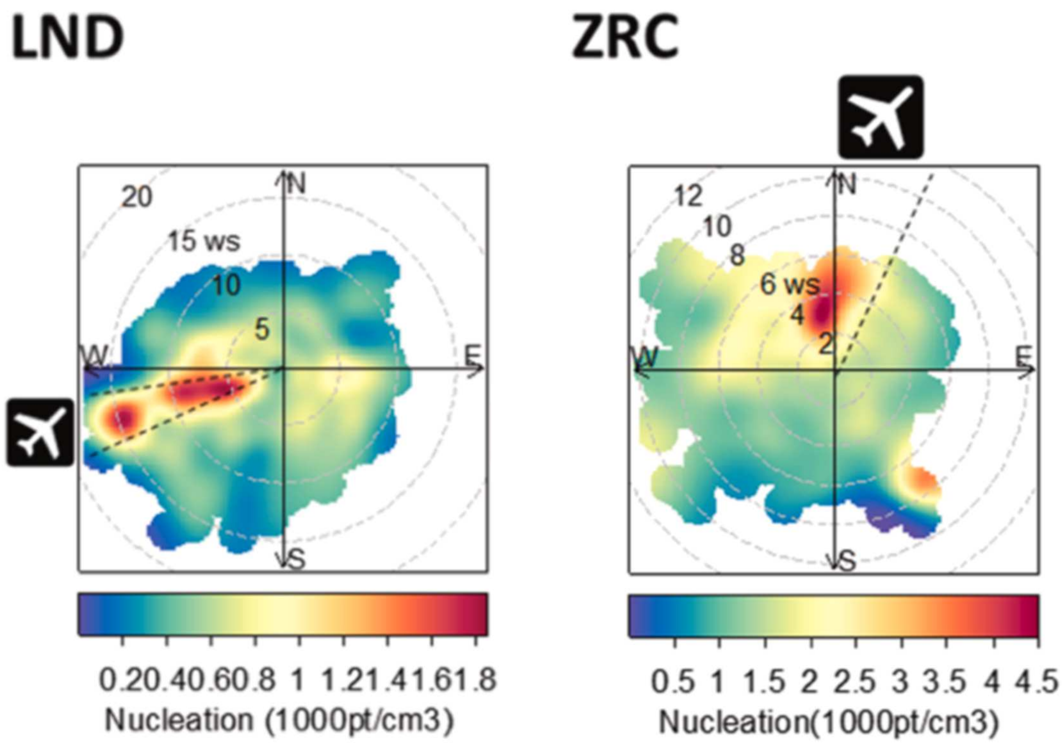

Fig. 2: [from Rivas 2020[21] fig 6; see text] The polar plots show contributions to the generation of ultra fine particles as a function of wind speed and wind direction within the cities of Zürich (ZRC) and London (LND). What the publication calls "nucleation" denominates the secondary generation of ultrafine particles (from gas to particle conversion). These processescan be initiated by eg via sulphuric acid derived from oxidation of fuel sulphur, which is still present in kerosene. Although particles generated b nucleation are smaller than 20nm, for London the recorded particle sizes were 17-604nm; for Zürich 10-487nm.
The diagrams show the number of particles at the respective stations which are at "Kaserne" in the center of Zürich close to the main railway station (10km distant from Zürich Kloten airport) and "North Kensington", which is located at Sion Manning School in St Charles Square (18km distant from London Heathrow airport).
For both cities the highest contamination is measured if the wind blows from the direction of the respective airports.
It is easy to depict that high concentrations of ultrafine particles can only be registered at the measuring stations if the wind blows from the direction of the respective airports, irrespective of the local traffic and other sources. For London wind speeds from 2-3 up to 15 m/sec, for Zürich only wind speeds from 2-6m/s bring ultrafine particles to the center of the city, implying that higher wind speeds lead to a dilution of the particles.

For many cities data about UVP contamination and the suspected contribution of the airports was investigated[22-25]. A very recent publication[21] measured UVP size distribution and modeled rates of generation for the different particle fractions in European cities and found an astonishing clear correlation between wind direction and location of the airports, see figure 2 (showing examples for Zürich and London). The remarkable finding was that even at very distant measuring points the signature of airport pollution was detected. The Heathrow airport e.g. was about 20 km distant to the location of particle measurement (Kensington). The Zürich measuring station was at the "Kaserne" located in the city center about 10 km South of the airport.

