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NOISE OPTIMISATION OF AIRCRAFT JET ENGINES

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Abstract

Aviation industry is source of noise, which has negative impact to human health and significantly influences surrounding fauna and flora. Nowadays tendency and also a need of higher care about environment concerns the aviation sector as well, which has eminent negative aspects to environment. This study is concentrated on concept solution of changes of jet engine´s output parameters, especially focused on noise emissions, using shape changes of nozzle of created 3D jet engine model, what allows simpler, economic undemanding, but relevant resulting analyse of fluid flow through the engine. Object of the research is influence of the nozzle shape to the created noise effect, which was made by fluid flow going through this shape. The goal of the study is to make and analyse as much as possible ideal shape characteristics of jet engines with the reference to the noise. The result is evaluation of possibility to do some kinds of research and analysis of jet engines on 3D models of jet engines, their comparison with reference to another parameters, such as: thrust or fuel consumption. To completing research were used facilities, devices and places of Air Department, also necessary tools and other stuff which belongs to the owner of this study. For modelling 3D model of engine and nozzle shapes, was used computer software and production of these shapes allows 3D printer. Used methods for creating nozzles are with regards to real shapes of engine. Results and conclusions of this research are appropriate to be used in praxis of air or another industry, whose purpose is utilizing thrust units. With application of these data is possible the achieve reduced noise of certain unit, with some changes of other parameters, such as: increased or decreased fuel consumption or thrust, according to the initial requirements. Moreover, these results can be used not only for industrial purposes, but also are relevant for economics.

Keywords

jet engine, noise emissions, fluid flow, shape, shape characteristcs

1. INTRODUCTION

Aviation industry is a subject of many studies, including various aspects. One of them is called emission mitigation. Mostly, the studies are focused on carbon emissions, which are linked with global situation, rising sea levels, melting of glaziers and many more. On the other hand, there are also emissions called noise emissions. People are not usually familiarized with effects of noise.

2. HEALTH ISSUES

According to the part of introduction, noise causes a health issues, which are more dangerous than is public known. Between the biggest belongs annoyance, sleep issues, ischemic heart disease, cognitive disorders and more. Few studies claim that children rising in the vicinity of the airport, where is high negative impact of a noise, have slower development. [1] [2] [3] [4] [5]

3. SOURCE OF NOISE

The source of noise may be distinguished into 2 parts. First part is generation on noise due to interaction of an air with a plane. The second, and the topic of this research, is the noise generated by the engine.

Noise created by the engine is sort out to the next sub-parts. Here belongs jet noise, noise of combustion chamber, turbomachinery noise.

Depending on the position of the engine towards to the noise measure facility, each of mentioned source of noises supreme.

Noise is measured in many unites, mostly used is a scale of dB (deciBel). Moreover, there are many variations of this scale, sometimes used so called PNdB, what is Perceived Noise in dB. Figure 1 shows the impact of a position of an engine to the value of noise.

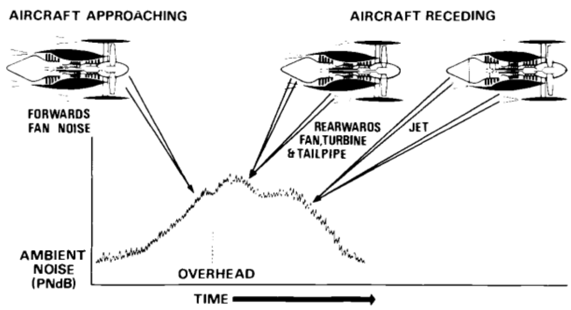


Figure 1 Dependency of a position of the engine to the impact of noise

Exist several of possibilities how to diminish the noise. However, aviation industry is a very specific sector, where all optimizations must be considered as appropriated, since one of the privileges of the aviation is sustainable economy. Any modifications cannot have negative impact, f.e. higher weight or increased aerodynamic drag. [6]

4. REGULATIONS

In regards of Annex 16, Volume II, which describes the regulations of noise impact, each aircraft must have certification which agrees with current regulations.

