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EVALUATION OF THE IMPACT OF OIL PRESENCE IN THE AVIATION FUEL ON PARTICLE SIZE DISTRIBUTION

Summary. Emissions from aircraft engines represent a highly complex and important issue, which is related to the risk to human health. Particles emitted in urban areas and in the vicinity of airports affect air quality and have a particularly negative impact on airport workers. The development of measurement techniques and the methodology for evaluating exhaust emissions have allowed for the elaboration of appropriate procedures for the certification of aircraft and the enhancement of existing standards. Particulate matter emissions depend, among other things, on the composition of the fuel used and its additives. Some aircraft engine designs require a fuel additive in the form of oil, which ensures the proper operation of the fuel supply system. This article presents the results of studies conducted on jet engines powered by clean aviation fuel and fuel with the addition of oil. The aim of the study was to evaluate the effect of the addition of oil on the size distribution and concentration of emitted particles. It was found that, for small values of thrust, oil additive increases the concentration of particles. With an increase in the thrust force, the reduction of particles concentration was recorded in the case of the engine powered by fuel with oil additive. There was no significant effect of oil additive on the size distribution of emitted particles.

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1. INTRODUCTION

As a result of the high speed and intercontinental range of aircraft, air transport has become a major part of the global transport system [9]. For many years, there has been a strong correlation between the rate of growth in the largest global economies and the development of air services [10]. Comparing the growth of gross domestic product around the world and air traffic, it can be seen that the growth rate of air transport is greater than the growth of the global economy. According to an analysis of the largest manufacturers of aircraft (Airbus and Boeing), the growth in aviation in the near future will be much more dynamic than the world's economies. This is because of the dynamic development of low-cost carriers, increasing the capacity of the aircraft, the introduction of new fleet and the dynamic growth in emerging markets, such as China, India and Japan [3]. By 2020, according to forecasts, the market in the Far East will enjoy the highest growth in world traffic (by 31%). The rapid development of the Asian market will represent 27% of global air transport conducted in Asia [3].

The development of air transport is associated with increased external environmental costs, which, in accordance with EU definitions, include the impact of the air transport in terms of, inter alia, air pollution, climate change and noise [4]. These negative effects are due to the increasing volume of air traffic, as well as associated infrastructure expansion. Aviation infrastructure is associated with the occupation of large areas and has a crucial impact on the environment. The inherent aspect of the functioning of an airport is the handling of air traffic, which is associated with magnetic radiation and the possibility of aircraft collisions with animals. Another negative effect of air traffic is air pollution and its impact on greenhouse effects. According to the European Environment Agency, air transport only accounts for a 0.5% share of total emissions of nitrogen oxides and only 0.1% in emissions of non-methane organic compounds. That said, its impact, particularly on air quality in areas adjacent to airports, affects the composition of the atmosphere in the upper layers, where air transport is the only source of pollution. In turn, this negatively affects the atmosphere on a global scale and contributes to climate change and ozone layer impoverishment [2].

The various efforts to reduce toxic emissions are in response to the deterioration of atmospheric air quality, particularly in urban areas. Currently, one of the biggest problems concerning air quality in urban areas is the increased concentration of particulate matter [7, 8], resulting in a reduction of visibility in the form of smog, which also brings negative effects on human health appearing in the form of heart and lung disease [5].While the EU has taken legislative measures focused on reducing the emissions of harmful compounds from automotive vehicles, much more attention needs to be paid, especially by the scientific community, on exhaust emissions from aircraft engines.

One of the fundamental issues in the assessment of air quality is the concentration of particulate matter. The term "particulate matter" describes a type of air pollutant, consisting of different particle mixtures, which differ in size, composition and formation. There are many sources of particulate matter, such as factories, power plants and vehicles. The basic division of solid particles, due to their aerodynamic diameter, has allowed for the determination of two main groups, PM2.5 and PM10, which respectively refer to particulate matter with a diameter of less than 2.5 μm and 10 μm.

