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IMPACT OF WORK OF TURBINE ADAPTIVE ENGINES FOR THE NATURAL ENVIRONMENT

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Abstract

The article describes the problem of the operation of turbine jet, adaptive engine work on the natural environment. In particular, the analysis of noise generated by turbine jet engines has been made. It points out possible directions of noise decrease with particular emphasis upon structural changes within the engines, the task of which is to reduce the noise mission. The example of the modernization is based upon the "bypass" type of one-flow turbine jet engine. The essay contains theoretical basis of calculation of the noise emission level and the results, which graphically indicate a relative level of noise of this type of engine depending upon the amount of discharged air and the diameter of the discharge nozzle and the radius, upon the basis of which the noise level is determined. This work also includes a comparison of the relative noise level of this type of engine with regard to one-flow turbine engine equipped with the function of air discharge to the environment and with regard to two-flow turbine jet engine equipped with air stream flow mixing device. The use of low-emission combustion chambers in the "bypass" turbine engine was indicated. This allowed addressing the problem of emissions of toxic exhaust components by this type of aircraft engines. At the same time, the dependence of this emission related to the mass of fuel used on the engine's thrust range was indicated. The article was concluded with a short summary.

Keywords*:* *noise of aircraft engines; the environmental impact of a jet engine turbine, emission of toxic compounds from aircraft engines, turbine jet engine*

1. Introduction

Turbine jet engines, commonly used in civil and military aviation, have a significant impact on the natural environment. First, as a result of the burning of huge amounts of fuel, they introduce toxic compounds into the atmosphere, such as nitrogen oxides, carbon oxides, carbon dioxide, etc. Secondly, they emit excessive noise emitted mainly from working aircraft engines, especially during the take-off of the aircraft, which is carried out at the maximum speed range (maximum power).

The noise of aircraft and the intensity and organization of air traffic have a significant impact on the airport's inconvenience for local residents. In the area of flights above the airport, planes on climb routes and expectations for landing emit noise at levels from 80 to even 120 dB. It should be remembered that the limit of pain for the human ear is approximately 130 dB, depending on the distance from the sound source. Examples of the sound level (in dB) for different types of sound are shown in Tab. 1.

Aircraft noise depends on their technical solutions and on the maximum take-off weight. New generations of aircraft are usually less noisy, which, however, has no significant connection with military aircraft, where the more important elements are their manoeuvrability and speed of action while performing a combat task. While the area exposed to noise of 80 dB is for older types of aircraft − around 150 km^2, for newer generation airplanes, it is only 35-45 km^2. The noise emitted by planes taking off and landing, as well as being in motion, covers not only the area of the airport, but makes unusable areas from a few to several kilometres from the airport border − depending on the location of the runways. Freight airports are particularly burdensome for residents because flights often take place at night.

Tab. 1. The volume level for each type of sound

The type of sound	Noise level [dB]	The type of sound	Noise level [fon]
The threshold of hearing	0	Road traffic	90
Rustling leaves (mild wind)	10	Motorcycle (without silencer)	100
Whisper	20	The work of a chainsaw	110
A hushed conversation	40	Aircraft (distant 4 km)	120
Noise in offices	50	Take off a fighter	140
Vacuum cleaner work	60	Bomb explosion	160
Interior of the restaurant	70	Take off a space rocket	190
Scream, loud music	80	Explosion of atomic bomb	220

The current situation indicates the need for radical measures to eliminate aviation noise throughout the country. The analysis of the take-off and landing operations within 24 hours indicates a very large number (from 20 to even 130 flights per day) It should be noted that the share of night flights is currently well over 10%. Despite the fact that light airplanes are usually used at the airport, the fact of their very low flights and helicopter flights does not reduce the nuisance of the airport for the surroundings.

All of the attempts to eliminate the noise generated by the airports are very difficult. Currently, in order to reduce the air noise, the premises of the airports are distanced much from the areas inhabited by people. Moreover, the premises of the airports (especially the military ones) are surrounded by forest usufructs.

In order to minimize the noise emission, the airports try to modernize the planes, especially within the field of airframe and engine. The newest investments encompass new planes, which emit considerably low noise level.

In order to struggle with the air noise special "Environmental Protection Programmes" are prepared. Civil airports and military airports prepare new procedures for taking off and approaching planes as well as optimize the approach and take off airport flight zone corridors.