While Zürich airport even published its own measurements[26], no one has considered those measurements at Basel as urgent. As long as there is no legal limit, the airport administration sees no need to perform UFP immission measurements. We thus took the effort and used commercial hand held UFP counters to provide an initial insight into the potential burden of

UFPs generated by the Basle-Mulhouse Airport traffic. We show that in the airport perimeter the concentration of UFPs goes up to over 3 Million UFPs per cm^3. Thus around the airport UFP concentration can be 100-fold higher than normal ambient air.

We are aware that the limited observation period of just some hours does not allow a quantitative assessment of the burden in the nearby towns.
But our initial measurements show that this very special pollution originating from the Basel-Mulhouse airport needs much further attention and should be included to the measuring campaigns that are required for other pollutants by the authorities.

Methods

Two portable measurement devices were used: P-Track (TSI) and DISCmini (Testo) both devices are able to determine the number and size of ultrafine particles. The P-Trak operates as a condensation Particle counter (CPC) while the DISCmini is an electrometer charging the particles. The P-Trak is able to detect particle sizes between 20 and 1000 nm and the range of DISCmini covers the size of 10 to 700 nm. In order to reduce the limitations of the individual device accuracy we used these two different devices in parallel to determine particle sizes and numbers.

The input tubing of the devices were fixed to the left rear window of a normal civil car and the devices connected to the 12 V car electrical supply. The actual location was recorded using a portable GPS device and the time of recording of the particle number/size was synchronized with time and GPS position.

The output parameters provided by the devices were:
a) total number of particles
b) average size of particles
c) the relative amount of particles between 10-20 nm within a sample to indicate the presence of typical aircraft jet engine size fraction.
d) the „lung deposited surface area (LDSA)". This parameter is an indicator of the alveolar area potentially affected by the uptake of the ultrafine nanoparticle aerosols. There is no lower limit where toxic effects can be excluded. Reference values in towns range over 10 – 150 μm^2 per cm^3 volume of air.

With this set up we measured from 6:40 pm until 8 pm on Friday April 27th and from 11:45 am until 3:30pm on Saturday 28th of April 2018 at different locations in the vicinity of the airport. All sites were in the unrestricted area and could be reached by car.
The goal was to show which UFP size fractions and concentrations occur in the ambient air in the vicinity of the airport.

Results

We first drove from Germany over the Palmrain bridge to the airport and measured the pollution along the at that time busy connecting road, see figure 3. Only in the close vicinity of the A35 an increase in particle numbers was evident, which was limited to 50.000 pt/cm3 and the particle size did not drop below 30 nm. But then arriving at the airports catering building the size distribution shifted to significantly lower values.

