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ANALYSIS OF AIR-TRAFFIC THREATS

Summary. Globally, air transport has seen a greater increase in recent years. This manuscript is divided into three parts for analysing the negative effects of aviation. The first part is focused on the identification of sources of aircraft noise. While the second part of this article describes the basic principles of the construction and operation of an aircraft jet engine concerning the gaseous emissions produced by such an engine (Third part missing?). The main benefit of this article is the evaluation of the reliability of the human factor because the human factor is an integral part of technical systems and processes. Reliability assessment was performed using the TESEO method. The ergonomic parameter, that is, the cabin noise, was quantified in the given method. The measurement was performed on two types of aircraft, namely in the cabin of a transport jet aircraft and in the cabin of asmall transport aircraft equipped with turboprop engines.

Keywords: environment, air-traffic, threat, noise, gaseous emissions

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1. INTRODUCTION

It is a well-known fact that during the last few years, a multi-percent increase in air transport has been recorded globally. However, air transport also has relevant negative environmental impacts, even though its share is relatively low compared to other modes of transport [1]. These impacts are mainly manifested by air pollution, which is caused by emissions from aircraft engines, increased noise, high fuel consumption, and the occupation of land necessary for the building of airports.

Transport, as the main factor of global business, negatively affects all elements of the environment [1-3]. According to the 2016 European Aviation Environmental Report, the number of flights will increase by 45% by 2035 (although it may not be so high, due to the current COVID-19 pandemic). About one-third of Europe's overall energy is consumed in the transport industry [4].

The Ministry of Transport, Construction and Regional Development of the Slovak Republic states that the air is the most affected by the combustion of hydrocarbon fuels in internal combustion engines, which are installed in the vehicles where carcinogenic substances, toxic substances, and substances that contribute to global warming of the Earth's atmosphere are produced. One of the goals of the Strategic Development Plan is to achieve a 40% use of sustainable low-carbon fuel in aviation by 2050 [5].

The negative impacts of air-traffic, except for high emissions, also include increased noise, high fuel consumption, and pollution in airport surroundings. Air pollution damages human health and the environment. A significant proportion of Europe's population lives in areas, particularly in cities, where the air quality standards are exceeded: namely, the pollution caused by ozone, nitrogen dioxide, and particulate matter poses serious health risks. Some studies point to a link between air pollution from traffic and the incidence of atopic eczema in children [6].

It is extremely important to address the objective of protecting human health and the environment in a whole complex system [7]. The negative influences of air-traffic can be classified as follows: influences due to the demands of air transport concerning the territory; impacts on the territory, which is affected by the operation of air transport; influences due to the operation factors of air transport equipment and the transport process in general.

The main influences due to the demands of air transport concerning the territory are caused by the seizure and degradation of agricultural land. The construction of an airport must consider sensitive areas for noise, the occurrence of protected nature areas, national parks, health-resorts, the possibility of oil spills into water sources, etc. [8]. The planning and construction of airports must consider the economic development balance and the sustainability of the land fund (that is, Sustainable Land Management (SLM)) [9].

The most important impacts on the territory, which is affected by air transport, are air pollution due to dust swirl and exhaust gases.

The negative influences due to the operation factors of air transport equipment and transport processes, in general, are incorrectly situated airports and noise around airports.

2. MATERIALS AND METHODS

Nowadays, aircraft jet engines are the most widely used driving units of modern commercial and military aeroplanes. Therefore, it is very important to analyse their environmental impacts.

2.1. Identification of noise threats in air-traffic

Transportation is one of the largest contributors to community noise. The aviation environment is characterised by multiple sources of noise, both on the ground and in the air. Noise affects people in many ways, and as its level increases from detectable, it could get annoying. Knowledge of the noise source plays a significant role in determining the community noise responses, for example, three different transportation noises, including those of aircraft, rail, and road traffic, are often rated differently when the average A-weighted Sound Pressure Level (LA) is the same [10, 11].

Although noise is a factor which can generally cause hearing losses, jet aeroplanes are manufactured under international standards, producing noise levels below hearing threshold limits [12]. Noise annoyance is defined as physical or psychological. Aircraft noise is considered unpleasant if it interferes with everyday activities. Although aircraft are nowadays more than 20 dB quieter than in the past, these benefits are not fully perceived by aircraft passengers. Passenger demands for enhanced cabin comfort, along with the easing of legislation on noise pollution and human exposure to noise, have made aircraft interior noise an important commercial asset and one of the primary market catalysts [13]. There are many different sources in and around an airport that produce noise. Noise is produced by aircraft equipment power plants, transmission systems, jet efflux, propellers, rotors, hydraulic and electrical actuators, cabin conditioning and pressurisation systems, cockpit advisory and alert systems, communications equipment, etc. [31].

