Evaluation and impact of noise pollution caused by turbojet engines on people and the environment

Sebastian Marian Zaharia

Faculty of Technological Engineering and Industrial Management, Transilvania University of Brasov, Brasov, Romania. Corresponding author: S. M. Zaharia, zaharia_sebastian@unitbv.ro

Abstract. The functioning of turbojet engines determines the sounds effect that presents a serious problem because of the intensity of both ecological and order constructive danger posed by fatigue acoustic integrity of the aircraft. Noise is one of the important parameters to be taken into account in the design of aircraft, so limiting noise with all the consequences became a indisputable necessity. In this paper we analyzed noise turbojet engines and the primary factor behind the noise. In the case study we have implemented accelerated acoustic fatigue testing techniques of turbojet engine nacelles, following to determine the main characteristics of reliability and quality.

Key Words: noise pollution, turbojet engine, nacelle, accelerated tests, acoustic fatigue.

Introduction. Propulsion systems are energy sources that move an aircraft. These power sources mounted on aircraft are engines. The engine is a fundamental element for assessing the performance of aircrafts. The exerted actions are direct, when the force is acting directly on the aircraft, and indirectly when the force is acting through a circumstance. The propulsion system is able to generate some form of energy. This energy is transferred to a fluid. If fluid is unable to move, it will deform. If the fluid can move when it receives energy transforms into mechanical work (force, movement). The turbojet engine (Figure 1) is an air-jet engine composed of: air intake device, centrifugal or axial compressor, combustion chamber, gas turbine and intermediate chamber, exhaust nozzle and auxiliary elements (Kerrebrock 1992).

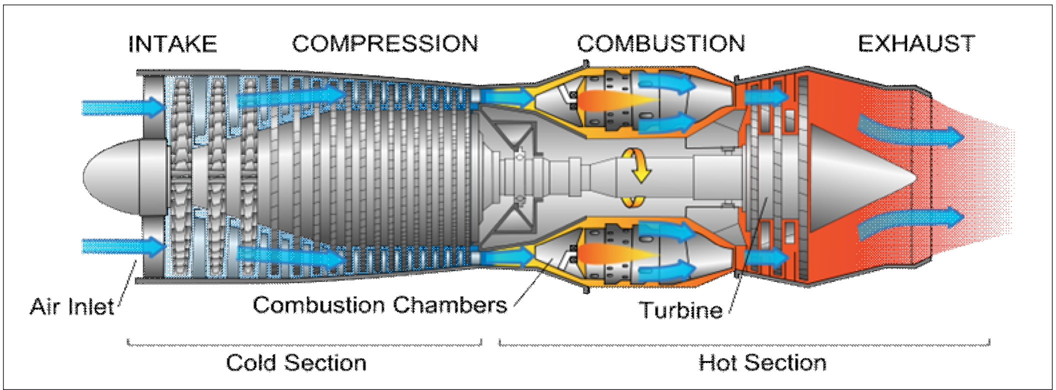


Figure 1. Turbojet engine components (Hunecke 2010).

The principle of operation is based on chemical transformation of potential energy of the fuel into mechanical energy. The operation consists of:

- aspiration of atmospheric air through the intake device;
- compressing air by a compressor (centrifugal or axial);
- burning chemical fuel-air mixture in the combustion chamber;
- expanding gases of combustion turbine that driving the compressor;
- expanding gases in the outlet device (the exhaust nozzle) as a spray reagent.

Since the advent of the turbojet engines, which constitute the major sources of noise, amplified the problem of noise pollution, while generating sustained concerns for noise reduction of these propulsion systems. Reducing aircraft noise is one of the most important issues in the aviation industry and is intensively studied (Filippone 2014) by experimental studies, specialized articles and patents. Current research (Grahamn et al 2014) carried out revealed several methods of noise reduction instruments, but choosing one should make an analysis of a number of specific issues, such as: efficiency acoustic method, the concrete conditions of location of airports, costs related the implementation of measures, the intensity of air traffic, their influence on technical and economic characteristics of the aircraft and engines that have been applied (Krebs et al 2008).