Unfortunately, in the case of so big surfaces, acoustic screens would not bring desired effects, also due to costs. One protection of this type is constituted by the formation of special shafts and construction of concrete partitions. Upon the military airports one may frequently find the so-called shelters, which allow for the activation of planes, execution of ground trails, etc., the solution that also reduces the level of noise, which reaches the adjacent neighbourhoods (fig. 1).
In order to protect human health near the airport premises it is indispensable to use windows with high degree of acoustic insulation in connection with a proper system of mechanical ventilation of apartments, especially in the case of areas with the highest level of noise exposure. Although the authorities and organizations of any civil airports, military airports and aero clubs strive to reduce the noise level, all of the calculations have shown that the degree of difficulty connected to the

existence of such airports has not been reduced. Such situation stems from the failure to observe the procedures of take offs and approaches of planes, which take into consideration the necessity to protect residential areas. Therefore, not all of the technologies are completely human friendly.

Fig.1. Aircraft shelters at the military airport

Other attitude is illustrated in the interference with structures of air engines, which already at the stage of designing take into consideration the problem of noise. A frequently appearing element is constituted by the so-called mechanical noise silencers, which act based upon the rule of forcing of the intensification of mixing of fuel stream with air by disintegrating the stream or sucking up of an additional air mass from the environment. A new approach is to construct engines, the structures of which allow for the reduction of considerably significant level of noise emission. Such solution is applied, amongst other, in the design of a "bypass" type of turbine jet engine.

The concept of the "bypass" type of turbine jet engine describes a one-flow jet engine in which the air discharged from behind the compressor is supplied with external ducts to the place behind the turbine, where it is subject to mixing with the basic fuel stream. The diagram of this type of engine is presented upon fig. 1. Apart from typical assemblies of every engine, it shows the external flow ducts supplying the air discharged from behind the compressor and supplied to the place behind the turbine.

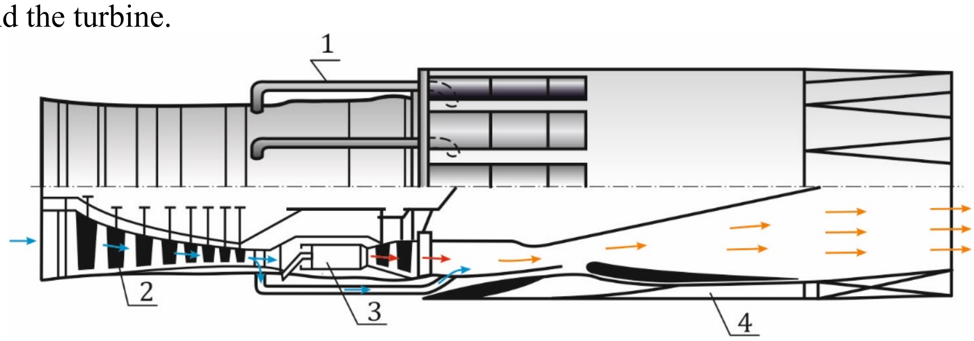

Fig.2. Diagram of the "bypass" type of turbine jet engine: 1 – one-flow duct of air supplied from behind the compressor to the place behind the turbine, 2 – regulated compressor, 3 – combustion chamber of low level of emission of toxic components of combustion gases, 4 – discharge nozzle with a thrust reverser

As a complex sound, the noise is one of the methods to transfer the energy to the environment. The basic source of noise of the turbine jet engines is constituted by the stream of gases discharged at high speed from the discharge nozzle as well as the air stream flowing through the inlet ducts of the engines.

Additional sources consist of mechanical vibrations of the elements of drive assembly, the flow of air through the palisades of blades of the compressor and the turbines as well as of the progress of the consumption process and work of hydro-mechanical sub-assemblies of the fuel supply control.

The noise level may be calculated depending upon the following [3]:

$$L = 10 \cdot log \frac{I}{I_0} \quad [dB], \tag{1}$$

where:

$I = \frac{N}{2\pi r^2}$ – sound intensity upon the surface of the half-zone of the radius r, at the centre of which the noise source is located;

$N = K\frac{\rho_5^2 D_5^2 c_5^2}{\rho_H a_H^5}$ – acoustic power of the noise emitted by the engine;

I_0 – sound intensity upon the audibility threshold;

D_5 – diameter of the diagonal cross-section of the discharge gases;

ρ_5 , c_5 – respectively: density and speed of stream of discharge gases;

ρ_H , a_H – respectively: air density and sound speed inside the air;

K – proportionality factor determined experimentally.