There are three sources of aircraft engine noise: (1) combustion in the engine; (2) the vibration of engine parts; (3) engine emissions.

Tab.1 lists the various noise sources with their sound level in dB for illustration, there is a comparison of sources from air transport, including jet aircraft, small single-engine aircraft, helicopters with one rotor, and a jet engine, and other types of noise sources.

Tab. 1

Level of noise sources [31]

Noise sources	Level (dB)
Urban home, Average office	40-60
Noisy Office, Low Traffic Street	60-80
Jet Transports (Cabin)	60-80
Small Single Plane (Cockpit)	70-90
Public Address (PA) Systems	90-100
Single Rotor Helicopter (Cockpit)	80-102
Power Lawn Mower, Chain Saw	100-110
Rock Concert	115-120
Jet Engine (Proximity)	130-160

The most known source is a single-engine aircraft, and the first thing you may think of when recalling aircraft noise is its engine [14]. Engines are indeed a major source of noise, but they are gradually getting quieter. Their construction and technology have reached a point where few things can be done to decrease the noise of the engine. Most of the noise generated from aircraft engines typically occurs from the high-velocity exhaust gases and the air flow in the fan system.

Another aspect of an aircraft that generates noise is the airframe. Many people are not aware of this noise, however, it may become a concern as the engine efficiency and noise reduction have decreased as much as is technologically possible.

Exhaust noise results from the aircraft’s high-speed turbulence that moves outward into a relatively dormant atmosphere. Behind the exhaust port, the jet stream ejects outward at an extremely high speed. The outward atmosphere, meanwhile, has not yet fully blended with the jet stream and, consequently, high-frequency noise occurs due to the high-speed jet stream in this area. When the jet stream leaves the exhaust port and keeps moving behind the aeroplane, it gradually decelerates and starts to blend with the atmosphere. Then, rough sounds occur and the frequency of the jet stream noise reduces. As the energy of the engine emitting airflow gradually disappears, most of it turns into low-frequency noise. In terms of the mechanical noise from turbo spinning, it is high-frequency noise. Even though high-frequency noise is more annoying, it disappears faster when transmitting in the air and is subject to interference by construction, the terrain, and the atmosphere. Therefore, high- and low-frequency noises are both important for areas close to an airport, while low-frequency noise is the main consideration for areas farther away [15].

One of the sources of aircraft noise is wind. Computing tools at the design stage of new aircraft, model the aerodynamics to highlight areas of high airflow that are likely to increase cabin noise [16]. Aircraft noise sources are turbulent airflow around the aircraft, radio-correspondence, air conditioning, and supersonic bangs [12]. These sources can be classified as follows:

1. Source of noise and type of aircraft design – the sources of noise in the jet aircraft are the engine intake port and the outlet nozzle. The inlet noise is close to the intensity of 90-100 dB(A). The outlet nozzle noise is broadband in nature and radiates to a conically widening gas outlet area. Noise levels are up to 140 dB(A). Motors and propellers are similar sources of noise in propeller aircraft. Propeller noise has a relatively narrow frequency spectrum. It affects the engine mode, propeller speed, and blade count. The mean intensity value is 110 dB(A). Maximum noise emissions occur in the aeroplane axis.
2. Source of noise and the air circulation plane – noise is caused by the turbulence of air between the layers of air that bypass the plane. This is noise over a wide frequency range. In particular, the high-frequency component also increases with an increasing speed. The intensity and character of the noise level are influenced by the aerodynamic layout of the fuselage and aircraft carrier, the altitude and speed, and the flight path profiles.
3. Source of noise and radio-correspondence – this is a broadband noise of an impulse character with a maximum in the range of 500 to 4000 Hz. The maximum intensity value can be up to 110 dB(A).
4. Noise from aircraft systems – cockpit and cabin pressurisation and conditioning systems are often major contributors within cabins of both civilian and military aircraft. However, one of the most significant sources of cabin noise from commercial jet aircraft, other than the engines, is the Auxiliary Power Unit (APU), an on-board generator used in aircraft to start the main engines, usually with compressed air, and to provide electrical power while the aircraft is on the ground. Other internal aircraft systems can also contribute, such as specialised electronic equipment in some military aircraft.
5. Air conditioning in an aeroplane – passengers and aircrew are exposed to low-frequency sound in the long term. Its characteristics and intensity depend on the design of the air conditioning system, the engine running, and the size of the pressurised cabin, and can reach significant values of up to 100 dB(A) [31].

