Analysis of the particle size distribution near the civil airport runway

R Jasinski and K Przylebska

Poznan University of Technology, Institute of Combustion Engine and Transport, Piotrowo Street 3, 60-968 Poznan, Poland

e-mail: Remigiusz.w.jasinski@doctorate.put.poznan.pl

Abstract. Particles emitted from internal combustion engines are extremely dangerous to human health due to their very small size. Attempts to reduce particles emissions from motor vehicles, result in the installation of additional filters to purify the exhaust gases. In the case of aircraft, any interference in the exhaust system of the jet engine is unacceptable. For this reason, aircraft are an important source of particles emission in the regional aspect, so that airports can be considered as particles emission sources. The article evaluates the impact of aircraft take-off and landing operations on the concentration of particles in the ambient air. The measurements were carried out at the civilian airport area near the runway. Based on the measurements carried out, it was found that airport operations cause relevant changes in the concentration and size distribution of particles in the ambient air.

1. Introduction

Exhaust emission from internal combustion engines is the subject of analyses and scientific research due to its strict connection with deterioration of air quality and negative impact on human health. All over the world, and in particular in Europe, strict emission limits are introduced [1, 2]. In addition, new approval procedures are created to better simulate the actual conditions of vehicle operation [3, 4]. In the case of automotive, it is possible to purify the exhaust gases by aftertreatment systems. Due to the design and principle of turbine engines operation the above solution is impossible to implement in aviation [5].

One of the basic issues in case of assessing air quality is the concentration of particles [6]. Particles is a term generally used for the type of air pollutants, consisting of a complex of different mixtures of suspended particles that differ in size, composition and location. The main sources of this type of pollution include: factories, power plants, incinerators, motor vehicles and many more. The basic division of particles results from their aerodynamic diameter, which allowed to determine two main groups: PM2.5 and PM10 (Particulate Matter) for diameters smaller than 2.5 μm and 10 μm respectively [7]. The dynamic development of the particles issue and changes in their properties depending on their size forced a more detailed division. Ultrafine particles were assumed to be particles with a diameter of less than 1 μm and fine particles or nanoparticles are particles smaller than0.1 μm.

The pollution of the atmosphere with particles emitted by aircraft engines has a negative effect on human health. Particles with a diameter of 10 μm or less can cause diseases of heart and lungs, and related deaths. The intensity of diseases is combined with the long-term effects of particles in the environment. They contribute to the occurrence of diseases such as asthma and bronchitis. They are also one of the causes of cardiac arrhythmia and heart attacks. The most serious problems result from the interaction of fine particles. The lowest resistance to the negative effect of particles is demonstrated by people with heart and lung diseases, the elderly and children [8].

Determining the air quality is done by measuring the mass concentration of particulates (PM10 and PM2.5) in the air. The above method is ineffective due to the lack of determination of the particle number. Particularly dangerous are small particles with very small mass. Measuring only the mass content of particles in the air, without specifying their dimensions and number, it is not possible to determine the air quality effectively [9].

In the case of aircraft, regulations regarding particle emissions are reduced only to determination the Smoke Number parameter, which does not reflect the significance of the problem of particles emission especially theirs number [10]. Due to the lack of the possibility of testing exhaust emissions from aircraft engines in real flight conditions, measurements of air quality in the area of the airport are increasingly being conducted. The latest publications on particle measurements in airport areas are aimed at estimating the actual emission of PN (particle number) and its impact on air quality.

2. Methodology of the research

2.1. Purpose and conditions of the research

The purpose of the research was to determine the impact of take-off and landing operations on the concentration of particles in the air and their dimensional distribution. To achieve the goal, measurements of the particle number concentration in the vicinity of the civilian airport runway were made (Fig. 1).

Fig. 1. Poznan-Lawica airport and measuring area.

The research place was the Poznan-Lawica airport, located in close proximity to the city centre. The measuring apparatus was placed at a distance of 350 m from the threshold of the runway. The research was carried out on January 8th, 2018. Atmospheric conditions were typical for this season in Poland, the ambient temperature was 7°C and the windless conditions prevailed. The landings and take-offs of aircraft are dependent on the direction of the wind. Due to the windless conditions, ton that day the flight tower allowed pilots to choose from which direction they wanted to approach landing or take-off.