Having taken into consideration other factors, i.e. density, temperature and pressure of the stream of discharge gases as well as the stream speed determined for the critical ratio of pressures within the engine discharge nozzle, after the proper modification the formula may receive the following form:

$$L = 10\left[log F + x \cdot log T_4^* \right], \tag{2}$$

where:

F – coefficient, the value of which for the engine working upon the ground is practically dependent upon the diameter of the diagonal cross-section of the discharge nozzle D5 as well as upon the radius r (i.e. distance from the noise source to the measurement point);

$x = \frac{2(2k-1)}{k^{'}-1}$ – where: *k, k'* – the isentropic exponent for air and exhaust gases respectively;

T_4^* – exhaust gas temperature for the engine turbine.

2. Analysis of test results

A relative noise level of the "bypass" type of engine determined by a comparison of the noise level generated by this engine depending upon the regulation method, i.e. in accordance with the constant heat degree $\Delta^* = const$ and constant compression of the compressor $\pi_S^* = const$ as well as the amount of air discharged from behind the compressor is presented upon fig. 3.

It is visible that the increase of the amount of air discharged from behind the compressor to the place behind the turbine in the "bypass" type of engine results in the reduction of the relative noise level, for example for 25% of the amount of discharged air approx. 10% is added. The criterion of the engine regulation practically does not influence the change of values of obtained decrease of the relative noise level.

The value of this decrease is subject to change along with the change of the diameter of the cross-section of the discharge nozzle D5 of the engine and the radius **r**, upon the basis of which the noise level is determined. Such situation is presented upon fig. 4. The increase of r radius increases the decrease of the relative noise level for the given amount of discharged air, which in consequence means that the noise level emitted by the "bypass" type of engine is silenced much earlier than the noise from the one-flow engine with no air discharge function.

In practice, in the turbine jet engines, the air discharged from behind the compressor is frequently used in order to ensure the static work of the compressor within the scope of low rotary speeds, as a result of which the discharged air is carried out to the environment. Therefore, the comparison of the noise level emitted by this type of engine with the "bypass" type of engine evokes much more interest. Fig. 5 presents the ratio of levels of noise emitted by the one-flow engine equipped with the air discharge function to the environment to the "bypass" type of engine, depending upon the amount of discharged air and the regulation method.

It is visible that along with the increase of the amount of discharged air, the noise level emitted by the engine equipped with the air discharge function to the environment is higher than the noise level emitted by the "bypass" type of engine. Such situation is presented upon fig. 5 with a constant increase (above the index 1) of the curve which determines this ratio (for example for 25% of the amount of discharged air and the regulation programme in accordance with the constant heat level Δ*=const with approx. 5%).

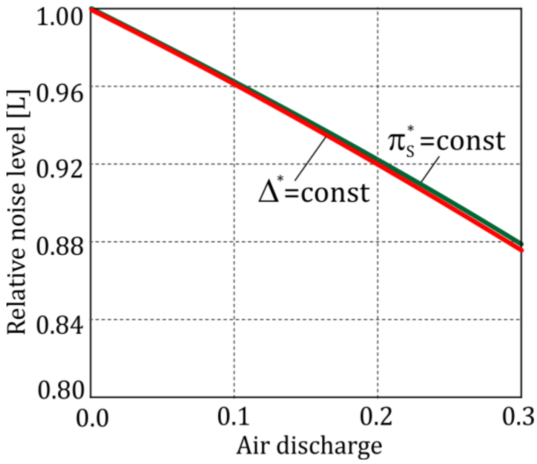

Fig.3. Influence of air supply from behind the compressor to the place behind the turbine onto a relative level of engine noise depending upon the regulation method (D = 0,3 m, r − l m)

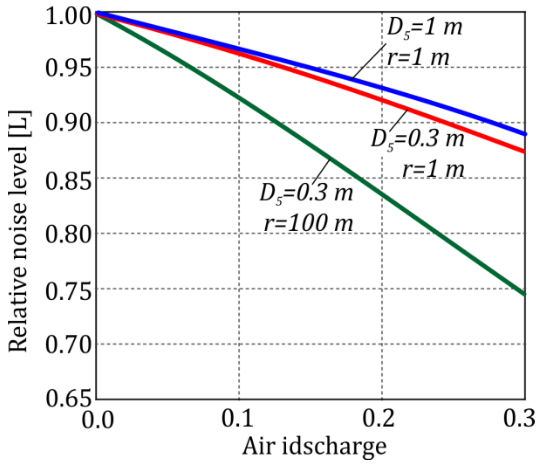

Fig.4. Influence of air supply from behind the compressor to the place behind the turbine onto a relative noise level depending upon the diameter of the discharge nozzle D_5 and the radius r