2.2. Environmental impact of gaseous emissions in air-traffic

Aircraft jet engines are the aircraft engines used in most commercial and military aeroplanes. These engines were intensively introduced into active operation during the 1950s.

The basic principle of the aircraft jet engine functioning can be simply described in the following way [17]. The input air flow enters through an annular air intake, which is situated in the front of the engine, and thereafter, the air flow passes into a compressor, which compresses the input air. The compressed air, with high pressure and temperature, enters the combustion chambers. It is mixed with the fuel in the combustion chambers and the fuel-air mixture is continuously burning during the jet engine operation after an initial step, that is, starting the ignition. The burning process results in a hot and fast outflow of gases flowing into the turbine. The turbine is driven by the kinetic energy of hot gases, whereby the turbine and the compressor are connected by a common shaft. After a final expansion in the turbine, the hot gases flow through the exhaust nozzle at a high speed and, in this way, the thrust force is created according to the physical law of “action-reaction”.

Regarding technical development, it is possible to say that the first aircraft jet engines were the turbojet engines, that is, jet engines without a bypass (Fig. 1). The second development step was the construction of the bypass engine with a low bypass ratio (Fig. 2). The following development introduced bypass engines with a high bypass ratio. These engines are also called the turbofan engines (Fig. 3).

Fig. 1. External shell of a turbojet engine [27]

Fig. 2. Bypass engine with a low bypass ratio [28]

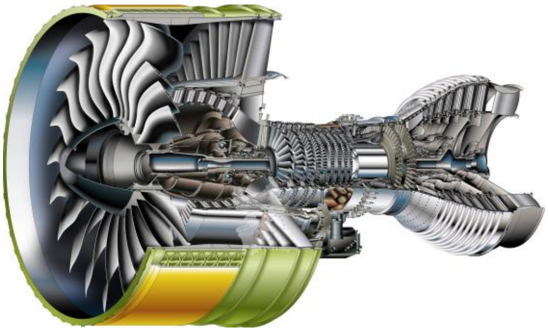

Fig. 3. Turbofan engine [29]

Fig. 4. View of a turbo-prop engine [30]

Turbojet aircraft engines, that is, jet engines without a bypass, are characterised by one compact stream of a gaseous medium, which passes through the engine. The external shell of these engines has a slim rotational shape (Fig. 1). In the case of bypass engines, the stream of compressed air is divided into two parts. The first part is the external flow, that is, the cold flow or bypass air flow. The second part is the internal flow, that is, the hot stream, which flows behind the compressor towards the combustion chambers. According to the ratio between the external and internal flow capacity, bypass engines can have either a low or high bypass ratio (Fig. 2 and Fig. 3). A special kind of jet engine is the turbo-prop engine, shown in Fig. 4, which is included in most propeller aircraft.

There are two different categories of jet engine emissions: noise emissions and gaseous emissions [18]. The noise, which is generated by the aircraft jet engines, is perceived immediately, and above all, in the area close to the airports. The gaseous emissions, which are caused by the aircraft driving units, are not so obvious. Another relevant aspect is that the share of the fuel consumption of modern passenger aeroplanes in terms of the global consumption of petroleum fuels is only about 5%. The specific fuel consumption of the present-day long-haul commercial aircraft is less than in the sector of individual automotive transport or it is fully comparable to it (Tab. 2).

Tab. 2

Mutual comparison of specific energy consumption in passenger transport [18]

Passenger Transport	**Specific Consumption of Energy** (kJ/person·km)
Automotive	2500
Air	**2100**
Railway	1300
Bus	700

Fig. 5. Boeing B-737 with the turbofan engines [23]

Fig. 6. Visible smoky trails [24]

For example, the specific fuel consumption of the newest versions of the worldwide popular passenger aircraft, Boeing B-737 (Fig. 5), which is driven by engines with a high bypass ratio, is approx. 4 litres of kerosene per 1 passenger and 100 km of flying distance. Such specific fuel consumption is similar to the fuel consumption of a typical passenger vehicle. The most harmful pollutants that occur in the gaseous emissions of aircraft jet engines are carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X), and sulphur dioxide (SO_2). The real chemical composition of the exhaust gases is variable regarding the jet engine operational regime (Fig. 7).

