EEET ECOLOGICAL ENGINEERING
& ENVIRONMENTAL TECHNOLOGY

*Ecological Engineering & Environmental Technology* 2022, 23(2), 193–198
https://doi.org/10.12912/27197050/146242
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Received: 2021.12.29
Accepted: 2022.01.25
Published: 2022.02.01

# Exhaust Toxicity of a Gas Turbine Engine with Step-by-Step Post-Treatment: the Environmental Aspect of the Impact on Atmosphere

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**ABSTRACT**

The development of technology imposes new, higher requirements on those that exist. Encourages the creation of new materials. In order to reduce the weight of aircraft structures, for example, multi-layer structures that combine lightness, rigidity, and strength are used. For many areas of technology is necessary such that combine structural strength with high electrical, thermal, optical, and other properties. Regulating the structure of traditional materials is a promising way to improve quality. Thus, by means of directed crystallization of steels and alloys, cast parts are obtained, for example, gas turbine blades, consisting of crystals oriented relative to the main stresses in such a way that the edges of the grains are unobtrusive. Directional crystallization allows increasing plasticity and durability several times. The greatest environmental pollution occurs in the area of airports (airfields) during the landing and take-off of aircraft, as well as the warming up of their engines. When engines are running on take-off and landing, the maximum amount of carbon monoxide and hydrocarbon compounds enter the surrounding environment, and the maximum amount of nitrogen oxides enter the flight process. A jetliner that makes a transatlantic flight requires from 50 to 100 tons of this gas. On the territory of the airfield, engines are launched, taxiing, take-off, and landing of aircraft, during which harmful exhaust products of aviation engines, pre-launch (waiting location) and on the runway enter the atmosphere.

**Keywords:** modeling, air pollution, environment, monitoring.

## INTRODUCTION

Currently, the process of directed crystallization is widely used to produce working blades of a gas turbine engine (GTE) with a directed and single-crystal structure. The choice of technological parameters that ensure the necessary quality of the casting depends on the geometry of the casting and the design of the thermal unit of the installation.

Forming the quality of steel products is a complex and multi-stage process. At each technological stage, some factors or operations affect the final properties of products. The most important factor that determines the main service properties of the final product (i.e., its quality) is the structure of the metal in a solid-state. The stage of transition of a melt to a solid-state, i.e. crystallization and processing of the metal already in the solid-state, after which its structure can change significantly (Franke, 2013). Increasing the efficiency and reliability of the blades of the first stages of GTE due to the qualitative improvement of the structure of single-crystal blades based on the control of the parameters of the technological process is an urgent task.

Most fully meets these requirements television pyrometry, that is, a set of methods and television means of measuring temperature by analyzing its radiation in a certain spectral range (mono-spectral pyrometry) or by comparing flows in several spectral ranges (multi-spectral pyrometry) (Zhao, 2017), which covers the field of measurement technology, including the theory and practice of measuring high temperatures by television means and is an extremely promising tool for thermal non-destructive testing.

Modern television information and measurement systems allow simultaneously providing the highest indicators among all other information and measurement tools relative to the maximum sample format, the minimum time for its formation, and spatial differentiation, which makes them indispensable in cases where such a set of indicators is the determining factor.

## POLLUTION BY AVIATION ENGINES

Pollution of the biosphere by combustion products of aviation fuels is the first manifestation of the impact of air transport on the environmental situation. However, Aviation has several distinctive features compared to other types of transport. The use of gas turbine engines (gas turbine engines) determines a different nature of the processes and structure of exhaust gas emissions, and the use of kerosene fuel quality changes the components of pollutants. The exhaust gases of aircraft engines are soldered to 75–87% of all civil aviation emissions, including atmospheric emissions from Special Motor Transport and stationary sources (Zhao, 2017).

The concentration of harmful components of aircraft engine exhaust gases in the air and the speed of their movement on the territory of the airfield largely depend on meteorological conditions. At the same time, the influence of the direction and speed of the wind is most clearly traced. Other factors include air temperature humidity, and solar radiation, which, although it affects the concentration of pollutants, is less pronounced and has a more complex relationship. The use of gas turbine engines in aviation and rocket science is huge. Exhaust gases of gas turbine propulsion systems (gas turbine engines) contain such toxic components as CO, NOx, hydrocarbons, soot, aldehydes, etc. Studies of the composition of combustion products of engines installed on aircraft have shown that the content of toxic components in combustion products significantly depends on the operating mode of the engine.