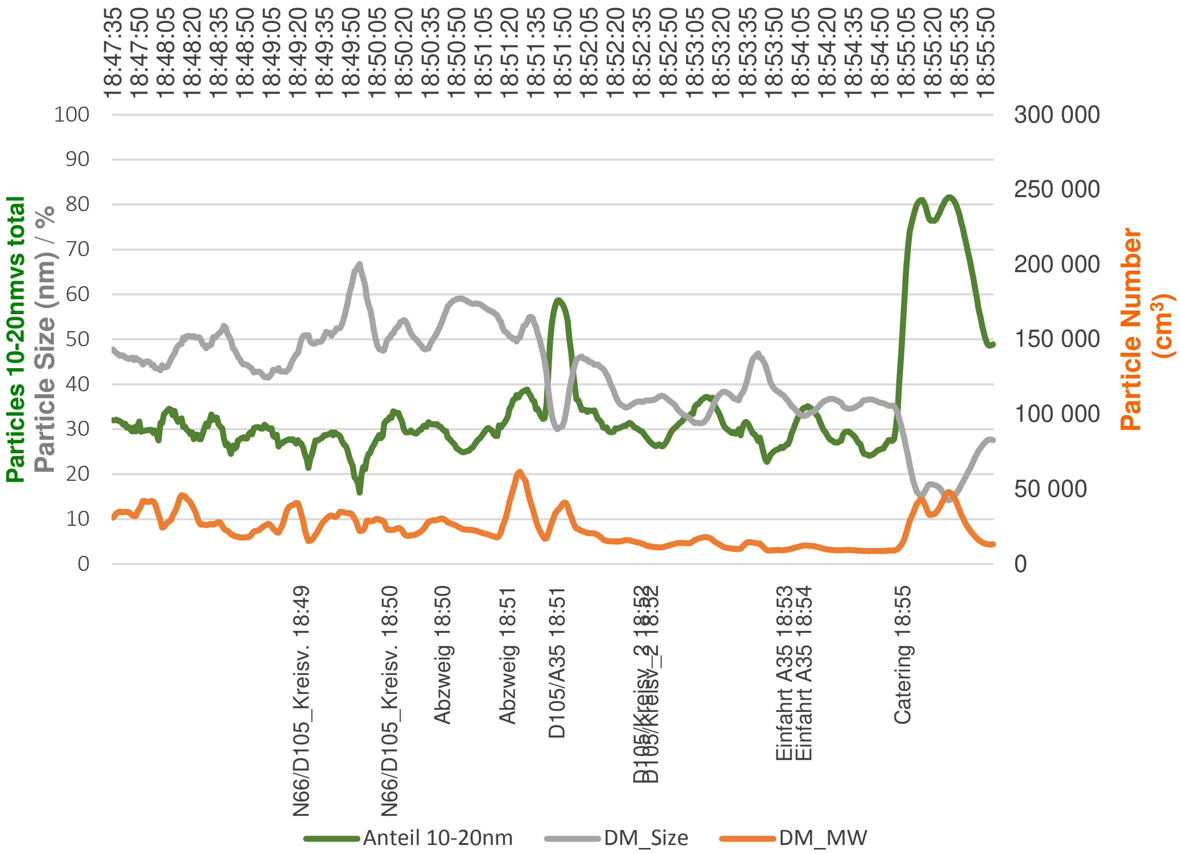

Fig 3 shows the recorded data on the tour from Weil am Rhein over the Palmrain bridge and D105 via St Louis to the south end of the airport.

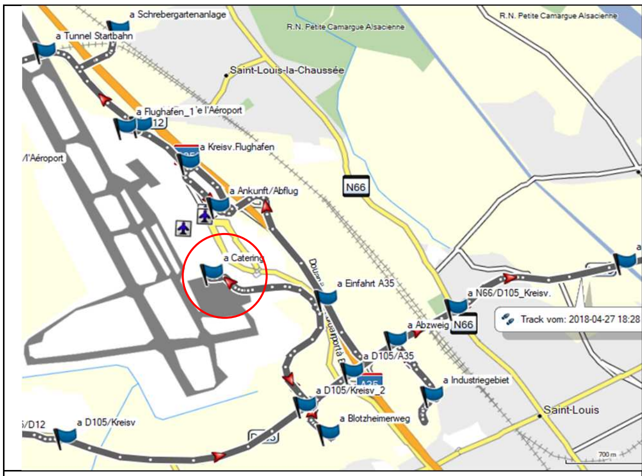	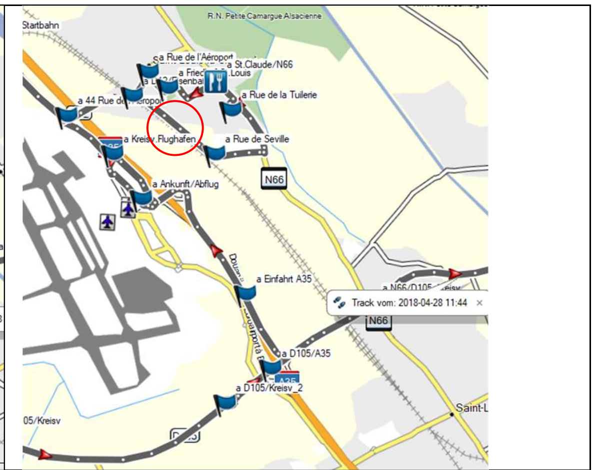
Fig. 4a: Tour track to reach the catering building arriving from Germany on D105	*Fig. 4b: Track for figure 6. Indicated is the zone of high concentration in Saint-Louis-la-Chaussée*