From the very beginning of aviation, nowadays certification requirements are stricter, and pressure of public forces those regulations to be more. On the next figure are shown chapters, which describes the noise limitations throughout the time. Each color represents one chapter. In past, the regulations were not so strict, but nowadays are. The last, the green shape also the smallest one, shows chapter from the year 2018 comparing to the past.

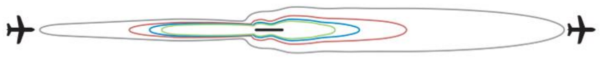


Figure 2 Chapters

Currently exists many manners of regulating noise. F.e. the airports use noise taxes, anti-noise walls, improved air procedures and many more, which could be sort as active or passive.

Between active diminishing belongs eliminating the noise in source of the noise, method of disposition, method of isolation, method of using material absorbing the noise, method using personal protecting equipment. [7]

The intensity of noise is measured in various units, mostly commonly used is decibel. For imagination of level of intensity, is Table, which shows different intensities regarding to the public known sounds.

Table 1 Comparing the intensity of noise to the public known sounds

Level of sound (dB)	Comparing
0	Audibility threshold
20	Wind lessness in the environment
40	Normal background noise
60	Slightly louder communication
70	Applause in the hall (from this level, the long-term effect has a negative effect on health)
75	Flushing the toilet
80	Going passenger car
90	Going train
100	Maximum power of the chainsaw
110	Rock concert
130	Jet start (pain threshold)

5. SOUND GENERATING MECHANISM

To diminish the noise of the aircraft, was introduced the mechanism, which simulates the flow of the air through the engine. This mechanism was created to replace a real jet engine, which would be financial unavailable. Sound mechanism could generate the flow of the air and simulates the real stream without a need to own a jet engine. Modifying nozzles influences this stream and noise generated by the interaction of the air with a construction of the engine is changed. Thus, this mechanism is designed to provide a flow, and to easily change the nozzles, to measure and evaluate the change of noise.

Figure 3 Constant, convergent and divergent shape of nozzle

Figure 4 Constant, convergent and divergent shape of nozzle with special shaped edge

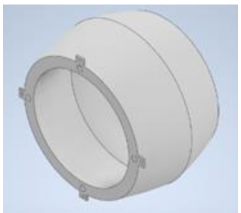


Figure 5 Divergent-convergent shape

Firstly, sound generating mechanism must be designed. In order to do it, Autodesk Inventor 2021 software was used. To create similar conditions as in a real jet engine, shapes and sizes ratios have been preserved. The final size must have been minimalized to the appropriate dimensions. The mechanism was made using 3D printer, and its size limits determined the final size of mechanism.

The fan was designed to provide air flow through the mechanism. It is conducted by the electromotor, put into the construction, and wires are led out of it using designed shell. Electromotor is connected to the remote control to operate it from the distance, so measuring of noise is not negatively impacted.

Besides the sound mechanism, the nozzles were designed and created. To secure easy and fast replacement of them, was designed a manner of pin connection with possibility to reach higher rigidity, using a screw connection.

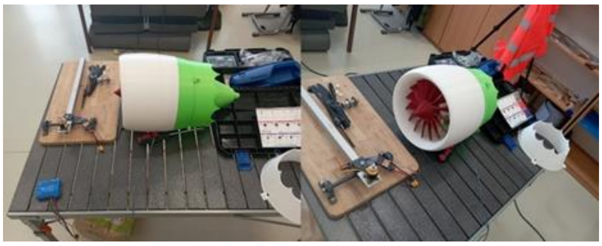


Figure 6 Created sound mechanism

Were printed the most basic shapes of nozzles, to observe the impact of shapes to the air flow, containing constant, divergent, and convergent shapes constructions, their mixing and special outlet shapes. Overall were made 7 shapes. Divergent and divergent with special shaped edge, convergent and convergent with special shaped edge, constant and constant with special shaped edge and divergent-convergent shape. Divergent-convergent shape varies from the others by the longitudinal length.