High concentrations of CO and CH are typical for low-speed driving (idling, taxiing, approaching the airport, landing), while the content of nitrogen oxides NOx (no, $NO_2$, $N_2O_5$) significantly increases when working in modes that are close to nominal (take-off, climb, flight mode) (Mirjalili, 2014). Harmful and toxic substances contained in the exhaust gases of engines, depending on the mechanism of their formation, are divided into groups: carbon-containing substances-products of complete and incomplete combustion of fuel ($CO_2$, CO, hydrocarbons, including polycyclic aromatic); substances whose mechanism of formation is not directly related to the fuel combustion process(nitrogen oxides-by thermal mechanism); substances whose release is associated with mixtures contained in fuel (compounds of sulfur, lead, and other heavy metals), as well as those formed during the wear of parts (metal oxides). The total emission of toxic substances by gas turbine engine aircraft is continuously increasing, which is due to an increase in fuel consumption to 20–30 t/h and a steady increase in the number of aircraft in operation. Emissions of gas turbine engines into the environment in airports and areas adjacent to test stations hurt life safety conditions. Comparative data on emissions of harmful substances at airports indicate that revenues from gas turbine engines to the surface layer of the atmosphere are: carbon oxides – 55%; oxadiazole – 77%; hydrocarbons – 93%; aerosols – 97%. Other types distinguish ground vehicles from internal combustion engines (Yang, 2004). The study aims to analyze the causes of atmospheric pollution by turbojet engines and determine ways to solve it.

Analysis of information sources (Miller, 2014) showed that the maximum pollution of the surrounding environment is possible during the maximum power pressure of the aircraft, during landing and Takeoff, as well as the warming up of their engines. During the operation of engines during takeoff and landing, the highest amount of coal oxide and hydrocarbon compounds enter the surrounding environment, and during the flight-the maximum amount of nitrogen oxides. Studies of ecologists have shown that the most polluted areas are the adjacent territories near the airfield and, in particular, the Runway (Miller, 2014). In this regard, the International Civil Aviation Organization (ICAO) has been publishing international standards on emission standards for Air-jet engines since 1977 (Miller, 2014), the use and compliance of which leads to a reduction in emissions of toxic compounds. ICAO engine emission data bank (EEDB – ICAO Engine Emission Bank) contains information about the EI value for certified engines (in grams of pollutant per kilogram of fuel for NOx, Co, and NS), as well as the consumption of special types of fuel (in kilograms per second ) for different operating modes of different types of engines. In addition, the number of smokiness is indicated here-a a dimensionless parameter that is calculated on a 10 – point scale and characterizes smoke emission as the “opacity” of the exhaust jet. Emission indicators for the engine, which is equipped, for example, with A330 Airbuses, are shown in Table 1 (Pollock, 1996).

**Table 1.** Emission indicators for the A330 Airbus engine

| Operating mode | Engine power, % | Time, min | Fuel consumption, kg/sec | Fuel emission index, g/kg | | | Smokiness indicator |
|---|---|---|---|---|---|---|---|
| | | | | HC | CO | $NO_x$ | |
| Takeoff | 100 | 0.7 | 3.042 | 0.02 | 0.3 | 42.46 | 4.22 |
| Climb | 85 | 2.2 | 2.471 | 0.02 | 0.35 | 32.71 | 2.36 |
| Decline | 30 | 4.0 | 0.869 | 0.04 | 0.96 | 11.35 | 0.65 |
| Small gas | 7 | 26.0 | 0.305 | 3.12 | 26.34 | 3.8 | 0.33 |
| Fuel (kg) and emissions (G) for ZPC | - | - | 1138 | 15041 | 12994 | 20269 | - |

Measurement of toxic component concentrations is regulated in the ICAO (International Civil Aviation Organization) instruction materials, reprinted in 2014 (Kubiak, 2015). This document contains measurement methods, processing of selected results, and recommended devices. In particular, smoke is measured in so-called “smokiness numbers” (SN) by filtering the combustion products through a controlled white filter. According to the degree of darkening of the filter surface by deposited particles, the level of smoke is estimated. Working out the launch of the gas turbine engine and its operation in the early stages of use with the development of processes during engine operation requires the formation of reliable approaches to predicting the starting power of the gas turbine engine (including the laying of starting properties at the design stage) and the corresponding choice of operating modes of the starting system of power plants of the aircraft (Kruzhilin, 2018). The study of the operating modes of the GTD at the initial stages makes it possible to determine not only the effective operating modes of the power plant but also their application with minimal impact on the environment relative to the maximum load of the aircraft. However, today, the issue of the use of gas turbine engines and their operating modes at the initial stages, provided that there are minimal emissions of harmful substances into the environment, is not sufficiently covered in the literature, which limits the acquisition of knowledge.