In order to prevent the negative effects of noise over the people and the environment it is necessary to introduce rules covering a high intensity that can lead to a pathological state. Noise physiological action on the human body is exercised by several factors: the sound pressure level, the harmonic components, frequency and particularities of man, action time. For noise standardization, it is necessary to introduce a criterion allowing its evaluation, by a number taking into account human perception of noise differentiated by different frequencies. One of the criteria of this kind that has gained widespread is perceived noise level PNL (Perceived Noise Level) expressed in PNdB. The PNL's values are useful for characterizing noise of aircraft isolated, in different operating conditions. These units are inadequate for noise situation around airports that are served by different types, whereas PNL system disregards a series of factors that appreciably affect the subjectivity reaction of population. The development of the aircraft noise assessment was reached to introduce a criterion of EPNL Effective Perceived Noise (Noise Perceived Effect Level) expressed in EPNdB. EPNL criterion takes into account not only the composition of the frequency noise, and other factors such as duration of action or discrete components of the noise spectrum (Hunecke 2010).

The noise of aircraft equipped with turbojet engines has as main causes: mixing gases leaving the engine with ambient air; pulsations in the fuel system of the engine that produce variations in the output speed of the blades; density jumps (shock waves) of supersonic flight which, by interaction airflows with engine-exhaust turbulent jet flow generates noise; the blade vibrations of the components (fan, compressor and turbine), which causes disturbance of the airflow and gas. Among the main sources of turbojet engines are: gas jet; fan compressor and turbine.

Aircraft noise regulations. The noise level is assessed according to FAR 36 certifications that apply**:** type certificates, and changes to those certificates, and standard airworthiness certificates, for subsonic transport category large airplanes, and for subsonic jet airplanes regardless of category (EASA 2015).

Any natural or legal person under whose name an aircraft is registered or will be registered in a Member State (Member State of registry), or its representative, shall be eligible as an applicant for a noise certificate for that aircraft. The holder of the noise certificate shall provide access to the aircraft for which that noise certificate has been issued upon request by the competent authority of the Member State of registry or by the Agency for inspection. The competent authority of the Member State of registry shall perform sufficient investigation activities for an applicant for, or holder of, a noise certificate to justify the issuance, maintenance, amendment, suspension or revocation of the certificate. The competent authority of the Member State of registry shall, as applicable, issue, or amend noise certificates without undue delay when it is satisfied that the applicable requirements of Section A, Subpart I are met. A noise certificate shall be issued for an unlimited duration. It shall remain valid subject to: compliance with the applicable type-design, environmental protection and continuing airworthiness requirements; and the aircraft remaining on the same register (EASA 2015).

Since FAR-36 and international rules set by the International Civil Aviation Organization which are generally consistent with it have been in force, airport noise has been a major design criterion for civil aircraft. Thus, an understanding of the mechanisms of noise production and of the techniques for alleviating it is crucial for aircraft propulsion research and development (Kerrebrock 1992).

Part FAR-36 is enunciated as three progressive levels of noise certification. The noise limits are stated in terms of measurements at three measuring stations, as shown in Figure 2 (Kerrebrock 1992): under the approach path one nautical mile or 2000 m before touchdown, under the takeoff path 3.5 miles or 6500 m from the start of the takeoff roll, and at the point of maximum noise along the sides of the runway at a distance of 450 m (FAR 2015).