In recent years, attention has been increasingly paid to the emissions from areas around airports, due to the rapid increase in air traffic volume and the growing demand for air transport in the coming years. Most of the research and publications in this area offer an inadequate explanation of the phenomena, which are the subject of intensive research because, as the literature shows, air transport emissions can significantly affect the quality of the air in the vicinity of airports [1, 6].

In terms of particle emissions, the chemical composition of the fuel is very important. Fuel for Jet A-1 turbine aircraft engines is produced from components obtained under a specific regime involving the technological processes of hydrodesulphurization, hydrocracking and distillation. The components meet the established quality requirements. The fuel contains many additives (antioxidant and antistatic). The use of oil additive in the fuel is common in military and civil aviation in order to ensure the proper thermodynamic phenomena and friction. To date, the influence of additives in aviation fuel on particulate emissions is remains an unexplored issue.

2. OBJECTIVE AND METHODOLOGY

2.1. Purpose of the research

The aim of the study was to determine the size distribution of particles emitted by the GTM-120 jet engine, powered by Jet A-1 and Jet A-1 aviation fuel with a 3% addition of Mobil Jet Oil II.

Mobil Jet Oil II is a high-quality lubricant designed for aircraft gas turbines, based on a combination of a highly stable synthetic oil base and a unique additive package. This combination provides thermal and oxidation stability in order to counteract deterioration and deposit formation in both phases for both liquid and gas, as well as provide resistance to foaming. The effective range of oil operation is at temperatures between -40°C and 204°C.

Mobil Jet Oil II is designed for aircraft turbine engines used in commercial and military service requiring high performance. It was developed to meet the high requirements of aircraft gas turbines, operated in a wide range of difficult operating conditions. The product has a high specific heat in order to ensure a good heat conduction from oil-cooled parts of the engine. According to extensive laboratory testing and the verification of performance during flights, oil stability can be observed at temperatures up to 204°C. At the same time, the evaporation rate at this temperature is low enough to prevent excessive fluid loss.

Determination of the size distribution of particles based on the used fuel mixture allowed for the effect of oil on the emission of a jet engine to be determined. Measurements were carried out under laboratory conditions on a prepared test stand.

2.2. Test object and measurement equipment

The object of the study was the GTM-120 turbine engine (Fig. 1), constructed of a single-stage radial compressor and driven by a single-stage axial turbine. The test stand with the engine allows for the measurement of the shaft speed, exhaust gas temperature at the nozzle, thrust, and exhaust gas mass flow. Particle size distributions were measured at six points, including in terms of minimum and maximum thrust values. The measurements were performed twice, once for each fuel mixture used.

For measuring the size distribution of particles, a TSI Incorporated - EEPS 3090™ mass spectrometer was used, which enabled the measurement of a discrete particle diameter range (from 5.6 nm to 560 nm) on the basis of their different speeds. The scope of the electric mobility of the particle matter was exponentially changed, with the particles' size measured at a frequency of 10 Hz.

