Particulate matter from aircraft engines affects airways

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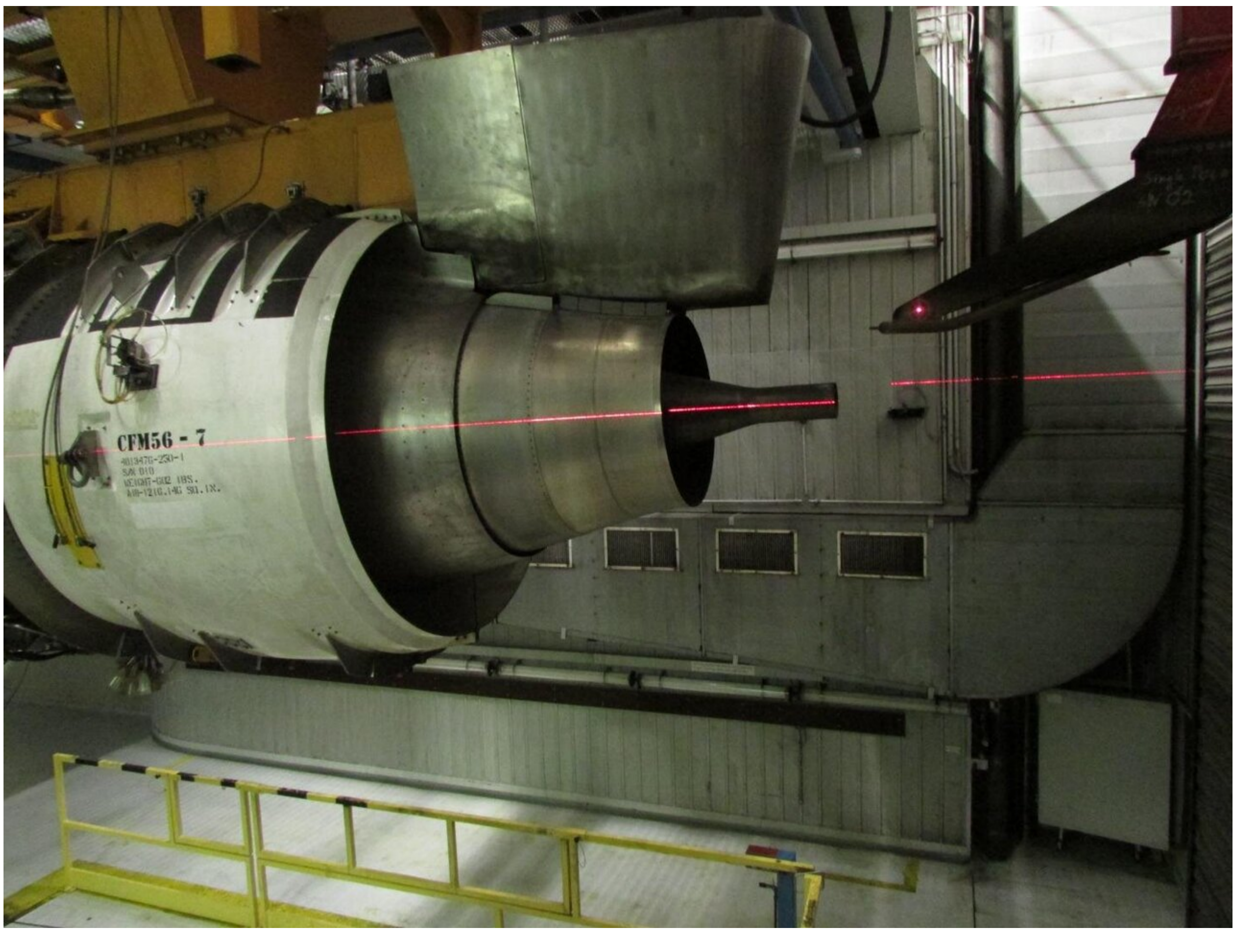

Close-up of the turbine engine at the testing facility with the aerosol sampling probe in place (right). Credit: University of Bern /SR Technics Switzerland AG

In a unique, innovative experiment, researchers under the leadership of the University of Bern have investigated the effect of exhaust particles from aircraft turbine engines on human lung cells. The cells reacted most strongly to particles emitted during ground idling. It was also shown that the cytotoxic effect is only to some extent comparable to that of particles from gasoline and diesel engines.

According to the World Health Organization (WHO), seven million people worldwide die as a consequence of air pollution every year. For around 20 years, studies have shown that air-borne particulate matter negatively affects human health. Now, in addition to already investigated particle sources like emissions from heating systems, industry and road traffic, aircraft turbine engine particle emissions have, in the wake of increasing air traffic, also become more important. As a result, scientific research of the particulate matter from air traffic is important for the development of environmental standards in the aviation sector.

The primary solid particles, i.e. those emitted directly from the source, have the strongest effect on people in its immediate vicinity. However, the toxicity of the solid particles from aircraft turbine engines is still widely unresearched. Now a multidisciplinary team, led by lung researcher Marianne Geiser of the Institute of Anatomy at the University of Bern, together with colleagues from Empa Dübendorf and the University of Applied Sciences and Arts Northwestern Switzerland (FHNW), has shown that primary soot particles from kerosene combustion in aircraft turbine engines also cause direct damage to lung cells and can trigger an inflammatory reaction if the solid particles—as simulated in the experiment—are inhaled in the direct vicinity of the engine. The researchers demonstrated for the first time that the damaging effects also depend on the operating conditions of the turbine engine, the composition of the fuel, and the structure of the generated particles. The present study was published in the journal *Nature Communications Biology*.