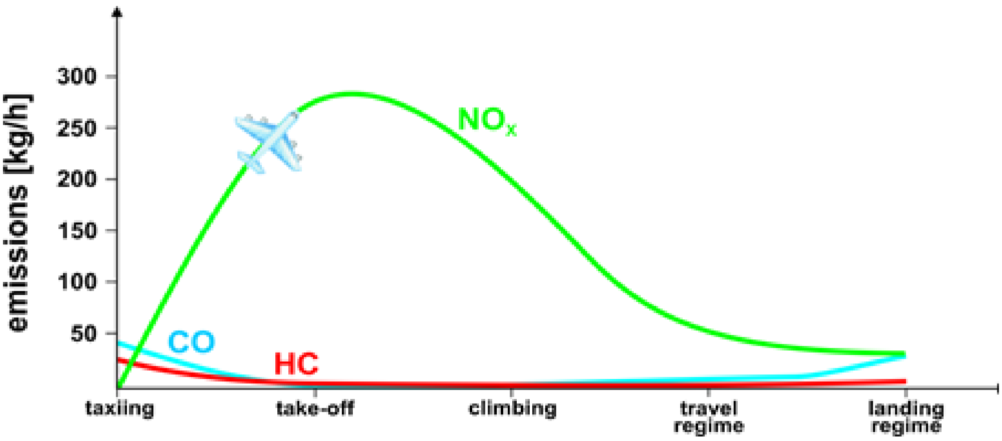

Fig. 7. Generation of gaseous emissions depending on the working regimes of the jet engine [18]

The production of NO_X is typical for a high thrust regime of a power unit, namely during take-off and the climbing phase of a flight. The unburned hydrocarbons (HC) and CO are characteristic of a low level of thrust, especially during the idling operational regime aground or when a plane is taxiing. The amount of SO_2 depends on the quality of fuel, namely on the amount of sulphur. Unburned hydrocarbons (HC) and CO are typical for a low level of engine thrust, especially in the idling operational regime during waiting on the ground or when the plane is taxiing. NO_X emissions are characteristic in the case of a high engine thrust regime, especially during the take-off and the climbing phase of a plane. The emissions of SO_2 depend on the fuel quality, that is, on the content of sulphur in the fuel.

Another undesirable phenomenon, which occurs during the aircraft jet engine operation, is the production of smoke emissions. Visible smoky trails are generated if the composition of the fuel-air mixture is not optimised and due to this fact, the burning process in the combustion chamber is not optimal. In such a case, the small fuel drops are carbonised on the internal shell inside the combustion chamber. This imperfect combustion process creates the smoky trails, which are visible as a black track behind the aeroplane shown in Fig. 6.

2.3. Human factor in air-traffic

Air inspectors argue that air accidents do not have one cause, but rather, are a group of several unfortunate circumstances. Statistics show that the most common cause of aviation accidents is human error [25].

The Statistics of Causes of Fatal Accidents [26] on air accidents that have occurred since 1950 states that in 53% of the cases, the main cause was pilot error. This is followed by technical failure (20%), weather (12%), sabotage and terrorism (8%), maintenance errors, ground dispatcher failure and the refuelling of inappropriate fuel (6%), and others.

The Swiss Air Archives Office states (from a database of 20,000 accidents) that up to 68% of air accidents are caused by the human factor. The aviation statistics show that in 16% of cases, accidents occurred due to weather, and in 5%, accidents occurred due to engineering failure [26]. The human factor of failure requires airlines to increase their effort to pay great attention, mainly in terms of pilots. Therefore, the pilot must be able to react in different situations. Their psychological profile is also very important. The important role of reliability in terms of the human factor, that is, the pilot has a suitable working environment, means that any legislative required limits must not be exceeded.

The aircraft's personnel are exposed to noise. A high noise level affects the performance, reliability in driving, and decision making. Pilots must meet the high physical and mental requirements imposed on them and which are regularly verified by the Commission Regulation (EU) No 1178/2011 of 3 November 2011, laying down technical requirements and administrative procedures related to civil aviation aircrew pursuant to Regulation (EC) No 2018/1339 of the European Parliament and of the Council, as amended. The applicant must not suffer from any disease or condition that could render the applicant suddenly incapable of performing their duties safely. The previous section describes the construction and types of engines, and their impact on the environment.