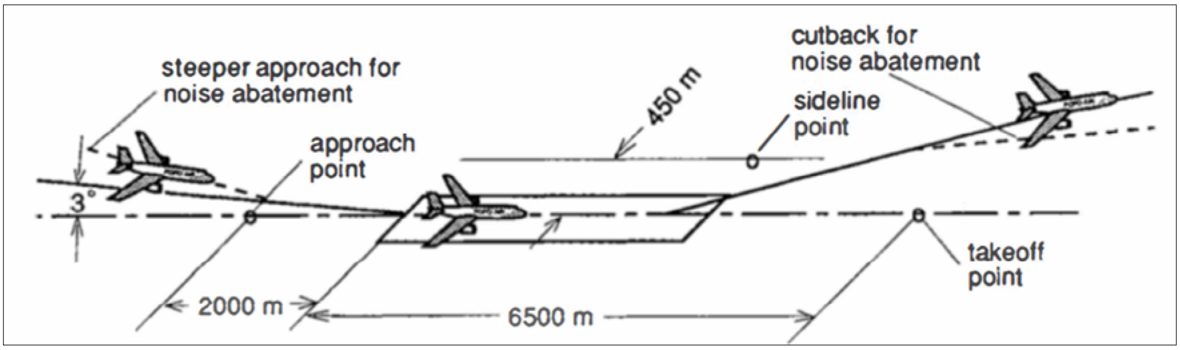


Figure 2. FAR part 36 - noise certification requirements (Kerrebrock 1992).

Next will study some aspects regarding noise limits for different configurations of engines installed on aircraft. For single-engine airplanes for which the original type certification application is received before February 3, 2006 and multiengine airplanes, the noise level must not exceed 76 dB(A) up to and including aircraft weights of 1,320 pounds - 600 kg. For aircraft weights greater than 1,320 pounds, the limit increases from that point with the logarithm of airplane weight at the rate of 9.83 dB (A) per doubling of weight, until the limit of 88 dB (A) is reached, after which the limit is constant up to and including 19,000 pounds - 8,618 kg. For single-engine airplanes for which the original type certification application is received on or after February 3, 2006, the noise level must not exceed 70dB (A) for aircraft having a maximum certificated takeoff weight of 1,257 pounds - 570 kg or less. For aircraft weights greater than 1,257 pounds, the noise limit increases from that point with the logarithm of airplane weight at the rate of 10.75dB (A) per doubling of weight, until the limit of 85dB (A) is reached, after which the limit is constant up to and including 19,000 pounds - 8,618 kg (FAR 2015).

Statistical analysis of data resulted from acoustic fatigue tests of the nacelle engines turbojet. The nacelle is housing, separate from the fuselage that holds engines, fuel, or equipment on an airplane. The nacelle of a jet engine is shown in Figure 3.

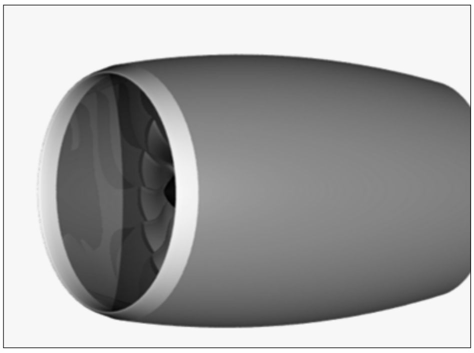


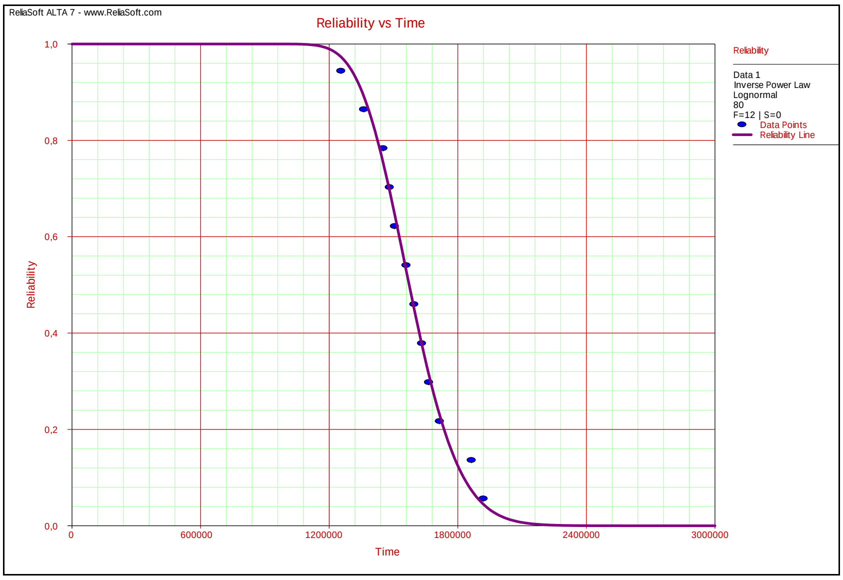
Figure 3. The nacelle of engine.

