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RELIABILITY BASED INSPECTION TECHNIQUES OF TURBOJET ENGINE COMPRESSOR BLADES

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ABSTRACT

In terms of jet engine integrity, the role of the blades is fundamental. The blades exist in a large number of elements in the structure of aviation engines, being altogether the most stressed items, in this case being justified the study of the factors that determine defects and directly influences the strength and resource of the blades. In this paper there were studied ten of compressor blades, in the jet engines' structure, at the fatigue stress using degradation tests. Using experimental data, were determined and plotted the main indicators of reliability using inspection times and length of blade cracks. Through rigorous determination of the reliability indicators and of the average lifetime of the compressor blades it can increase the blade resource through preventive inspections at pre-set time dates and detect possible damage caused in service.

Keywords: reliability, fatigue, mean life, inspections, blade compressor, turbojet engine

1. INTRODUCTION

Aeronautical construction domain is one of the most dynamic and rich in spectacular achievements, developing in a rapid pace in recent years. This area presents a particularly demanding and complex degree in operation of aeronautical structures. The growth of aviation highlights a continuous and sustained concern of the aircraft manufacturers to increase the speed and height of flight taking into account economic aspects. Propulsion systems are the energy sources that move an aircraft. These energy sources mounted on aircrafts are the propulsion systems. The propulsion system is a fundamental element for assessing the performance of some aircrafts. Propulsion systems and aircraft installations must operate in perfect safety conditions and maximum service life, taking into account economic efficiency indicators and the performances required.

The turbojet is an air-jet engine and is composed of: air intake device, centrifugal or axial compressor, combustion chamber, gas turbine and intermediate chamber (exhaust cone), reaction nozzle and auxiliary units. The operating principle is based on the transformation of the chemical fuel's potential energy into mechanical work.

The operation process consists of [1]: suction of atmospheric air through the intake device; compressing air by a compressor (centrifugal or axial); burning of air- chemical fuel mixture in the combustion chamber; expanding gases resulted from the combustion in the turbine driving the compressor; expanding gases in the outlet (nozzle side) as a reactive jet.

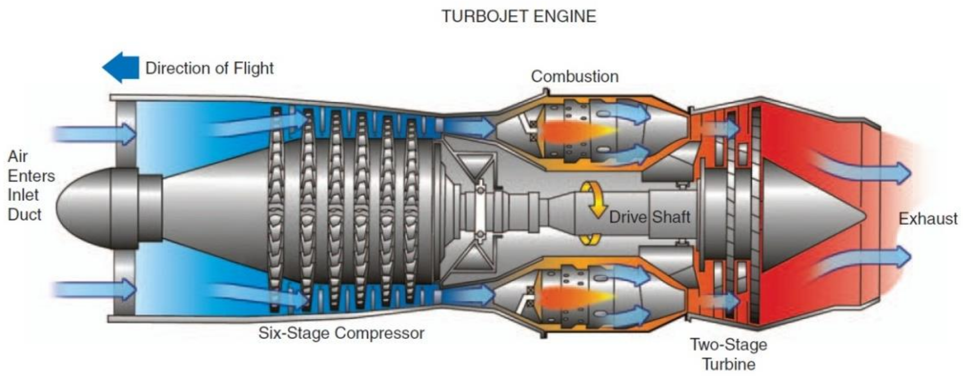


Fig. 1. The jet engine components [2]

2. RELIABILITY AND INSPECTION OF TURBOJET ENGINES

The reliability pursues a number of objectives, of which the most important are described in figure 2 [3]:

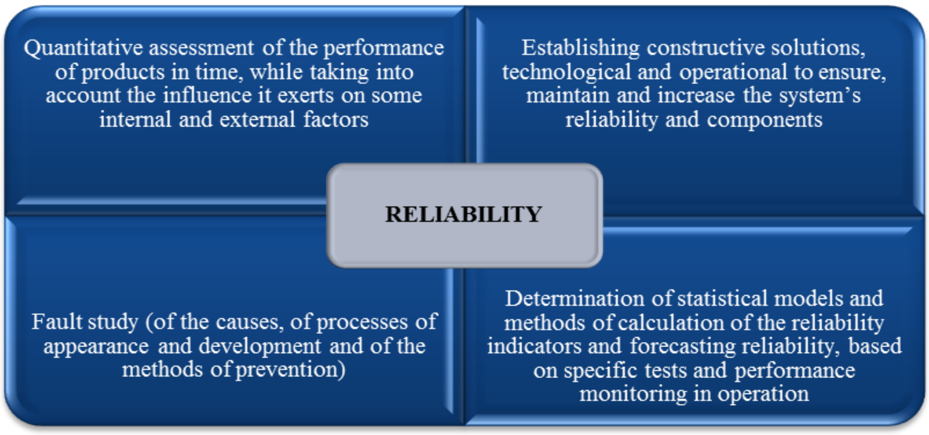


Fig. 2. The main objectives of reliability

Reliability theory applies in aviation and is characterized by safe operation, with an effective repair, and the reliability matter depends on the operational characteristics, of service, application and lifetime of the aeronautical product. The basic conditions of a full match of aeronautical products with the needs and requirements of reliability, is a strict respect to the following rule: reliability is determined in the design phase, is ensured in the production stage and is maintained during operation [4].