The tests consisted in measuring the concentration of the particles number in the air and its changes during the take-off or landing of an aircraft. In addition, the dimensional distribution of particles was measured. On the day of the tests, the aircraft performing the operations were Boeing 737-800 (Fig. 2a) and Bombardier CRJ-900 (Fig. 3a). The Boeing 737 was equipped with two jet engines CFM56-7B (Fig. 2b) while the Bombardier CRJ-900 had two CF34-8C jet engines (Fig. 3b). Technical specification of those two engines can be found in the Table 1.

a) b)

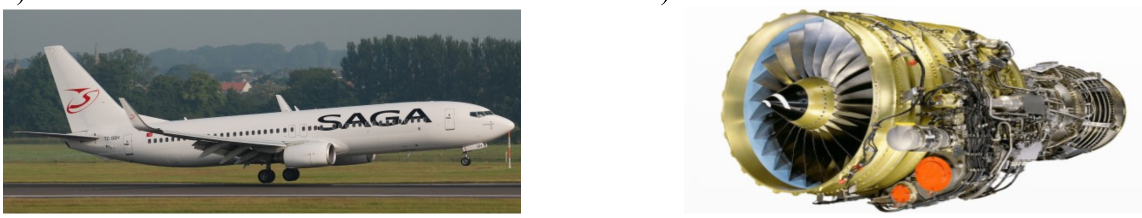

Figure 2. The view of Boeing 737-800 (a) and CFM56-7B jet engine.

a) b)

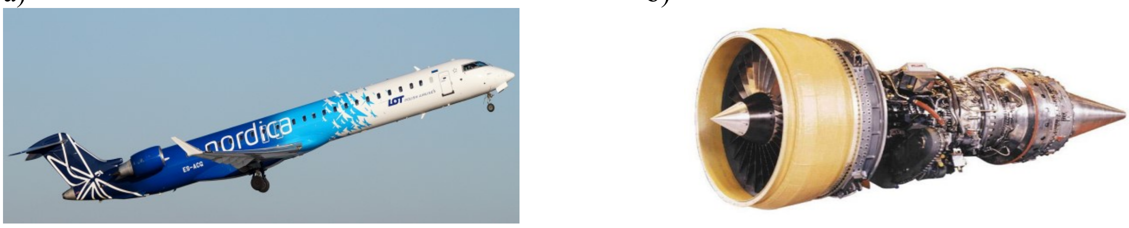

Figure 3. The view of Bombardier CRJ-900 (a) and CF34-8C jet engine.

Table 1. Technical specification of CFM56-7B and CF34-8C jet engines.

Parameter	CFM56-7B	CF34-8C
Maximum take-off thrust [kN]	108	62
Bypass Ratio [-]	5.1	5.1
Overall pressure ratio [-]	33	28
Thrust/weight ratio [-]	5.2	5.7
Weight [kg]	2370	1089
Length [mm]	2628	3251

2.2. Measuring apparatus

Measurement of particle diameters was performed with an EEPS 3090 (engine exhaust particle sizer™) (Fig. 4). It enabled the measurement of a discrete range of particle diameters (from 5.6 nm to 560 nm) on the basis of their differing speeds. The degree of electric mobility of particulate matter is changed exponentially, and measurement of their size is carried out at a frequency of 10 Hz.

Figure 4. The view and location of measurement equipment.

The sample is routed through a dilution system and to the spectrometer while maintaining at the desired temperature. The initial filter retains particles with a diameter greater than 1 micron, which are outside of the measuring range of the device. After passing through the neutralizer the particles are directed to the charging electrode; after getting electrically charged they can be classed by their size.

The particles deflected by the high-voltage electrode go to an annular slit, which is the space between the two cylinders. The gap is surrounded by a stream of clean air supplied from outside. The exhaust cylinder is built in a stack of sensitive electrodes isolated from one another and arranged in a ring. The electric field present between the cylinders causes the repulsion of particles from the positively charged electrode; then the particles are collected on the outer electrodes. When striking the electrodes, the particles generate an electric current, which is read bya processing circuit.

The measuring apparatus was set up in the approach axis for the landing and take-off of passenger aircraft. The measurements were divided into three phases: pre-landing measurement – to determine the measurement background; measurement during the landing – to determine changes in the concentration of particles during the landing operation; measurement after landing – to determine the maximum concentration of particles.

3. Research results and their analysis

The purpose of the measurements was to determine the change in the particles concentration in the ambient air caused by the aircraft take-off and landing. In addition, the particles size distribution was determined. The measurements were taken during single take-off operation of Bombardier CRJ-900 and its two landings, also the measurements were carried out during landing operation of Boeing 737.