Aircraft components with most frequent damage due acoustic fatigue are: engine nacelle, stringers, rivets, ribs and stringers of the wing, frames and spars of the fuselage, other equipment (Goksel 2013).

In this paper will estimate performance indicators of reliability nacelles using accelerated acoustics fatigue tests. In Table 1 is described the failure times of turbojet engine on ground testing, which is fully equipped with the nacelle fixed on the engine. The nacelle is made of aluminum 2024. For statistical analysis of dates will be used for accelerating the acoustic fatigue experiments.

A common way of tackling these problems is to expose the products to sufficient overstress to bring the mean time to failure down to an acceptable level. Thereafter, one tries to "extrapolate" from the information obtained under over stress to normal use conditions. This approach is called Accelerated Life Testing (Zio 2007). In these tests, reliability practitioners may force the product to fail more quickly than it would under normal use conditions. Accelerated failure time modelling is one part of the quantitative accelerated life testing. Accelerated testing is used with metals, including test coupons and actual parts, as well as composites, welds, bonds, and other joints. Performance included fatigue life, creep, creep-rupture, crack initiation and propagation, wear, corrosion, oxidation. Accelerated stresses include the mechanical stress, temperature, specimen geometry and surface finish. Chemical acceleration factors include humidity, salt, corrosives, and acids (Zaharia & Martinescu 2012). Figure 4a represents the reliability function which describes the probability that a nacelle will operate successfully at a particular point in time. Unreliability function (Figure 4b) expresses the probability that a nacelle will be failed at a particular point in time.

The probability density function (pdf) is a statistical/reliability function that describes the distribution. The probability density function can be represented mathematically or on a plot where the x-axis represents time, as shown in Figure 5a. Failure rate (Figure 5b) represents the number of failures per unit time that can be expected to occur for the nacelle.