Aero-engines have three stages of operation characterized by a qualitatively different level of operation:

I. Period of early failures, when appear premature failures that have a high frequency. Items that fail in this period are the weakest, with hidden defects that appear after a short time of operation.

II. Failures of constant rate, which is the main operating range, with the longest duration. During this period failures have a random character, with a low and relatively stable rate. It is the period that characterizes the reliability of the products and on it research is done to extend it more.

III. Late breakdowns period characterized by a sudden increase in the rate of failures caused by items' wear. During this period keeping in service the elements is irrational.

The reliability of turbo-jet engines influenced by the following factors (figure 3)

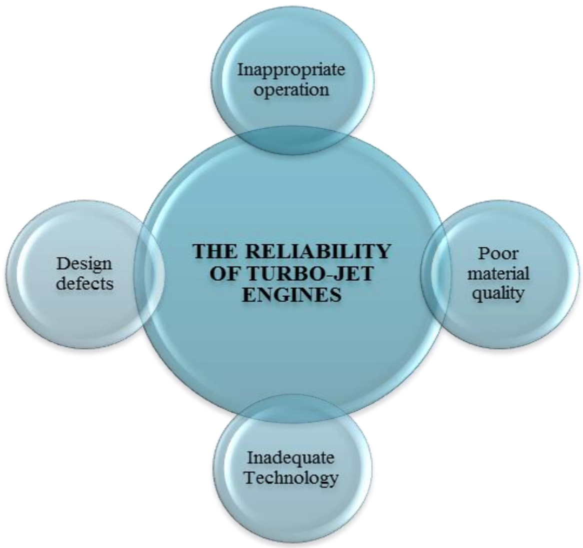


Fig. 3. Causes influencing the reliability of the jet engines [4]

To maintain operational reliability of the jet engines, it resorts to a maintenance program and a very well detailed inspection in order to maintain these engines in operation a longer period. As part of turbojet engine maintenance, two methods can be distinguished.

- Preventive maintenance is intended, as the name indicates, to prevent and not to repair the defects and it comprises of a set of planned and programmed controls to detect potential problems at predetermined intervals, even when it is not obviously necessary. Regular maintenance, planned and carried out correctly, is essential for maintaining safety and reliability of propulsion systems, helping to eliminate hazards from the workplace and preventing sudden and unexpected failure thereof.

- Corrective Maintenance consists of a set of activities implemented after the failure of the propulsion systems, after their sudden damage or failure, or after the degradation of their function unforeseen. In this type of maintenance, revisions are made to enable, for each part or assembly, after complete removal, an assessment of its condition, in order to be able to be put back into service after refurbishment or changes are done.

The need for surveillance of turbojet engines operation, for allowing an operation as long as possible, has led manufacturers to split the jet engine components therefore: the cold part comprising of compressors (axial and centrifugal), the hot part encompassing the combustion chambers, the afterburner chamber and the turbine and reaction nozzle. To check the operating status of the cold parts two inspections are required and for the hot parts are needed three controls for the same resource consumption. Figure 4 presents a schematic diagram of the factors determining the technical resource of a turbojet engines.

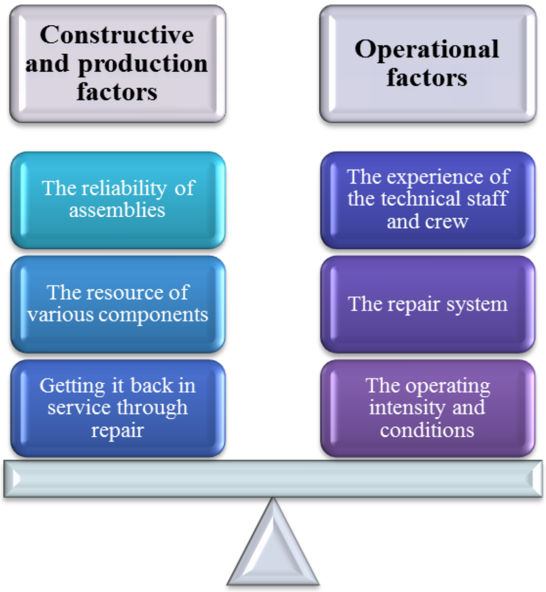


Fig. 4. Technical and service factors influencing the technical resource of jet engines [4]

Reliability and maintenance of compressor blades were studied and widely used in aerospace and other industries, including the marine industry applications [5]. Other studies have focused on the fatigue behavior of the helicopter turbo-engine compressor blades [6] or of gas turbine compressor blades [7]. Recent studies were also conducted on determining the stresses and strains with finite element analysis for compressor blades [8, 9, 10].