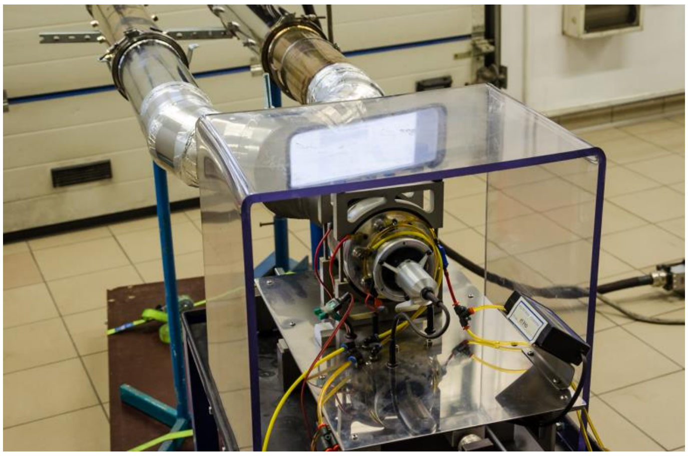
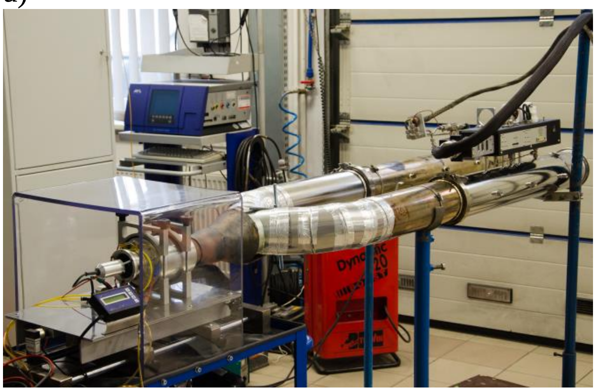


Fig. 1. View of the GTM-120 engine

The initial filter retains particles with a diameter greater than 1 μm and thus are outside the measuring range of the device. After passing through the neutralizer, the particles are directed to the charging electrode; after being 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. An exhaust cylinder is built into a stack of sensitive electrodes isolated from one another and arranged in a ring. The electric field that is present between the cylinders causes the repulsion of particles from the positively charged electrode; the particles are then collected on the outer electrodes. When striking the electrodes, the particles generate an electric current, which is read by a processing circuit. An exhaust flow meter (EFM) with a diameter of 125 mm and a high-speed EFM (EFM-HS) flowmeter characterized by a sampling frequency of 2500 Hz were used. The engine workbench and its schematic are shown in Figure 2.

a) b)



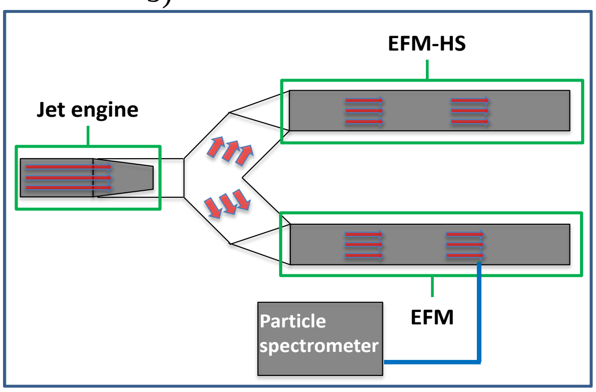


Fig. 2. View of a) the engine workbench and b) its schematic

3. MEASUREMENT RESULTS AND THEIR ANALYSIS

Diametrical distributions of particles emitted by the GTM-120 engine turbine were determined using an apparatus for measuring particulate emissions from combustion engines. Figures 3-8 present the measurement results for each level of engine thrust.

In the case of an engine powered by pure Jet A-1 fuel at minimum value of engine thrust (10 N), particles with a diameter of 30-45 nm dominated (Fig. 3a). The characteristic value of particle diametrical distribution obtained from the measurements was 35 nm. There were no emissions of particles with a diameter greater than 100 nm. The diametrical distribution of particles emitted in the case of an engine supplied with oil additive (Fig. 3b) was similar to the distribution obtained when the engine was fuelled with clean Jet A-1 fuel. The main difference was a twofold increase in the concentration of particulate matter resulting from the use of oil as a fuel additive.

a) b)