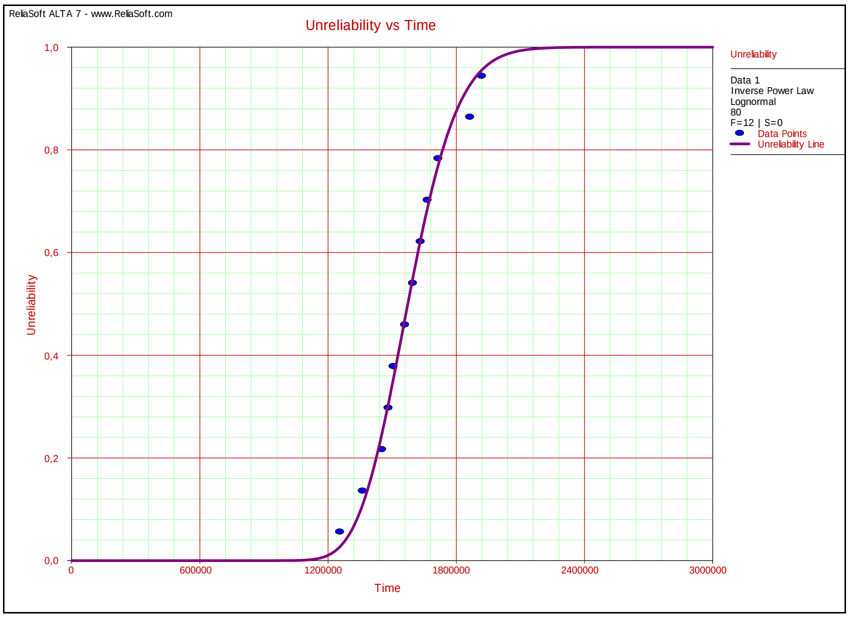
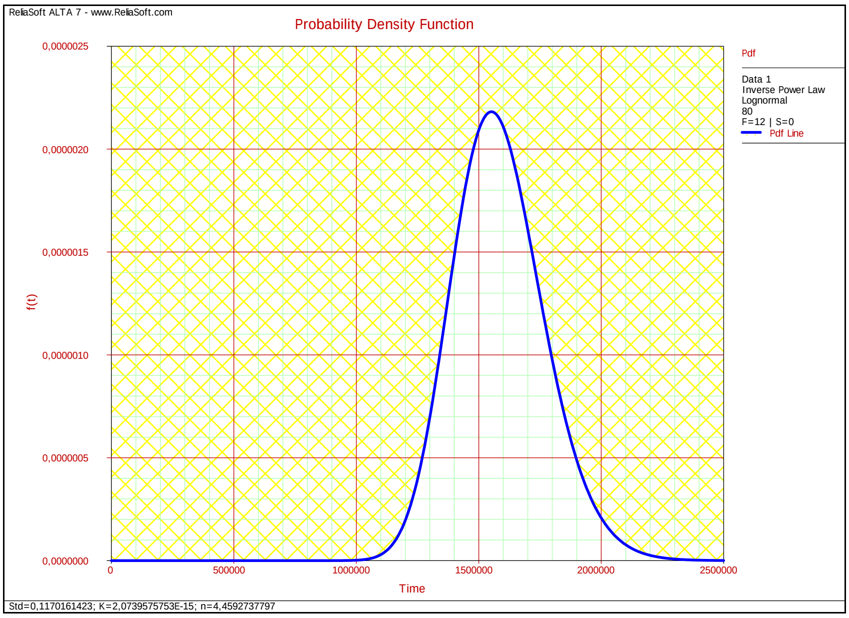


Figure 4. Reliability indicators: a) Reliability function; b) Unreliability function.

Table 1

The variation between the number of cycles to failure and noise level

No.	*Cycles to failure*	*Noise level [ENdB]*
1	805436	90
2	876453	90
3	890470	90
4	943987	90
5	603546	100
6	634176	100
7	689043	100
8	709632	100
9	303456	110
10	350863	110
11	376892	110
12	402431	110



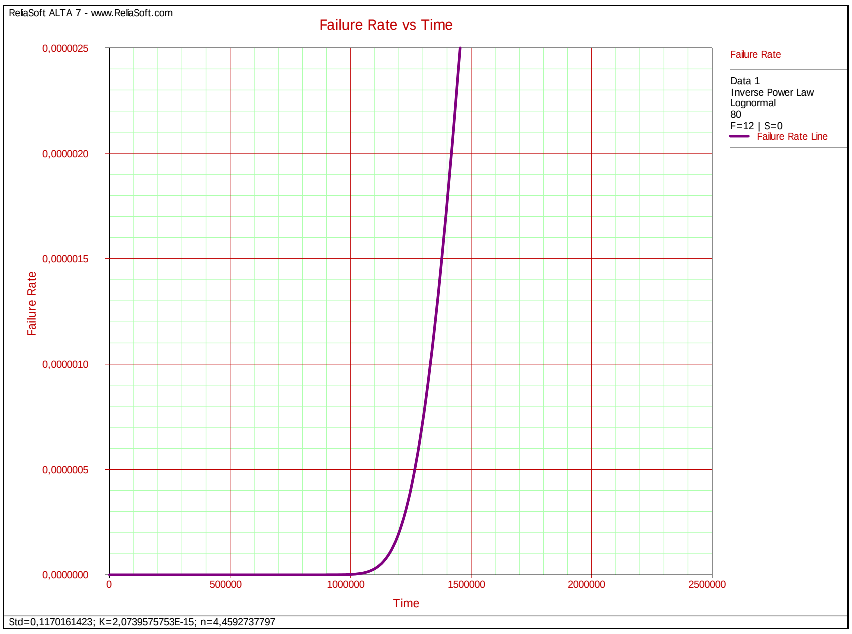


Figure 5. Reliability indicators: a) Probability density function; b) Failure rate.