6. SIMULATIONS

Except for noise measurement, is important to do other measurements. Noise optimization, as was mentioned, must preserve another engine parameters, such as thrust or fuel consumption. Noise optimization, which would case lower thrust, higher fuel consumption or would have negative impact on the other engine parameters, could be considered as ineffective.

To prove, that sound generating mechanism is relevant manner how to measure and optimize noise characteristics of jet engines, computer simulations must be done.

For computer simulation was used CFD simulating software, which allows to observe air flow parameters. Designed sound mechanism was put in, and were set parameters to simulate air flow. For each nozzle was made simulation and values were written into the table to see with an ease the results.

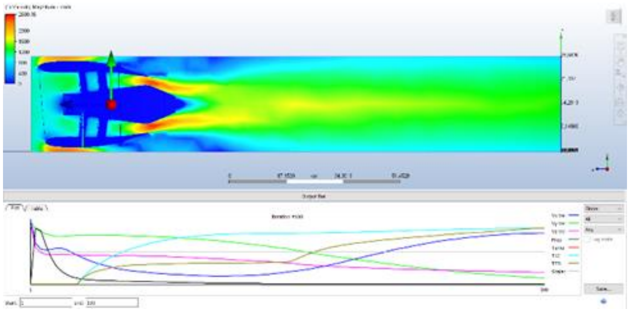


Figure 7 Demonstration of convergent nozzle using simulating software

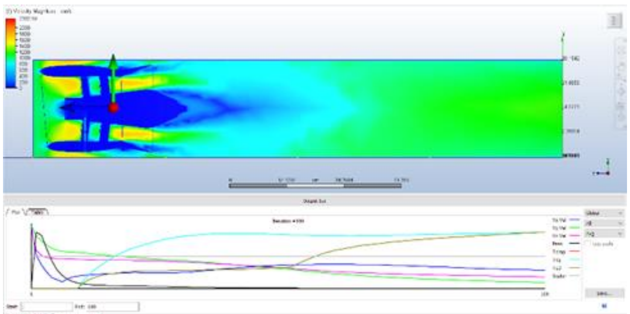


Figure 8 Demonstration of divergent shape of nozzle

Each simulation shows color resolution, as can be seen in Figure 7 and Figure 8, what represents the change of speed of the air through mechanism and beyond it.

Comparing Figure 7 and Figure 8, the change in flowing air through and beyond the engine is markable. The airflow hit the furthest part of the simulation in case of convergent nozzle, on the other hand, the divergent nozzle has only small impact in the further distances. However, the cone, which is created beyond the engine, is in case of divergent shape wider, what could affect another axes.

All parameters are also written under the simulation and graphs are made of it. Regarding to the results of simulation, a table of the most important parameters is made. Maximum speed is measured in m/s (meter per second) and turbulence in Mega Joules.

Table 2 Air parameters of CFD simulation

Shape	**Maximum speed (m/s)**	**Amount of accelerated air**	**Turbulence (MJ)**
Constant	22	Regular	2,86
Constant with special shaped edge	20	Regular	5,34
Convergent	25,5	Regular	3,15
Convergent with special shaped edge	25,6	Regular	5,27
Divergent	21	Small	8,22
Divergent with special shaped edge	20	Small	6,13
Divergent-convergent	21	High	3,5

Following the Table 2, the best nozzle for the created speed are convergent shapes. These results are logic, since they follow the Bernoulli equation of flowing fluid. The amount of accelerated air is also very important, and it can be seen, except of divergent shapes, all of them are appropriate. In this case, divergent-convergent shape is influenced by the dimension of it since the longitudinal axis of this shape is longer than the others. Optimal shape regards to the created turbulence is constant shape. However, this is not the only parameter which impact the generated noise, and the real experiment must be done.

After the simulations using the CFD software, the real experiments were done. First, the thrust measurement was performed. Sound generating mechanism was hanging in vertical axis, attached to the sensor of weight using lean ropes. Sensor of weight is connected to the computer, to write down all outputs. After turning on the fan of the mechanism, it started to generate thrust, which caused the change of weight in vertical axis. This change was processed in computer. The results were evaluated and graphs for each nozzle was made and so was a table. Thrust force is measured and processed in Newton unit.