The value of the particles concentration before the Bombardier's take-off operation was $1.8 \cdot 10^4$ cm–3. The aircraft's take-off caused a thirty-fold increase in the concentration of particles to the level of $5.2 \cdot 10^5$ cm^{-3} (Fig. 5a). The presented results of the particles concentration measurements in function of time were divided into four phases: reference level, take-off, dispersion and again reference level. The reference level corresponds to the particle concentration before the take-off or landing operation. The dispersion phase is the period in which the particle concentration stabilizes and equalizes to the level of the measuring background. In the case of Bombardier's take-off the dispersion phase lasted for 250 seconds. The average size distribution of particles during take-off and the phase of dispersion is shown in the Figure 5b. The dominant particles are from 6 to 15 nm. This is a characteristic dimensional distribution of particles for aircraft engines. Particles with these diameters are at the measurement limit. In spite of their very large number, they are invisible to the human eye, therefore they do not pose a threat. The fact is that they are the most dangerous to human health.

a) b)

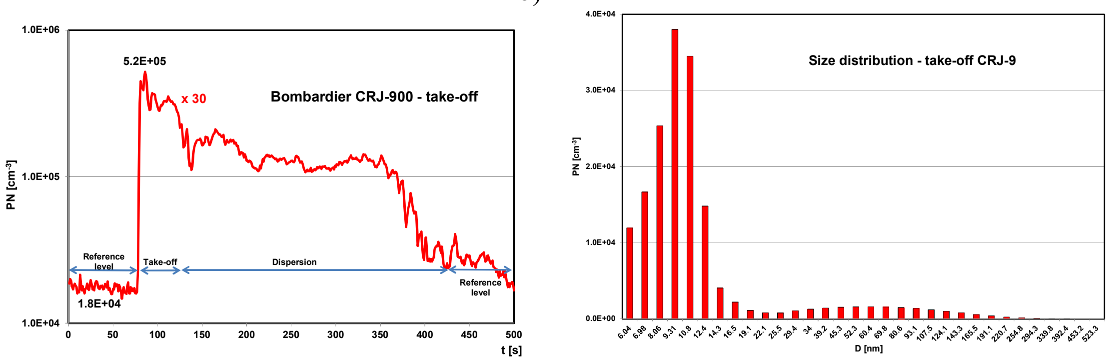

Figure 5. Total concentration of particles (a) and size distribution (b) during CRJ-900 take-off.

The value of the particles concentration before the Bombardier's landing operation was $1.1 \cdot 10^4$ cm^{-3} and was assumed as reference level. The aircraft's landing operation caused a twenty two-fold increase in the concentration of particles to the level of $2.4 \cdot 10^5$ cm^{-3} (Fig. 6a). The dispersion phase lasted for 200 seconds and was characterized by a turbulent course.

The average size distribution of particles during take-off and the phase of dispersion is shown in the Figure 6b. The dominant particles are from 6 to 15 nm, close to log-normal distribution. Particles with the smallest dimensions had the highest concentration. The resulting distribution is significantly different from the dimensional distribution determined during the start of the same aircraft model.

a) b)

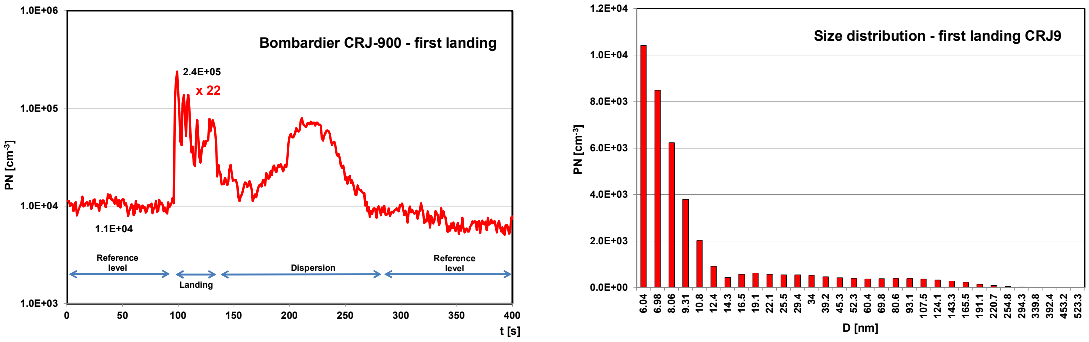

Figure 6. Total concentration of particles (a) and size distribution (b) during CRJ-900 first landing.

The value of the particles concentration before the Bombardier's second landing was 6.9 • 10^3 cm^{-3} and was assumed as reference level. The aircraft's landing operation caused almost twenty-fold increase in the concentration of particles to the level of 1.3 • 10^5 cm^{-3} (Fig. 7a). The dispersion phase lasted for 100 seconds. The dilution of particles emitted by the aircraft was regular. A clear landing and dispersal phase cannot be determined because the measurement results show only the dilution phase.