Our first stationary measuring position, see map in figure 4a took place at the catering building close to the gates. The air temperature was 23°C and the dew point ~ 3°C. Soon after we arrived an aircraft in upwind position to us was pushed back and started the engines. The north westerly wind, according to METAR 6 km/h with gusts up to 15 km/h, was strongly kerosene scented. This sensual impression correlated well with the collected data. And whenever the particle number rose from its background level of about 10'000 pt/cm^3 the dominating particles size represented the 10-20 nm size fraction, see figure 5.
If we consider 10'000 UFPs per cm^3 as normal for air in urban settings, it has to be **acknowledged that aircraft emissions can generate more than a 100 fold increase in UFP** burdens at close downwind locations.

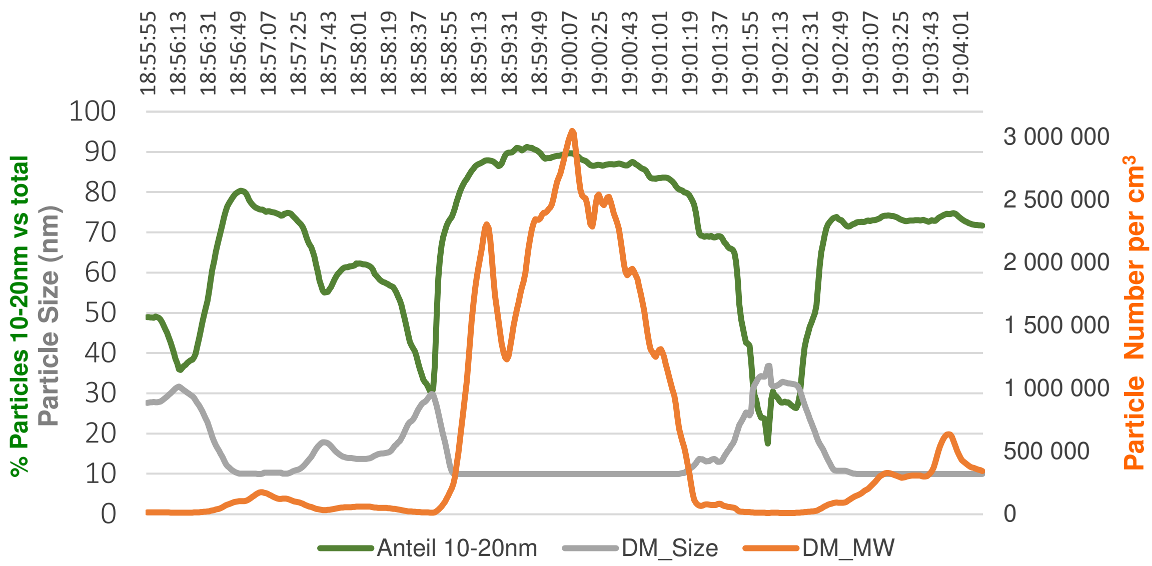

Fig. 5 shows the UVP signature of a departing aircraft that just started the jet engines during push back. The distance to the aircraft during the measuring period was as close as 150m. The relative amount of small particles (green line) increases up to 90% and the number of UVPs peaks at 3 Million pt/cm^3. Initially the average size (gray line) of the particles in the air is about 30 nm, but it decreased to the lower detection limit of 10 nm as soon as combustion air was present. The straight line indicates that many particles emitted by the jet turbines must be even smaller than 10 nm.