The mean time of the nacelles in the population is expected to operate before failure. This concept is often referred to as "mean time to failure" (MTTF) or "mean time before failure" (MTBF). The Quick Calculation Pad (QCP) provides you with a quick and accurate way of gaining access to some of the most frequently requested reliability results in ALTA software. The main objective of accelerated experiments is to determine the mean life of nacelles in normal testing conditions. The mean life of nacelles is 1584069 cycles in normal testing conditions - noise level - 80 ENdB (Figure 6).

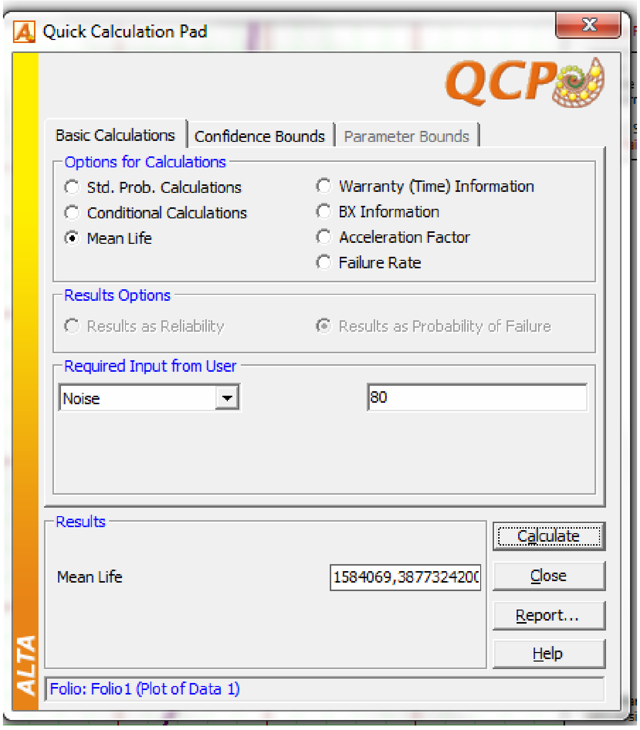


Figure 6. The determination of the number of cycles to failure of the nacelles in normal testing conditions.

Conclusions. Noise pollution is manifested, especially in recent years, with serious restrictions on the use of certain types of engines and aircraft. The biggest challenges aircraft manufacturers are making engines quieter and with low emission of pollutants. Aggressiveness on the environment is no longer much of a problem to be left solely to the care of nature and aircraft, and builders have to find systems and modern methods, sometimes expensive, to meet current standards.

In this paper was presented a case study on turbojet engine nacelles experiments using accelerated acoustics fatigue testing and reliability testing. The reliability of turbojet engines is one of the basic parameters, since it determines to a large extent flight safety of aircraft and flown population. For the case study under analysis, figure 5 shows the number of cycles to failure from the data under normal testing conditions for the nacelles turbojet engine. We can observe that, by using the acoustic fatigue accelerated tests, the testing time has been reduced by 2.5 times. Due to the fierce competition between aviation companies to implement such accelerated testing methodologies such time causes a decrease in product testing and a significant reduction of material costs associated with these tests.

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Author:
Sebastian Marian Zaharia, Department of Manufacturing Engineering, Transilvania University of Brasov, 29 Eroilor Street, 500036, Brasov, Romania, e-mail: zaharia_sebastian@unitbv.ro

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