## ENVIRONMENTAL SECURITY OF AIR POLLUTION

Information on environmental security or compliance with environmental standards in the areas of aerodromes is also limited, making it difficult to assess the nature of their impact on the ecosystem. This is because today insufficient attention is paid to environmental research in the area of airdromes (Kruzhilin, 2018). Therefore, the study of a possible assessment of the state of the external environment in the area of airfields is a relevant direction for reducing harmful emissions with exhaust gases. At the same time, special attention should be paid to the issue of assessing the release of harmful substances of gas turbine engines in the ecosystem.

Regardless of the ignition system of the fuel-wind mixture in the gas turbine engine combustion chamber (if these are electric spark systems or electric plasma chiller systems), the features of the operation modes of internal combustion engines (Jarczyk, 2013) and emissions of combustion products of aviation fuel depend on it.

To date, the principles of their operation, the impact on high specific power, and the possibility of efficient use of power traction due to the combination of several functions have already been studied – sources of torque during launch and on-board source adjustment during flight under operating mode (Jarczyk, 2013). At the same time, the main areas of research on the launch of gas turbine engines are the study of operating modes and modeling of gas turbine engines in ground and flight launch conditions, autorotation launch, and the study of the characteristics of gas turbine engine components during launch.

In addition, at the present stage of Social Development, questions about emissions of combustion products of aviation fuel and their impact on the natural environment are interesting. It remains a priority to study the degree of influence of combustion products of aviation fuel during the release of aircraft from the gas turbine engine and the possibility of determining the components of combustion products. Therefore, based on the analysis of the environmental situation in the area of airdromes, it is advisable to determine the directions of changes in the degree of influence of gas turbine engines on the surrounding environment (Reed, 2006).

The main pollution products found in jet engine exhaust are nitrogen oxide $NO_x$, carbon monoxide co, unburned hydrocarbons, and particles (smoke).