Therefore, this study, applying the TESEO method (Human Reliability Assessment techniques), focused on estimating the probability of pilot error, depending on the noise from the aircraft engines.

2.4. Noise and pilot failure assessment

The activities of pilots are influenced by factors such as the flight duration, aircraft type, ergonomic design of the aircraft interior, communication devices, etc. The TESEO method was applied for the analysis of the pilot´s activity in Tab. 3.

Tab. 3

TESEO method with noise exposure

Factor	Criteria	Quantitative characteristics	K_i value
K1	Type of activity carried out	Simple routine activity	0.001
		Action requiring attention	0.01
		Non-routine (unusual) activity	0.1
K2	Stress factor of usual activities	Available time < 2 s	10
		2 - 10 s	1
		10 - 20 s	0.5
	Stress factor of extraordinary activities	<3 s	10
		3 - 30 s	1
		30 - 35 s	0.3
		45 - 60 s	0.1
K3	Factor of worker´s qualities	Expert, professionally competent	0.5
		Average knowledge and competence	1
		Poor knowledge and competence	3
K4	Factor of anxiety and stress	The condition of a serious unpredictable event	3
		Potential emergency situation	2
		Normal state	1

K5	Ergonomic factor	Excellent vibro-acoustic environment and operational coordination (under $L_{AEX,8h} < 75$ dB)	0.7
		Good vibro-acoustic environment ($L_{AEX,8h}$ = 75 to 80 dB)	1
		Disturbing the vibro-acoustic environment ($L_{AEX,8h}$ = 80 to 85 dB)	3
		Disturbed vibro-acoustic environment with poor operational coordination (above $L_{AEX,8h}$ = 85 to 87dB)	7
		Unsuitable vibro-acoustic environment (above $L_{AEX,8h} >$ 87 dB)	10

A human reliability assessment study was performed for two types of aircraft. The first assessment was made for the cabin of a transport jet aircraft, where there was a common space for the crew of passengers and two pilots. The measured noise exposure level was 75 dB, which is in line with the fact that in the cabin of current jet airliners, a noise level of up to 80 dB is permissible within ANNEX 16. The second assessment was applied to a small sports (transport) two-pilot aircraft (with a turbo-prop engine). In this case, the measured noise exposure values were much higher, exceeding 87 dB.

For analysis of the pilot´s activity, the TESEO method as shown in Tab. 3, was used to reveal the likelihood of human failure in individual activities. The individual criteria (categories) were adjusted considering the impact of noise, as well as other factors that normally affect the activities of pilots. After measuring the noise exposure of pilots, they were asked to assign *Ki* weights corresponding to their workload.

Synergy of noise and other factors of the working environment increases the risks and likelihood of a human failing to perform their work. The TESEO method is based on the following formula (1):

$$P(HEP) = K1 * K2 * K3 * K4 * K5. \quad (1)$$

Practical application in aircraft control no. 1:
Select parameters:
Extraordinary (unusual) activity - 0.1
Stress factor of extraordinary activities - 0.3
Expert, professionally qualified - 0.5
Severe unpredictable state of the event - 3
Good vibro-acoustic environment (LAEX, 8h = 75 dB to 80 dB) - 1
The resulting P (HEP) value for the pilot in the cabin with noise exposure of up to 80 dB, for example, Jet Transports (Cabin), is

$$P(HEP) = 0.1 * 0.3 * 0.5 * 3 * 1 = 0.045. \quad (2)$$

Practical application in aircraft control no. 2:
Select parameters:
Irregular activity - 0.1
Stress factor - 0.3

Professionally qualified worker to perform work - 0.5
Serious events - 3
Unsuitable vibro-acoustic environment (over LAEX, 8h > 87 dB) -10
The resulting P (HEP) value for the pilot in the cabin with noise exposure above 80 dB, for example, Small Single Plane (Cockpit), is

$$P(HEP) = 0.1 * 0.3 * 0.5 * 3 * 10 = 0.45. \tag{3}$$

If the resultant P (HEP) is greater than 1, the probability of human factor failure is 1. The closer to 1 the value is, the higher the probability of human factor failure.
From the examples, it can be concluded that when operating an aircraft, noise exposure may affect the reliability of the pilot and may lead to an undesirable event, such as an accident. We are aware that the investigated statistical sample of four pilots is relatively low, however, their practical experiences can be considered for future research in this area.