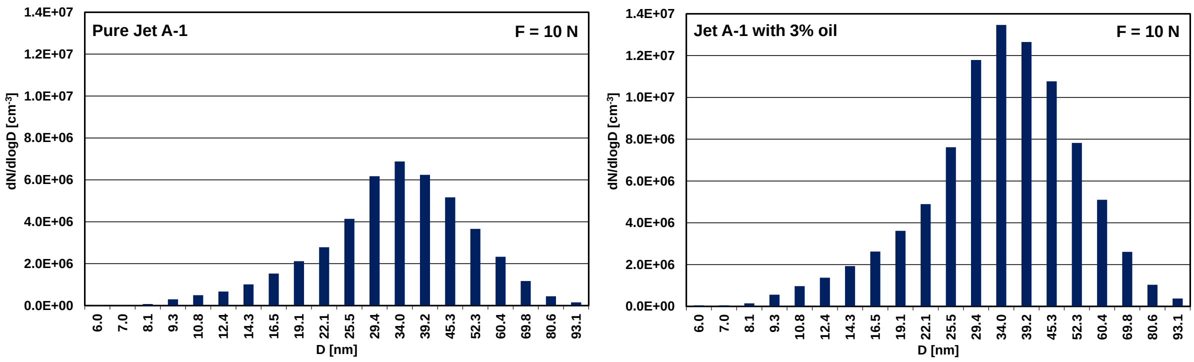


Fig. 3. Dimensional distribution of particulate matter corresponding to 10 N of a jet engine powered by a) pure Jet A-1 or b) a blend with oil

The obtained diametrical distributions of particulate matter for the engine fuelled with Jet A-1 and operated at 25% of maximum thrust were dominated by small particles with a diameter of 30-50 nm (Fig. 4a). There were no emissions of particulates with a diameter greater than 100 nm. No significant effect was observed of the addition of oil on dimensional distribution or concentration of particles emitted.

The obtained diametrical distributions of particulate matter for the engine fuelled with Jet A-1 and operated at a medium level of engine load (Figs. 5-6) were dominated by small particles with a diameter of 25-40 nm. There was no emission of particulates with a diameter greater than 100 nm. The addition of oil to the Jet A-1 fuel caused an almost twofold reduction in the concentration of particulate matter in the exhaust of the jet engine (Fig. 6).

Increasing the level of engine load for the engine fuelled with Jet A-1 to 80-100% resulted in a reduction of the diameter of the particles emitted (Figs. 7-8). Emissions were dominated by particles with the smallest diameters, from 15 nm to 25 nm. The use of oil additive resulted in no change in the size distribution of particles compared to the distribution obtained for the particles emitted from an engine supplied with clean jet fuel. It was found that using oil additive causes a slight reduction in particulate matter concentration.

a) b)

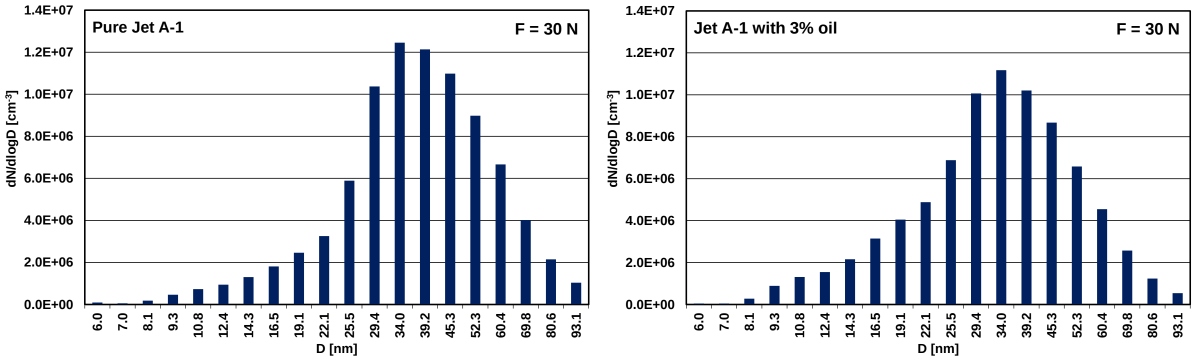


Fig. 4. Dimensional distribution of particulate matter corresponding to 30 N of a jet engine powered by a) pure Jet A-1 or b) a blend with oil

a) b)