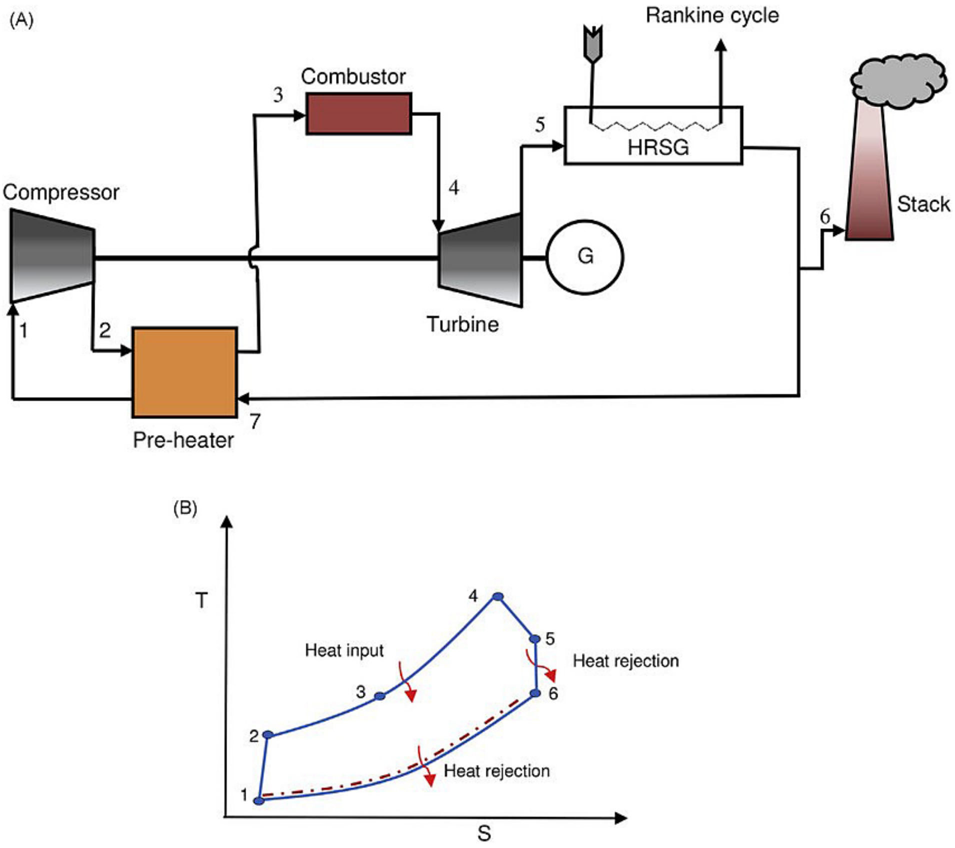

**Figure 1**. Semiclosed cycle gas turbine ecology

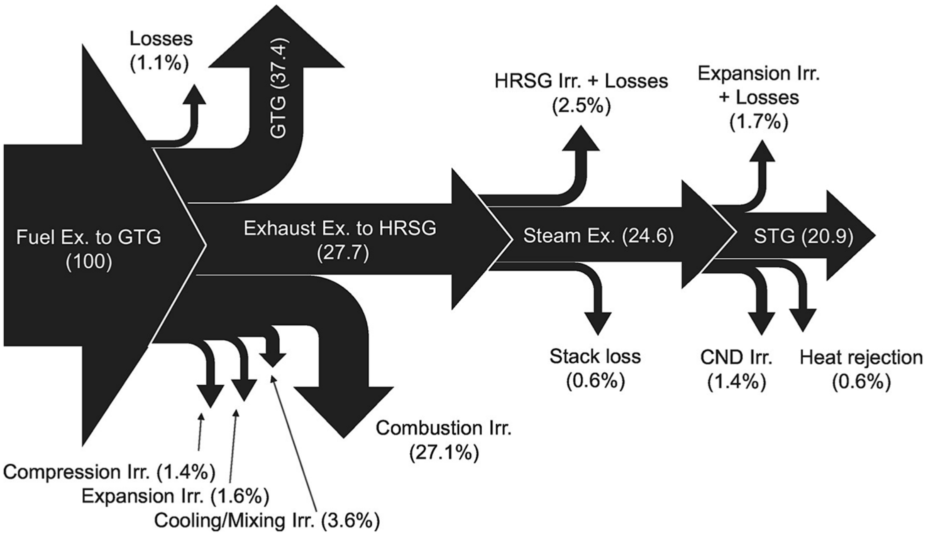

**Figure 2**. Gas turbine exhaust system

The exhaust also contains other atmospheric pollutants: sulfur oxides, aldehydes, aerosols, odorants, as well as aromatic polycyclic hydrocarbons, for example, benzopyrene (Guo, 1997). If we look at the number of harmful products formed in the form of a mass fraction from the burned fuel, then for most engine operating modes, the yield of these products is usually 0.1–1%. The concentration of emissions largely depends on the operating mode of the engine. The combustion chambers are designed to achieve maximum efficiency in approach and cruising mode. When the engine is throttled, the completeness of combustion decreases, and, as a result, the number of pollutants released increases.

So, in the low-gas mode, the completeness of combustion is 88–96% and depends on the size of the engine, its power, resource, the amount of air released from the compressor, and so on. The main emissions at low gas are coal oxide (up to 50–60 g/kg of fuel) and hydrocarbons (up to 10–20 g/kg of fuel) both in the form of fuel (physical underburning) and in the form of partially oxidized fuel components (chemical underburning). The latter substances cause a characteristic smell inherent in all airports using aircraft with gas turbine engines. The low completeness of combustion is explained by low values of temperature (360–450 K) and pressure (about 2–4) × 105 $P_A$ at the entrance to the chamber. In addition, with poor mixture compositions in the small mode, gas fuel injectors operate at small pressure drops (2–4) × 105 $P_A$, which leads to a significant decrease in spray dispersion and uneven distribution of fuel in the combustion zone.

The problem is further complicated by the poor flight quality of aviation fuel. As the engine power increases, the pressure and temperature at the entrance to the combustion chamber increase. At full power, the completeness of combustion is up to 100%, and the content of CO and NS in the exhaust gases is very low. However, high temperatures and pressure in the chamber lead to the formation of nitrogen oxides and smoke. $NO_x$ emissions reach 40–50 g/kg of fuel and smoke –up to 10–15 units (SAE) (Szeliga, 2016). Sulfur oxides are formed by the oxidation of sulfur contained in the fuel. Emission levels are directly related to the sulfur content in the fuel and do not depend to a greater extent on the type of engine. Since the removal of oxides from exhaust gases in a reactive engine is difficult, emission control is carried out by reducing the sulfur content in the fuel. The release of aldehydes from gas turbine engines can be compared with their release from piston engines: in both cases, the emission index is 1 g/kg of fuel (Gribust, 2018). A relatively high concentration of aldehydes of relatively low emissions of unburned hydrocarbons is associated with the combustion of a poor fuel mixture. The level of emission depends on the device of the combustion chamber, especially when the temperature of the combustion products changes over time.