The average size distribution of particles during landing and the phase of dispersion is shown in the Figure 7b. The dominant particles are from 6 to 15 nm, close to normal distribution. The obtained dimensional distributions during landings differ, but the fact is that the dominant particles are those with diameter 6–15 nm.

a) b)

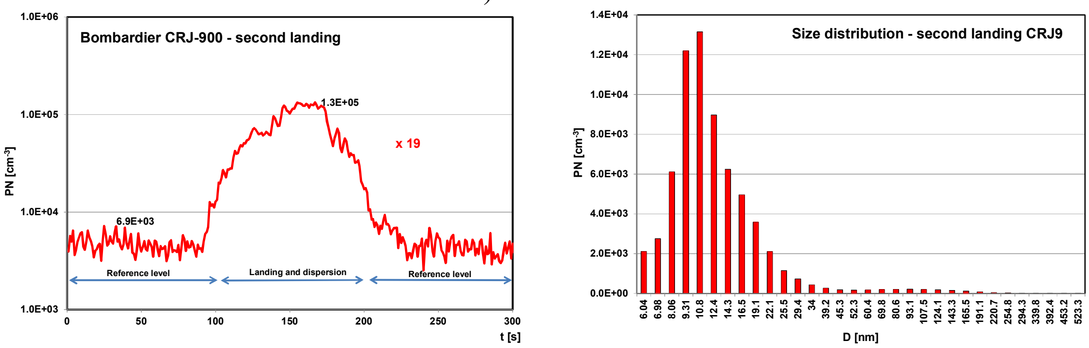

Figure 7. Total concentration of particles (a) and size distribution (b) during CRJ-900 second landing.

The value of the particles concentration before the Boeing landing was 4.7 • 10^3 cm^{-3} and was assumed as reference level. The particles concentration after landing was one thousand bigger and reached 1.3 • 10^5 cm^{-3} (Fig. 8a). The dispersion phase lasted for 200 seconds. The dilution of particles emitted by the aircraft was regular.

The average size distribution of particles during landing and the phase of dispersion is shown in the Figure 8b. The dominant particles are from 6 to 15 nm, close to normal distribution. The larger concentration of particles in the ambient air after Boeing landing is caused by the fact that it is equipped with twice as large engines as the Bombardier. This involves more thrust and a proportionally greater flue gas stream, which results in increased particles emissions.

a) b)

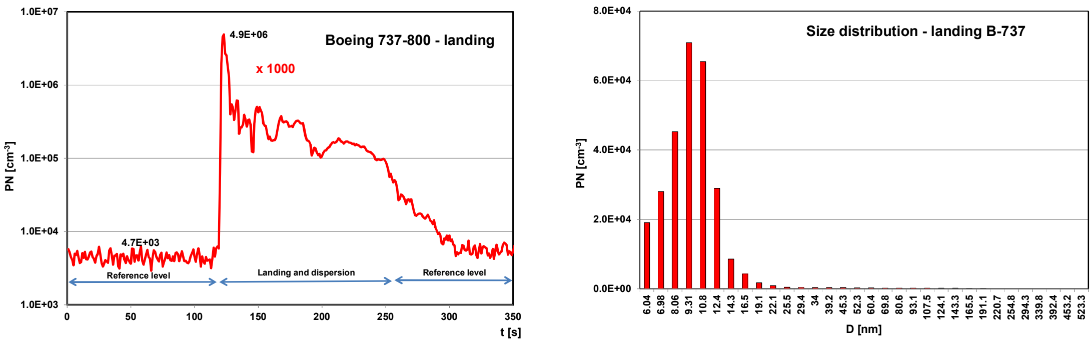

Figure 8. Total concentration of particles (a) and size distribution (b) during B-737 landing.

4. Summary

Based on the results of the tests, it was found that take-off and landing of the same model of aircraft show a different impact on the air in the area of the airport. During the start, the concentration of particles in the ambient air is clearly higher than after landing, while the dimensional distributions obtained in both cases are similar, the dominant particles are in the range of 6–15 nm. It was noted that the dispersion phase, whether the spread of particles and reducing their concentration takes up to twice as long in the case of take-off rather than landing. Landing operation of an aircraft equipped with engines with twice bigger maximum thrust resulted in up to fifty times greater increase in the concentration of particles in the air in comparison to smaller aircraft. The dimensional distribution of solid particles did not differ significantly from the distributions obtained in the case of aircraft equipped with smaller engines.

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