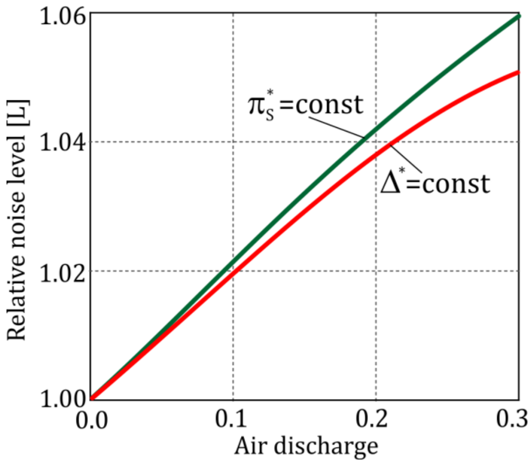

Fig.5. Ratio of the levels of noise of the engines: one-flow engine equipped with the air discharge function to the environment and the "bypass" type of engine depending upon the amount of discharged air and the regulation method

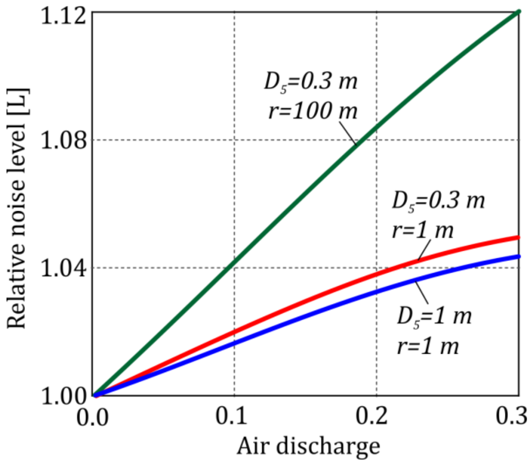

Fig.6. Ratio of the levels of noise of the engines: one-flow engine equipped with the air discharge function to the environment and the "bypass" type of engine depending upon the amount of discharged air and the radius r as well as upon the diameter of the discharge nozzle D_5

The criterion of regulation in accordance with the constant compression of the compressor $\pi_S^* = \text{const}$ increases this value with additional 5%. The influence of the radius r, upon the basis of which the noise level and the value of the diameter of the cross-section of the discharge nozzle D_5 is determined is presented upon fig. 6.

It is visible that the increase of the radius r increases the value which determines the ratio of the noise levels emitted by the engine equipped with the air discharge function to the environment and by the "bypass" type of engine, whereas the increase of the diameter of the discharge nozzle D_5 decreases it slightly. Such situation confirms that due to the emitted noise level, better effects are achieved in the engines equipped with small diameters of the discharge nozzles.

It is also interesting to compare the noise levels emitted by the two-flow engine equipped with air stream flow mixing device with the "bypass" type of engine. Fig. 7 presents the comparison, which illustrates that the increase of the amount of air flowing through the external ducts of both engines practically does not result in any changes of values of the emitted noise level. The change of the radius does not change this character, the fact that is visible upon fig. 8.

However, regarding the emission of toxic exhaust components, it should be emphasized that it is dependent on from the design and operation of the combustion chamber. The main factors affecting the emission of toxic exhaust components are:

- temperature and excess air coefficient in the zone of the original stream in the chamber,
- the degree of homogenisation of the combustion process in this zone,
- cooling characteristics of the walls of the fire pipe cover,
- fuel sputtering characteristics.