The next day on April 28th the wind blow less intense, with just gusts up to 6 km/h and the wind direction changed several times around noon time. The air temperature was around 16°C and the dew point 7°C. We surrounded the airport by car taking continuous measurements and collected data from further locations at the east and west side. In figure 6 again the very characteristic difference of road traffic pollution and jet exhaust is demonstrated. At 12:02:42, coming from the airport terminal building, we crossed the bridge over the highway A35 heading towards Saint-Louis-la-Chaussée. Near the highway a clear increase of the average particle size was observed, that quickly fell to background values after the A35 bridge. We then drove along the railway line to the south. At the perimeter of the residential area, just before the turnoff to the rue de Seville, we encountered for about 20 s a very localized high concentration zone of pollution with the typical small particle distribution for jet exhaust. At a car speed of 30 km/h this corresponds to a spread of about 200 m. Considering that this point was at the distance of 1 km from the terminal building or 1.2 km from the runway the concentration of 300'000 particles per cm^3 was astonishing high and showed that substantial UFP pollution will reach residential areas.

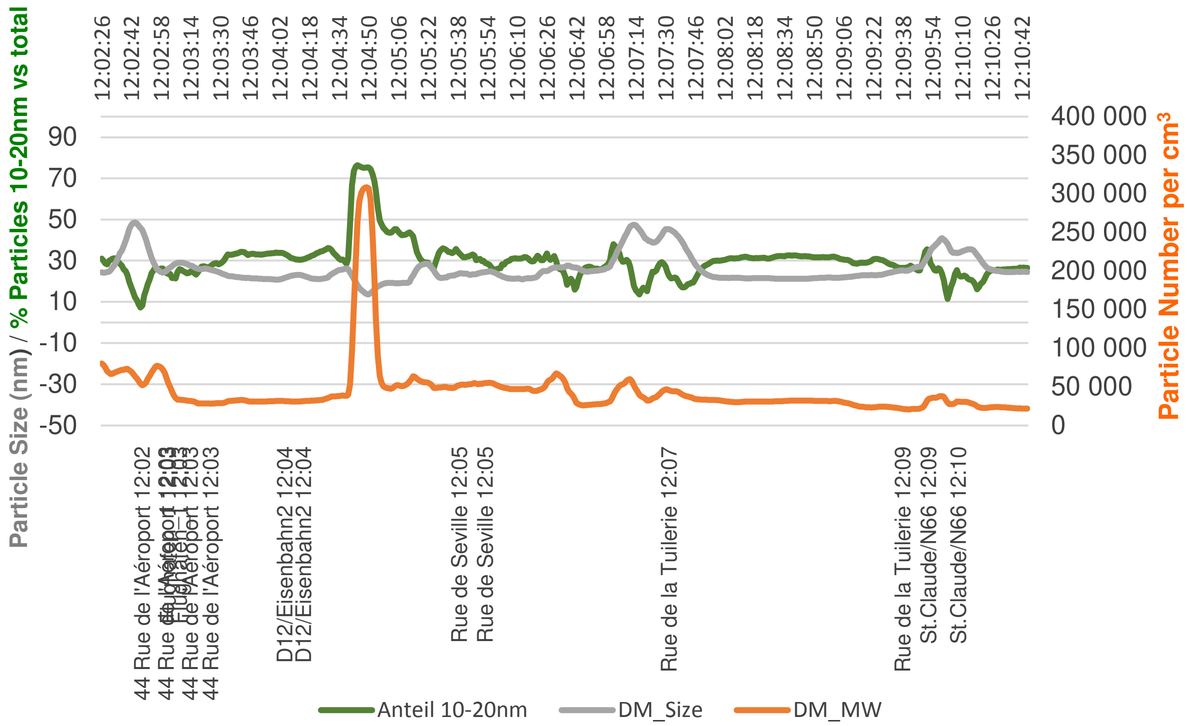

Fig. 6 Continued recording by car on April 28th at noontime, see map in figure 4b. Track description: arriving from the terminal building, crossing the highway A35 towards Saint-Louis-la-Chaussée, then following the railway lines to the south, turnoff into rue de Seville before returning by small residential roads to the north.

Discussion

Our goal was to provide evidence for the relevance of the burden of UFPs emitted by the Basel-Mulhouse airport and to generate sensibility for ultrafine particles[27]. In consequence we request from the airport, from the responsible air surveillance authorities, and from politicians to initiate an in depth evaluation of the UVP contamination, that spreads into the residential areas in a perimeter of minimally 20km around the airport.