Extremely small particles in the nanoscale range

Particles emitted from aircraft turbine engines are generally ultrafine, i.e. smaller than 100 nm. By way of comparison, a human hair has a diameter of about 80,000 nm. When inhaled, these nanoparticles—like those from other combustion sources -efficiently deposit in the airways. In healthy people, the well-developed defense mechanisms in the lungs normally take care of rendering the deposited particles ineffective and removing them from the lungs as quickly as possible. However, if the inhaled particles manage to overcome these defense mechanisms, due to their structure or physico-chemical properties, there is a danger for irreparable damage to the lung tissue. This process, already known to researchers from earlier experiments with particle emissions from gasoline and diesel engines, has now also been observed for particle emissions from aircraft engines.

Unique interdisciplinary experimental setup

In innovative, combined experiments, the researchers investigated the toxicity of particles from the exhaust of a CFM56-7B turbofan, which is the most commonly used aircraft turbine engine globally. The turbine was run in climb mode (simulating aircraft take-off and climb) and at ground idling speed at the SR Technics testing facility at Zürich Airport. Within this framework, the researchers were able to use a globally standardized measurement method, applied for the environmental certification of aircraft engines. Fuel composition was also investigated: the turbine engine was run using conventional kerosene Jet A-1 fuel or biofuel. The latter is composed of kerosene fuel with 32% HEFA ("hydrogenated esters and fatty acids") from old frying oil, animal fats, algae and plant oils.

An aerosol deposition chamber developed specifically for investigating the toxicity of inhaled nanoparticles in vitro and built at FHNW, made it possible to deposit the generated particulate matter in a realistic way on cultures of bronchial epithelial cells which line the inner surface of bronchi. Thus, the researchers were able to deposit an aerosol directly on human lung cells, which would not have been possible in an experiment with human test persons for ethical reasons. Moreover, the particles were analyzed for their physico-chemical and structural properties to examine possible links with the effects of the particles. "This is a worldwide unique experiment, combining emission measurement technology with medical analyses under realistic conditions," says Benjamin Brem, aircraft turbine engine aerosol researcher at Empa, now at the Paul Scherrer Institute.

Toxicity depends on the operating conditions of the turbines and the type of fuel

The cells were exposed to the aerosol for 60 minutes. During this time, a particulate mass of 1.6 to 6.7 ng (billionths of a gram) per square centimeter of cell surface area was deposited while the turbine was running at ground idling, and 310 to 430 ng while it was in climb mode. This is equivalent to the daily airway intake of mildly polluted rural air with 20 µg (millionths of a gram) of particles per cubic meter of air up to heavily polluted air in a large city (100-500 µg of particles per cubic meter of air).

Evidence of increased cell membrane damage and oxidative stress in the cell cultures was identified. Oxidative stress accelerates ageing of cells and can be a trigger for cancer or immune system diseases. The particles turned out to cause different degrees of damage depending on the turbine thrust level and type of fuel: the highest values were recorded for conventional fuel at ground idling, and for biofuel in climb mode. These results were surprising. The cell reactions in the tests with conventional kerosene fuel at full engine thrust—comparable with takeoff and climb—in particular, were weaker than expected. "These results can be partly explained by the very small dimensions and the structure of these particles," says Anthi Liati, specialized in the nanostructure of combustion aerosols at Empa. Moreover, the cells responded to biofuel exposure by increasing the secretion of inflammatory cytokines, which play a central role in our immune system. "This reaction reduces the ability of airway epithelial cells to react appropriately to any subsequent viral or bacterial infections," explains Marianne Geiser.

Overall, according to the researchers, it has been demonstrated that the cell-damaging effect caused by exposure to particles generated by the combustion of gasoline, diesel and kerosene fuel are comparable for similar doses and exposure times. Additionally, a similar pattern was found in the secretion of inflammatory cytokines after exposure to gasoline and kerosene fuel particles.

"The state-of-the-art measurement methods used in our study, the interdisciplinary approach, and the resulting outcomes all constitute a further important step in the research on air pollutants and their effects on human health," says Geiser.

Aerosols: distance from the source is crucial

Aerosols are the finest solid or fluid substance suspended in the air. In combustion processes, the composition of ultrafine particles is highly variable. In addition, aerosols are unstable, and they are modified after their formation. Primary ultrafine solid particles have a high diffusion velocity. As a result, at high concentrations such particles either stick together or attach to other particles. Therefore, the effect of primary ultrafine particles depends on the distance from the source, implying that there is a difference depending on whether a person is close to the source (such as people at the roadside) or at a greater distance (aircraft taxiing or taking off). Further research is needed to clarify how strong the impact would be at a greater distance from an aircraft engine. .

Environmental measures already met—Switzerland's special commitment

Since the Swiss "Particulate Matter Action Plan" was introduced in 2006, the Federal Office of Civil Aviation (BAZL) has, based on the precautionary principle, advocated the introduction of particulate matter certification for aircraft engines and a particulate matter emission limit at the International Civil Aviation Organization's (ICAO). The BAZL established a measurement infra-structure and created the foundation for the research at SR Technics specifically for this purpose. It has been supporting top-level research in this field, which has significantly improved scientific understanding of aviation emissions and emission measurement technology, through "Special Financing of Civil Aviation" since 2012. The research led to the first global particulate matter standard for measuring particle mass and number in 2016. In February 2019, the ICAO's environment committee, on which all major manufacturing countries were represented, agreed on a recommendation for limits that should apply to new types of engine from 01/01/2023. The results of the present study contributed to establishing these global limits. So far, aviation is the only sector to have introduced global limits on the emissions of ultrafine particulate matter.

More information: Hulda R. Jonsdottir et al, Non-volatile particle emissions from aircraft turbine engines at ground-idle induce oxidative stress in bronchial cells, *Communications Biology* (2019). DOI: 10.1038/s42003-019-0332-7

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