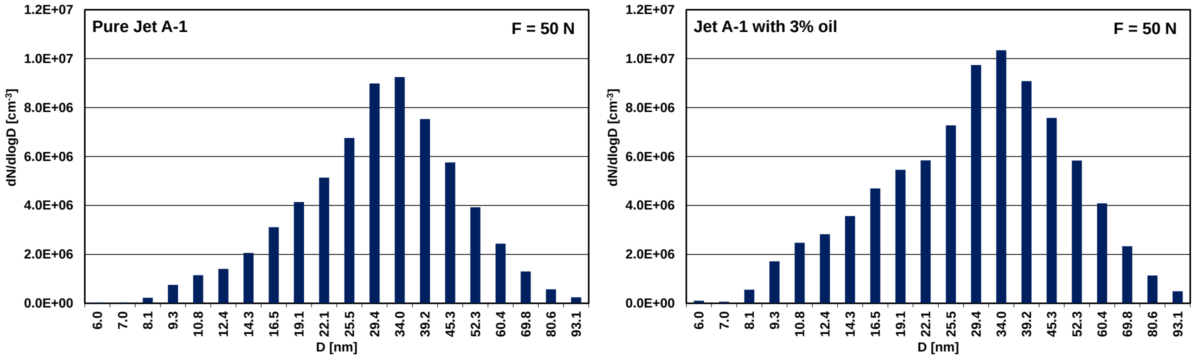


Fig. 5. Dimensional distribution of particulate matter corresponding to 50 N of a jet engine powered by a) pure Jet A-1 or b) a blend with oil

a) b)

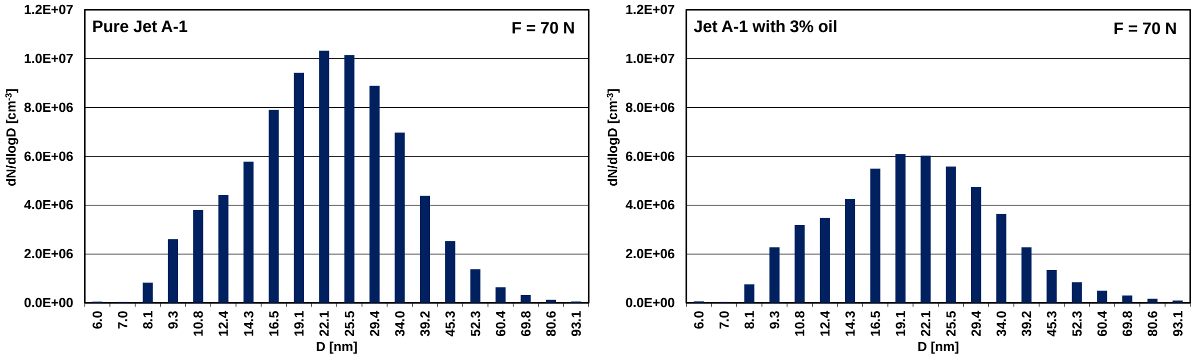


Fig. 6. Dimensional distribution of particulate matter corresponding to 70 N of a jet engine powered by a) pure Jet A-1 or b) a blend with oil