The health impact of combustion derived UFPs is documented in many scientific papers. In contrast to larger airborne particles, which are measured as PM10 or PM2.5 UFPs up to one Million times smaller. The ultrafine particles thus penetrate all barriers in the human body and enter lung and cells in a way that from the inhaled UFPs 90% remain initially in the body. Due to their chemical composition and reactivity UFPs are a source of the so called oxidative cell stress[28] and inflammation[29]. A drastic example was recently published in a study performed in Mexico City, suggesting that UFPs can cause premature Alzheimer`s disease[3].

A further peculiarity of the small mass of UFP is their unhindered distribution by wind, their interaction with other pollutants in the air and with sunlight. It has been shown that UFPs can be detected from their source for up to 20 km. Considering that from the Basel-Mulhouse airport only a small number of heavily polluting long distance flights depart, the critical zone will be reduced, but is expected have still a radius auf about 10 km. This means contamination by ultrafine particles from the airport must be considered as relevant at least from Berentzwiller in the West to Sierentz and Kembs in the North; Rümmingen, Riehen and Grenzach in the East, and Therwil in the South. This fully covers the area of Basel and Weil am Rhein including the western part of Lörrach.

Although we did not attempt to generate time averaged data for a specific location our results show:

- There is a considerable UFP immission generated by the airport activity in the nearby residential area.
- The UFPs from jet engines have a different size distribution and therefore can be distinguished from other sources such as road traffic.

In close vicinity to an aircraft on block with engines running ready for taxiing we could detect up to 3 Billion jet-derived UVPs per liter of breathing air. This is about 1000 fold above normal background levels and 1.000.000 fold higher as compared to clean air (alpine regions). We also show that at a substantial distance to the airport we were still able to identify and distinguish jet emissions from other sources.
The correlation between flight activity and its generated UVP burden is certainly complicated by the wind conditions. Our examples however show that with a combination of moving and stationary measurements the burden to the local population can be qualitatively determined.

In conclusion we state that the Basel Mulhouse airport does emit considerable amounts of UFPs which can be detected applying relatively simple methods.

In contrast to other airports, Basel-Mulhouse does not seem proactive in assessing and minimizing the UFP burden it generates.
Whereas other European airports proudly announce their achieved environmental improvements seen e.g. in Zürich Kloten [30] the Basel airport is not even willing to give clear timelines for the overdue pollution reduction steps, such us:

- Giving the airline strong incentives to longer visit the Basel airport with up to 30 years old heavily pollution cargo airplanes.
- Optimize apron traffic and minimize the delay to takeoff by introducing not just the low level, but the comprehensive Airport Collaborative Decision Making (A-CDM) process
- Supply of 400 Hz electrical grid power for <u>all</u> gates to limit kerosene driven APU use and phase out GPU use.
- Providing cooled air (PCA) for all gates where long distance flights depart
- Stopping to send several aircraft just before midnight onto the congested taxiway in order to have a gate departure time still before the night curfew starts.

The last point is a possible due to the special French regulation, that uses for the time restrictions the hardly noise relevant gate departure time and not the takeoff time that most other European airports apply.
To provide an illuminating example we refer to Table 1 which illustrates the time difference of 5 aircrafts between departure from their gates, and waiting with running engines on the apron for average 14 min prior to takeoff. The total time on the apron was thus 70 min with an estimated fuel consumption of 2 tons of kerosene. Calculating with $3x10^{14}$ UVPs /kg kerosene $6x10^{17}$ UVPs are generated. This evenly distributed would fill an air volume of 50x400x1000m with 30.000 UFPs/cm^3.

Reverting to our data we thus urge the airport to rethink the situation and include UFP assessment and reduction within his environmental strategy. And we expect not just declarations of intention but hard actions with binding timelines.