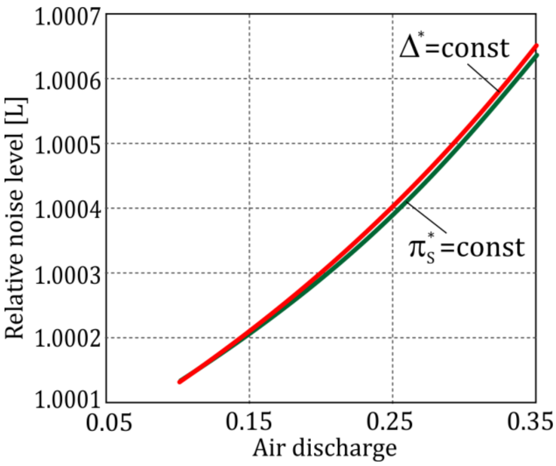

Fig.7. Ratio of the levels of noise of the engines: two-flow engine equipped with air stream flow mixing device and the "bypass" type of engine depending upon the amount of air flowing through the external ducts of both engines and the regulation method

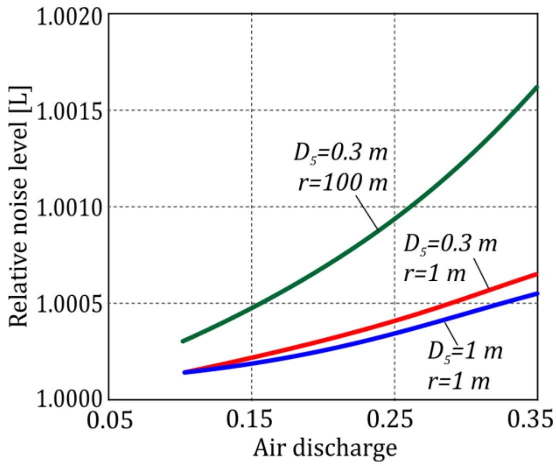

Fig.8. Ratio of the levels of noise of the engines: two-flow engine equipped with air stream flow mixing device and the "bypass" type of engine depending upon the amount of air flowing through the external ducts of both engines and the radius r as well as upon the diameter of the discharge nozzle D_5

In the bypass engine, we deal with a low-emission combustion chamber. The optimization of the combustion temperature has a significant influence on this state of affairs. It is the result that the combustion temperature in modern turbine jet engines ranges from 1000 K to even 2500 K. In addition, the formation of toxic exhaust components is strongly dependent on this temperature. For example, the formation of carbon monoxide (CO) is the strongest in the temperature range lower than 1700 K, and nitrogen oxides (NO_x) above 1900 K.

For these reasons, low-emission chambers must maintain the combustion temperature range in the intermediate range throughout the operating period of the aircraft engine – Fig. 9.

It should also be mentioned that the formation of toxic exhaust components is proportional to the mass of spent fuel, which depends on the load on the turbine jet engine, i.e. the engine thrust.

From this Therefore, the most pollutants to the natural environment are introduced by these propulsion units of passenger and transport aircraft, which are characterized by the highest power and the highest fuel consumption in relation to the generated thrust. In addition, the largest amount of toxic compounds is introduced in the upper atmosphere, i.e. from 8 to 12 km above sea level, i.e. at heights where long-haul flights are carried out.

As previously mentioned − a bypass turbine engine is an engine that involves a significant reduction in fuel consumption, hence along with the increase in the engine thrust there is also a decrease in the emission of carbon monoxide, hydrocarbons, while increasing the emission of nitrogen oxides and particulates. Therefore, as can be seen from Fig. 10, the amount of emissions of toxic components of exhaust gases decreases as well.

The evidence of a direct relationship between the emission of toxic exhaust components and the intensity of aircraft operation is Fig. 11, where the prognosis of the growth of selected indicators in relation to 2005 is shown.

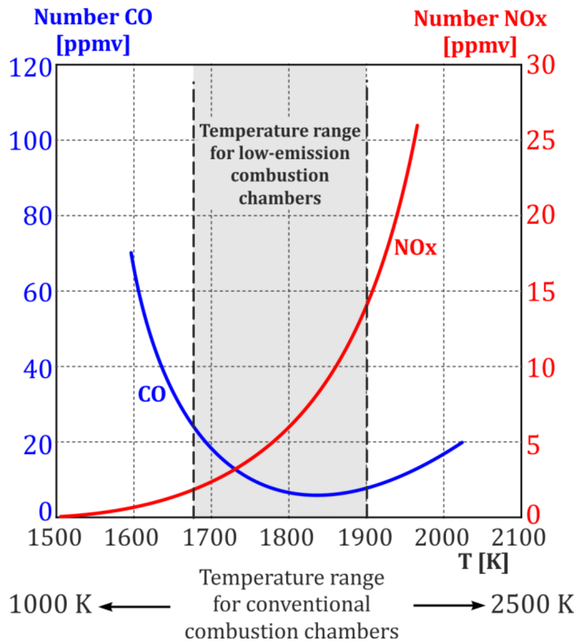

Fig.9. Effect of the combustion temperature in the primary zone on the emission of carbon oxides CO and nitrogen oxides NOx [2]