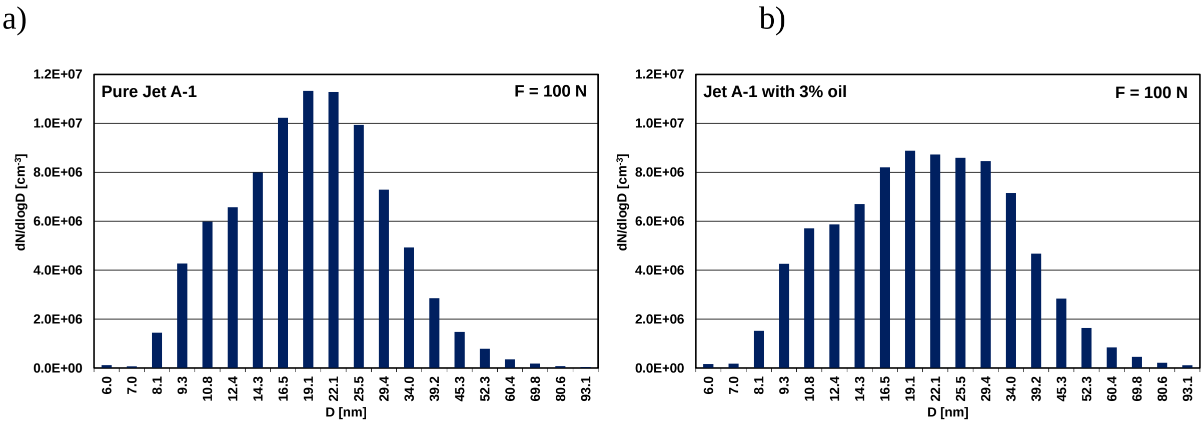


Fig. 7. Dimensional distribution of particulate matter corresponding to 100 N of a jet engine powered by a) pure Jet A-1 or b) a blend with oil

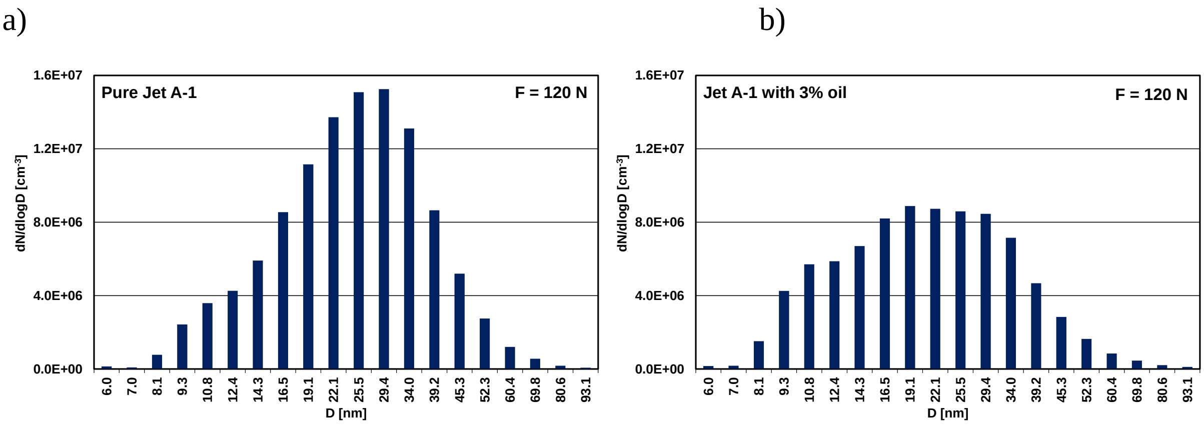


Fig. 8. Dimensional distribution of particulate matter corresponding to 120 N of a jet engine powered by a) pure Jet A-1 or b) a blend with oil

4. CONCLUSIONS

In order to consider the effects of the addition of oil to fuel on the intensity of the emissions of particle matter, proper measurements were performed on the GTM-120 jet engine, powered with pure kerosene (Jet A-1) fuel and its blend with oil (Mobil Jet Oil II). The presence of oil in the fuel resulted in a change in the concentration of particles emitted by the turbine engine in relation to the distributions recorded when using the Jet A-1 fuel without additives. In the case of the minimum level of thrust, oil additive causes an increase in the concentration of particulate matter compared to an engine powered by clean Jet A-1 fuel. There were no significant changes in the size distribution of particles emitted from the jet engine due to the use of oil additive. Increasing turbine engine thrust resulted in a particle concentration decrease for the engine fuelled with the oil additive. It was noticed that using oil additive causes a significant reduction in the number of emitted particulates for an engine operating at medium and high load levels. In the full range of measurements, the addition of oil did not result in significant changes in the size distribution of emitted particles.

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