Table 3 Thrust measurement results

Shape	**Thrust force in N**
Constant	35,34
Constant with special shaped edge	20,88
Convergent	29,72
Convergent with special shaped edge	20,1
Divergent	19,22
Divergent with special shaped edge	8,74
Divergent-convergent	1,66

Table 3 shows that, the highest thrust is achieved using constant shape, but the convergent shapes also achieve high values. The lowest thrust values are recorded using divergent shapes and divergent-convergent shape.

Observing the animations, that are the output of CFD simulation provide visual analyzing. Each shape of nozzle changes the air, which flows through the mechanism. As the flow is altered, engine parameters are altered as well. That means, that noise optimization must be considered with other engine characteristics, to preserve another values appropriate to be used in the airplane.

There is a difference between a simulation and real experiment. Divergent-convergent shape produce the least thrust and it is caused by low speed of air flowing through the mechanism produced by the fan. Other results are comparable, and to get better results, the method of thrust measuring might by improved.

Before the noise measurement are done, the conditions of this procedure must be set. Following the instructions of Annex 16, Volume II, correct procedures can be done. It describes very specifically the correct conditions under which the measurement must be done. First of all, choosing the right location is defined. Terrain, such as grass has special condition which allows to provide noise measurement, since the grass could absorb a part of noise energy. Another, such as snow or water must be cleaned out. Clay or sand have also special conditions under which could be measurement done.

Annex also defined obstacles, which are in the vicinity of measurement. Building, walls, trees, cars are unacceptable due to absorbing or reflecting the sounds waves.

Weather, such as rain, fog, drizzle has also negative impact on noise measuring.

Conditions for noise measuring are highly limited to ensure seamless process. Besides environment conditions, also another things are defined. Arrangement of microphones, the path of flying plane, the height of measuring point from the ground are also set. It is important to obtain some data from the engine or airplane, which is under measurement, to collect precise data of position above the microphone, also about engine rotation, attitude of the airplane and more.

Noise measurement of this research are done under specific conditions. F.e. the microphone with filter D, which is for aircraft noise measuring is, replaced with the filter A. In this case, it is not important to get the specific real values of noise, but to see the difference between these values according to the used shape. Also the hierarchy of microphone layout must be preserved to secure all numbers are measured at the same place relative to the sound generator.

The hierarchy layout of microphones consists of 3 axes. Longitudinal engine axis, the second axis at the angle of 30° and the last at the angle of 17,5° from the second axis. Microphones lay at the distances 1 meter from each other in each axis. The first is set 1 meter from the output of sound generator. Maximum distance of the last microphone is 3 meters. The high of microphone is the same as the center point of the output cone of the mechanism.

Measuring took place during the night to minimize the noise of the environment. The underlay was concrete, so noise energy was reflected, not absorbed. The temperature reaches 8,5°C and relative humidity was 65%. To measure all parameters was used multifunctional environmental meter MS6300.

Since, there are 3 axes, and 3 measuring distances in each axis, the results are for each nozzle very comprehensive. For reaching values which could be compared simpler, the average values are taken.

Besides the acoustic measurements, the measurements of air flow velocity were made. The speed of air and the amount of air are recorded by the MS6300 as well. The hierarchy of this air flow measurement is a bit changed. It also consists of 3 axes at the same angle as in previous instance, but the distances between measuring points are shortened in to the 0,5 m and the first point is 0,5 m from the output of the engine and the last in distance of 2 meters. The high of measurement point is the same as previous cause. The temperature and relative humidity are changed, due to measuring provided during the day. Temperature was 12,4°C and relative humidity was 65%.

Next tables show the results of measuring those parameters in separated axes.