Table 1: Example of fuel waste at the Basel-Mulhouse airport at midnight on July 27th 2019

Departure time from gate	**Takeoff time on runway 15**	**Aircraft Type**
23:48	00:02	B752
23:55	00:07	A319
23:57	00:09	A320
23:57	00:12	?
23:58	00:15	A332

Literature

1. Bai, L.; Weichenthal, S.; Kwong, J. C., Burnett, R.T., Hatzopoulou, M., Jerrett, M., van Donkelaar, A., Martin, R. V., Van Ryswyk, K., Lu, H. (2018). Associations of Long-Term Exposure to Ultrafine Particles and Nitrogen Dioxide With Increased Incidence of Congestive Heart Failure and Acute Myocardial Infarction. *Am. J. Epidemiology*, 188, 151-159

2. Barrett, S.R.H., Britter, R. E., Waitz, I. A. (2010). Global Mortality Attributable to Aircraft Cruise Emissions. *Environmental Science & Technology*, 44(19), 7736–7742

3. Calderón-Garcidueñas L., Torres-Jardón R., Kulesza R.J., Mansour Y., González-González L.O., Gónzalez-Maciel A., Reynoso-Robles R., Mukherjee P.S. (2020). Alzheimer disease starts in childhood in polluted Metropolitan Mexico City. A major health crisis in progress. *Environmental Research*, 183, 109137

4. Cohen A.J., Brauer M., Burnett R., Anderson H.R., Frostad J., Estep K., Balakrishnan K, et al. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study. *The Lancet*, 389, 1907-1918

5. Corlin, L., Ball, S., Woodin, M., Patton, A., Lane, K., Durant, J., Brugge, D. (2018). Relationship of Time-Activity-Adjusted Particle Number Concentration with Blood Pressure. *International J. Environmental Research and Public Health*, 15, 1-20

6. Donaldson, K., Tran, L., Jimenez, L., Duffin, R., Newby, D. E., Mills, N., et al. (2005). Particle and Fibre Toxicology. *Particle and Fibre Toxicology*, *2*, 1–14

7. Goldberg, M.S., Labrèche, F., Weichenthal, S., Lavigne, E., Valois, M-F., Hatzopoulou, M. et al. (2017). The association between the incidence of postmenopausal breast cancer and concentrations at street-level of nitrogen dioxide and ultrafine particles. *Environmental Research*, 158, 7-15

8. Hoek, G., Boogaard, H., Knol, A., De Hartog, J., Slottje, P., Ayres, J.G., Borm, P., et al. (2010). Concentration response functions for ultrafine particles and all cause mortality and hospital admissions: Results of a European expert panel elicitation. *Environmental Sci. & Technology*, 44, 476-482

9. Kapadia, Z. Z., Spracklen, D. V., Arnold, S. R., Borman, D. J., Mann, G. W., Pringle, K. J., et al. (2016). Impacts of aviation fuel sulfur content on climate and human health. *Atmospheric Chemistry and Physics*, *16*(16), 10521–10541

10. Krauskopf, J., Caiment, F., van Veldhoven, K., Chadeau-Hyam, M., Sinharay, R., et al. (2018). The human circulating miRNome reflects multiple organ disease risks in association with short-term exposure to traffic-related air pollution. *Environment International*, 113, 26-34

11. Lavigne E, Lima I, Hatzopoulou M, Van Ryswyk, K., Mary Lou Decou, M-L., Luo, W., et al. (2019). Spatial variations in ambient ultrafine particle concentrations and risk of congenital heart defects. *Environment International*, 130, 1-7

12. Miller, M. R., Raftis, J. B., Langrish, J. P., McLean, S. G., Samutrtai, P., Connell, S. P., et al. (2017). Inhaled Nanoparticles Accumulate at Sites of Vascular Disease. *ACS Nano*, 11, 4542–4552

13. Ostro, B.; Hu, J.; Goldberg, D.; Reynolds, P.; Hertz, A.; Bernstein, L.; Kleeman, M.J. (2015). Associations of mortality with long-term exposures to fine and ultrafine particles, species and sources: Results from the California Teachers Study Cohort. *Environmental Health Perspectives*, 123, 549-556.

13. Peters, A., Hampel, R., Cyrys, J., Breitner, S., Geruschkat, U., Kraus, U., et al. (2015). Elevated particle number concentrations induce immediate changes in heart rate variability: A panel study in individuals with impaired glucose metabolism or diabetes. *Particle and Fibre Toxicology*, 12, 1-11

15. Seaton, A.; Godden, D.; MacNee, W.; Donaldson, K. (1995). Particulate air pollution and acute health effects. *The Lancet*, 345, 176-178.