Aerosol emissions from gas turbines are quite high. The aerosol emission index for turbo-jet engines is 9 g/kg, while for piston aircraft engines it is 2 g/kg. Aerosols include small agglomerates and condensates and can be adsorbents for active particles. The role of aerosols in air pollution, except for the deterioration of visibility, is unexplored. According to the results of a systematic study, there are no characteristics of the smell of jet engine exhaust. The mechanism of formation of polycyclic aromatic hydrocarbons (PAHs) in the combustion of aviation fuels is clear only in general terms, but to date, there is not a single publication on systematic measurements of PAHs in gas turbine engine exhaust gases. However, aviation is one of the possible sources of widespread carcinogens in the atmosphere. The results of work on the study of the regularities of the occurrence of benzopyrene in the exhaust gases of aircraft engines are reflected in the works (Wang, 2016).

A more convenient unit of measurement for this value is the "emission intensity" – in grams of toxic substance released per second, or in the "emission indices (EI)" – in grams of a substance classified as a kilogram of burnt fuel.

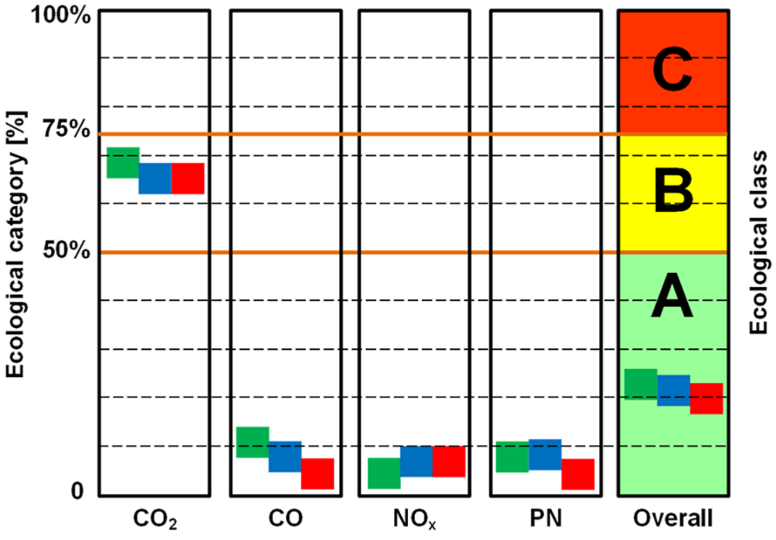

**Figure 3**. Ecological class and category of engine exhaust

Since the liquid metal poured into the mold for cooling technology is lowered into liquid aluminum. Due to the temperature difference, a sharp drop in the temperature of the metal occurs. To see at what point their temperatures will be equal, you need to look at the graph on which two curves are displayed (Fig. 3).

The second and third cycles are connected to each other and run in parallel. The first and second and third are performed sequentially. As for the fourth cycle, it combines all the cycles with each other so that the control process continues continuously throughout the above interval.

## CONCLUSIONS

Air pollution with turbojet engines occurs mainly during their operation before launch, takeoff and landing, ground testing during their production and after repair. The operation of a liquid-rocket engine is accompanied by the release of complete and incomplete fuel combustion products consisting of CO, $NO_x$, etc.

Emissions pollute the environment-higher in the area of the airfield and its surroundings. To reduce harmful emissions from robot engines, it is necessary to apply the following methods: use of fuel additives, water injection, etc.; fuel spraying; enrichment of mixtures in the combustion zone; reducing the operating time of engines on the ground; reducing the number of running engines in taxiing (waste emission is reduced by 3–8 times).

To reduce the specific content of toxic substances in the exhaust gases, along with improving the types of gas turbine engines in Operation, new gas turbine engines are created with new designs of combustion chambers, fuel-wind mixture injection systems, compressors that provide a rational ratio in the fuel-air mixture, better spraying and mixing of the mixture that is fed into the chamber, and more complete combustion.

Reducing the total fuel consumption and emissions of toxic substances is achieved by improving the methods of aircraft operation. It is proved that it is necessary to solve the problems of atmospheric pollution by air transport in a comprehensive manner. As a result, it is proposed to simultaneously improve the environmental emission indicators of aviation engines through chemical, structural, economic directions and introduce new technologies in aviation transport in compliance with the regulatory regime.

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