Table 4 Results of measuring noise and other air flow parameters in longitudinal axis

Highest velocity	Constant shape
Lowest velocity	Divergent shape
Highest amount of flow	Constant shape with special shaped edge
Lowest amount of flow	Divergent shape
Highest intensity of noise	Divergent shape with special shaped edge
Lowest intensity of noise	Convergent shape with special shaped edge

Table 5 Results of measuring noise and other air flow parameters in second axis

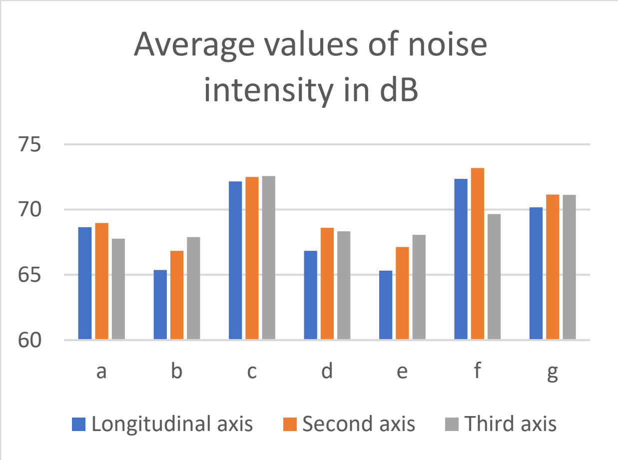
Highest velocity	Convergent shape with special shaped edge
Lowest velocity	Constant shape and divergent shape, both with special shaped edge
Highest amount of flow	Divergent shape
Lowest amount of flow	Divergent shape with special shaped edge and constant shape
Highest intensity of noise	Divergent shape with special shaped edge
Lowest intensity of noise	Convergent shape

Table 6 Results of measuring noise and other air parameters in third axis

Highest velocity	-
Lowest velocity	-
Highest amount of flow	-
Lowest amount of flow	-
Highest intensity of noise	Divergent shape
Lowest intensity of noise	Constant shape

In the next Graph 1 are marked the nozzle shapes using letters of alphabet to simplify the clarity.

a – constant shape, b – convergent shape, c – divergent shape, d – constant shape with special shaped edge, e – convergent shape with special shaped edge, f – divergent shape with special shaped edge, g – divergent-convergent shape.



Graf 1 Average noise intensities for each shape in each axis

Depending on the axis, the results vary. The best shapes for reaching the highest velocity of the air are constant and convergent. Lowest velocities are in different axis and in different distance are reached by using divergent shapes. Amount of flow varies in each axis and distance.

The highest intensity of noise is generated by divergent shapes, specially when uses shaped edge. The best shape for minimalizing noise is depending on the axis convergent or constant shape.

In the third axis, no air flow was measured for any shape.

7. COMPARING THE EXPERIMENT WITH THE SIMULATION

Comparing the results of the experiment and the computer simulation, allows to evaluate, whether is sound generating mechanism relevant for measuring of noise.

Simulation proved, that the highest velocity was reached by convergent shaped, following by the constant one. Experiment, on the other hand proved, that depending on the axis, the results are the same, and thus, convergent, and constant shapes reached the highest velocities. So thus, it proved same results for the lowest velocities.

Amount of flow showed that the minimum is created by divergent shape. Both, the simulation, and the experiment coincide. Maximum flow varies in this case comparing simulation and the real experiment.

Intensity of noise may be compared with the simulation turbulence. In this case, both showed the maximum intensity using divergent shapes.

In simulation, the minimum turbulence was reached by constant and convergent shapes. Measuring the real experiment proved similar results depending on the axis and the distance from the source of noise.

8. CONCLUSION

This research described the way of creating the sound generating mechanism, which after all measurements is considered as relevant. Simulation done using computer and real experiment are mostly coincided.

The best shape optimization for minimizing the noise generated by the flow, which interact with the construction, is the nozzle of convergent shape with special shaped edge, which preserves the engine most important parameters, such as thrust, and diminish the impact of noise.

Future improvement could achieve better results, closer reaching the real jet engine characteristics, by increasing the velocity of the air in the engine. Also, could be improved the method of measuring. Another improvement, such as adding the primary flow or the flow around the engine could cause more relevant results.

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