3. DISCUSSION

Based on the assessment of human reliability, it can be stated that there is a higher probability of failure for the human factor in the second case, that is, for small sport or transport aircraft with a turboprop engine. These aircraft represent not only a higher probability of human failure but also higher noise emissions caused by the operation of these aircraft. The TESEO method was applied because it allows various factors to be combined qualitatively and quantitatively for evaluation.

It is a well-known fact that aircraft jet engines represent superior engineering works with the top technical parameters. Thanks to this fact, the environmental impacts of the aircraft engines are continuously minimised [25].

Low-frequency noise can be a serious problem in the aircraft cabin, depending on the engine type. Low-frequency aeroplane noise during take-off and landing periods is a serious hazard. There is very little attenuation at low frequencies, and low-frequency sound can propagate to relatively long distances [27, 29].

The interesting thing about low-frequency sound is the fact that we do not have to hear it, but we feel its pressure in our ears. It emits acoustic energy that is harmful to humans. Noise affects not only our auditory organ, but also negatively affects the cardiovascular and nervous systems, and mainly on the reliability of the human factor. Using the TESEO method, it was found that the reliability of the human factor is lower in the case of a small transport aircraft with a tuber-propeller engine due to the higher noise level. However, failure cannot be ruled out, even in the first case, given the exposure time and the nature of the noise, depending on the type of aircraft engine. This fact will be the subject of a further study to be conducted by the authors.

Compared to other modes of transport (road transport, railway transport, and water transport), the number of aircraft accidents is almost negligible. However, in the case of air accidents, the consequences are often fatal and cannot be overlooked, mainly because of the media coverage that generates a certain sense of distrust among people concerning air transport. A high level of aviation safety is achieved in different ways, for example, employing the supervision of national and international institutions, through the legislative, control, registration, analysis, and proposal of solutions; training; selection of staff; special procedures, etc. These precautions have to solve both safety and security concerns. In some cases, they overlap with each other in terms of the effect of the actions of the aircraft crew on the passengers and vice versa.

However, assessing the probability of a pilot's failure, depending on the factors of the working environment, requires the development of an integrated methodology for assessing its performance to evaluate the relationship between the noise sources and the flight duration. Further research aims to extend the analysis of pilot reliability to different types of aircraft engines, noise sources, and flight durations, and to demonstrate the relationship between the noise level and exposure and pilot performance, that is, aviation safety.

The aircraft engine manufacturer follows the rules determined for environmental noise pollution (for example, in the case of airports), which results in the need for modern passenger aircraft engines to have an outlet nozzle adjusted using the required design intervention. The final purpose of this modification is for better dispersion of the noise trail into the surroundings, and thus, the avoidance of a more concentrated trace, such as is the case of military aircraft, which are not the subject of such design modifications. The result is a significant difference in the generation of noise from civilian and military aircraft.

4. CONCLUSION

The dynamic development of worldwide passenger and cargo air traffic in recent decades was possible due to the application of a wide range of operationally reliable, economically effective, and environmental-friendly aircraft engines. Although many design modifications are being made to reduce the external noise generated by the structure and engines of aircraft, the problem of the perception of the noise of pilots, especially during long-term exposure (intercontinental flights), remains relevant, which is related to air safety.

Modern jet engines are characterised by excellent technical parameters and very favourable operational results. They integrate a high engine thrust and operational efficiency, which is presented in the form of low-level specific fuel consumption.

There is a growing acceptance of the need to address low-frequency noise caused by aircraft operations. There are no acceptable limits. Impacts on the health and reliability of occupational exposure to low-frequency noise are areas where further research is urgently needed, especially in management activities such as pilotage.

Air transport is almost entirely dependent on fossil fuels as a source of energy. It is the only sector in which greenhouse gas emissions have steadily increased over the past 20 years. Today, these emissions from transport already exceed the 1990 level, which is considered as a reference year for most countries of the European Economic Area, by around one third. One positive aspect is that, according to the statistical data, the fuel consumption per one seat in new aircraft is 70% lower than in older aircraft. Technological innovation could lead to increasing fuel efficiency by approximately 35-45% by 2025 and by 60% by 2050, compared to the present state. The optimisation of air traffic management can reduce emissions by approx. 10% per flight. Furthermore, the European Union is proposing ambitious targets determined to create a sustainable and competitive air transport industry by 2050. For example, it addresses the goals to reduce the carbon dioxide emissions by 75% per passenger-kilometre, to reduce the NO_x emissions by 90%, and to reduce the noise by 65% compared to 2000, by 2050 [38].

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