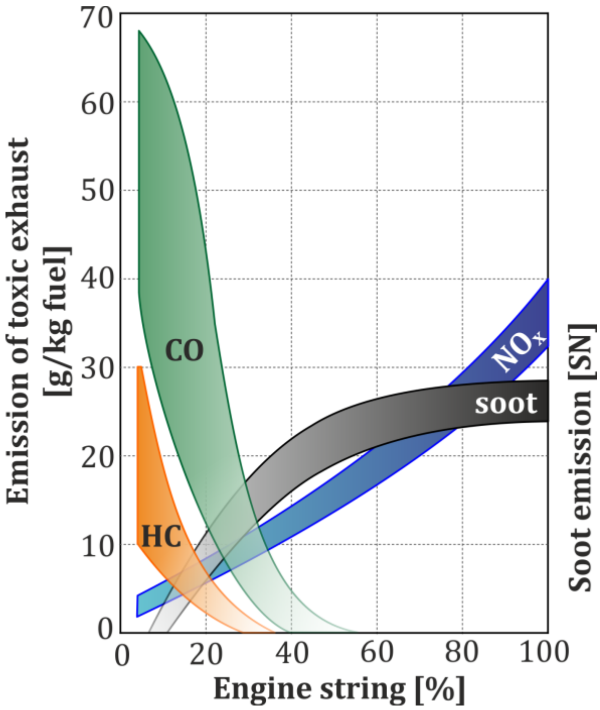

Fig.10. The mass of toxic exhaust components related to the mass of fuel consumed as a function of the turbine engine thrust [4]

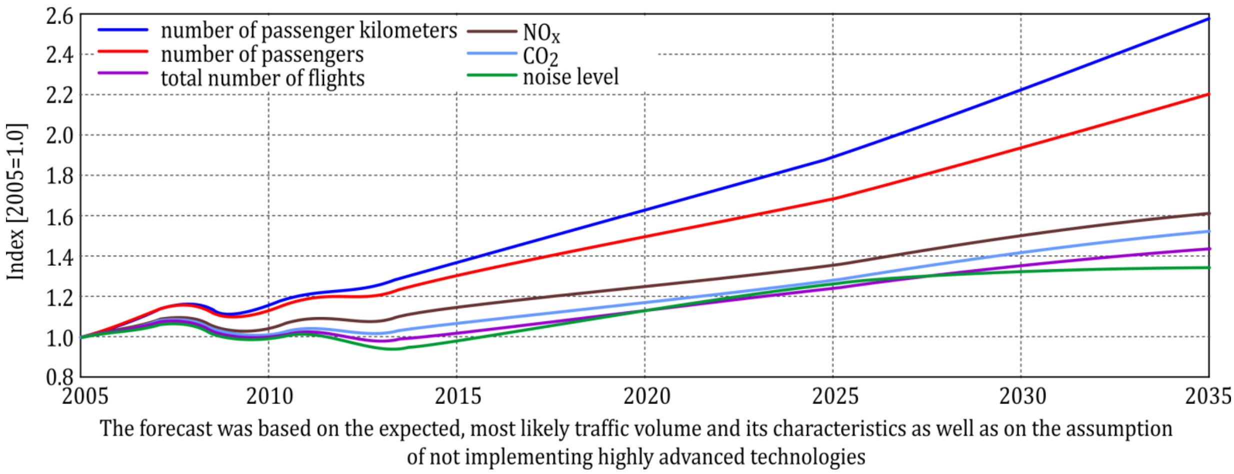

Fig.11. Forecasted emission levels of toxic exhaust components and selected passenger flight intensity indices in years − reference level year 2005 [1]

4. Summary

In conclusion, it is stated that this type of air venting in single-flow turbine jet engines, apart from economic and propulsive benefits [3] (which was not mentioned here) enables reducing the noise emitted during their operation, especially in relation to single-flow motors with air bleed to the environment.

With regard to the two-flow engines equipped with air stream flow mixing device, such solution allows for the maintenance of a similar noise level and hence enables the one-flow turbine jet engines to become competitive to two-flow engines equipped with air stream flow mixing device due to the more complex structure and production costs of the latter.

It was also pointed out that this type of air vent, not only reduces fuel consumption, but also reduces the emission of toxic exhaust components − results from the use of a low-emission chamber.

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