16. Weichenthal, S., Bai, L., Hatzopoulou, M., Van Ryswyk, K., Kwong, J. C., Jerrett, M., et al. (2017). Long-term exposure to ambient ultrafine particles and respiratory disease incidence in Toronto, Canada: a cohort study. *Environmental Health*, 16, 1-11.

17. Weichenthal, S., Lavigne, E., Valois, M.-F., Hatzopoulou, M., Van Ryswyk, K., et al. (2017). Spatial variations in ambient ultrafine particle concentrations and the risk of incident prostate cancer: A case-control study. *Environmental Research*, 156, 374-380.

18. Chow JC, Watson JG. Review of Measurement Methods and Compositions for Ultrafine Particles. Aerosol Air Qual Res. 207AD;7(2):121-173.

19. WHO Regional Office for Europe. (2013). Review of evidence on health aspects of air pollution – REVIHAAP Project, 1–309.
http://www.euro.who.int/__data/assets/pdf_file/0004/193108/REVIHAAP-Final-technical-report.pdf

20. Brem, B.T., Durdina, L., Setyan, A., Kuo, Y.-Y., Bahk, Y.K., Buha, J., et al.. (2016). Particulate Matter and Gas Phase Emission Measurement of Aircraft Engine Exhaust Final Report (04/2012 – 11/2015). EMPA-Report, 1–133
https://www.bazl.admin.ch/dam/bazl/de/dokumente/Politik/Umwelt/PM%20Measurement%20of%20Aircraft%20Engines_Swiss%20Research%20Public%20Results_2012-2015.pdf.download.pdf

21. Rivas, I., Beddows, D. C. S., Amato, F., Green, D. C., Järvi, L., Hueglin, C., et al. (2020). Source apportionment of particle number size distribution in urban background and traffic stations in four European cities. Environment International, 135, 1-19

22. Hudda, N., Simon, M. C., Zamore, W., Durant, J. L. (2018). Aviation-Related Impacts on Ultrafine Particle Number Concentrations Outside and Inside Residences near an Airport. Environmental Science & Technology, 52, 1765–1772

23. Keuken, M. P., Moerman, M., Zandveld, P., Henzing, J. S., Hoek, G. (2015). Total and size-resolved particle number and black carbon concentrations in urban areas near Schiphol airport (the Netherlands). Atmospheric Environment, 104, 132-142

24. Stacey, B., Roy M.Harrison, RM.,Pope, F. (2020). Evaluation of ultrafine particle concentrations and size distributions at London Heathrow Airport. Atmospheric Environment, 222, 117148

25. Weichenthal, S., Van Ryswyk, K., Goldstein, A., Shekarrizfard, M., Hatzopoulou, M. (2016). Characterizing the spatial distribution of ambient ultrafine particles in Toronto, Canada: A land use regression model. Environmental Pollution, 208, 241-248

26. Fleuti, E. (2017). Ultrafine Particle Measurements At Zürich Airport, Zürich Airport Publication, 1–14; https://www.zurich-airport.com/~/media/flughafenzh/dokumente/das_unternehmen/laerm_politik_und_umwelt/2017-03_zurich-airport_ufp_study.pdf

27. AQEG (2018). Ultrafine Particles (UFP) in the UK, UK Department for Environment, Food and Rural Affairs, London, PB14510; http://eprints.whiterose.ac.uk/156631/

28. Jonsdottir HR, Delaval M, Leni Z, et al. Non-volatile particle emissions from aircraft turbine engines at ground-idle induce oxidative stress in bronchial cells. Communications Biology. February 2019:1-11

29. Hertel, S., Viehmann, A., Moebus, S., Mann, K., Bröcker-Preuss, M., Möhlenkamp, S., et al. (2010). Influence of short-term exposure to ultrafine and fine particles on systemic inflammation. European Journal of Epidemiology, 25(8), 581–592

30. Fleuti, E. (2015). Environmental Benefits of A-CDM at Zurich Airport, Zürich Airport Publication, 1-4; https://www.zurich-airport.com/~/media/flughafenzh/dokumente/das_unternehmen/laerm_politik_und_umwelt/2015-10_a-cdm_env-benefits_zrh.pdf