3. CASE STUDY

Mechanical compression is indispensable to achieve aircraft take-off, because, by air compression, the engine thrust and its yield increase. Also, burning at constant pressure cannot be achieved without prior compressing the air. The compressor, as a component of the turbojet engine, has the role to provide air compression in order to obtain high tractions and good combustion of fuel in the combustion chambers. The compressor rotor is the movable part of the compressor, which is intended to transmit the work received from the turbine, via the mobile blades, to the air for compression. An axial compressor rotor consists of turbine blade (Fig. 5), discs or drums and shafts.

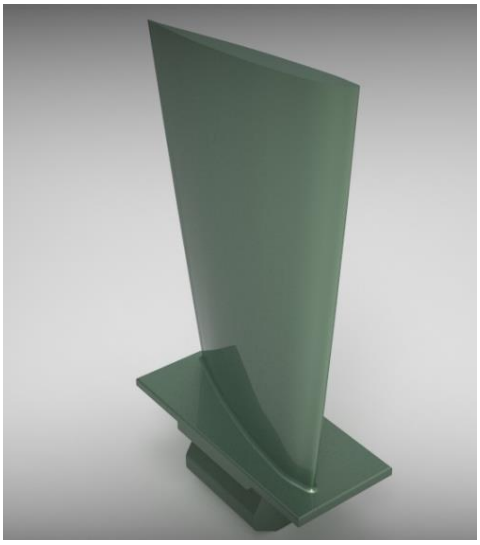


Fig. 5. Compressor blade

Ten of the compressor blades were tested for bending fatigue and vibration in order to determine the reliability and the mean life on the basis of regular inspections checking for the propagation of occurred cracks. The ten blades were fatigue tested in cyclic regime and inspected every 50,000 cycles to measure the occurred crack length. In this case study, failure is defined as a crack length exceeding 25 mm. Table 1 shows the cyclic fatigue test results for the ten tested blades along with the lengths of the cracks at the specified inspection intervals.

Table 1. Dependence of inspections carried out and crack length of the blades

	Crack lengths									
Cycles	**Blade 1 [mm]**	**Blade 2 [mm]**	**Blade 3 [mm]**	**Blade 4 [mm]**	**Blade 5 [mm]**	**Blade 6 [mm]**	**Blade 7 [mm]**	**Blade 8 [mm]**	**Blade 9 [mm]**	**Blade 10 [mm]**
50000	0.89	1.29	0.78	0.95	0.76	1.23	1.04	1.43	0.97	0.91
100000	0.97	1.87	0.99	1.23	1.34	1.45	1.98	1.67	1.45	1.35
150000	1.23	2.23	1.39	1.56	1.86	1.93	2.32	2.07	1.98	1.88
200000	2.34	2.94	1.85	1.94	2.09	2.45	2.67	2.56	2.08	2.18
250000	2.65	3.05	2.61	2.54	2.79	2.96	3.01	2.98	2.87	2.67

For statistical analysis, the software Weibull ++7 was used and for the statistical analysis, it was opted for the degradation analysis of compressor blades. The data in Table 1 were introduced in Weibull ++7 and the degradation curves were plotted for the ten blades, according to the time of inspection, using the Power degradation model.

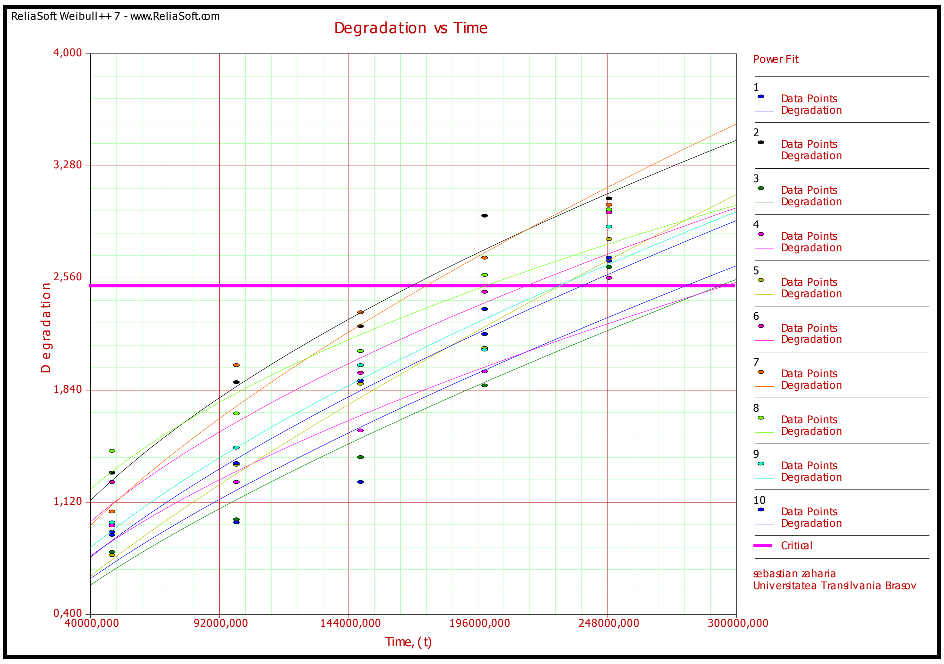


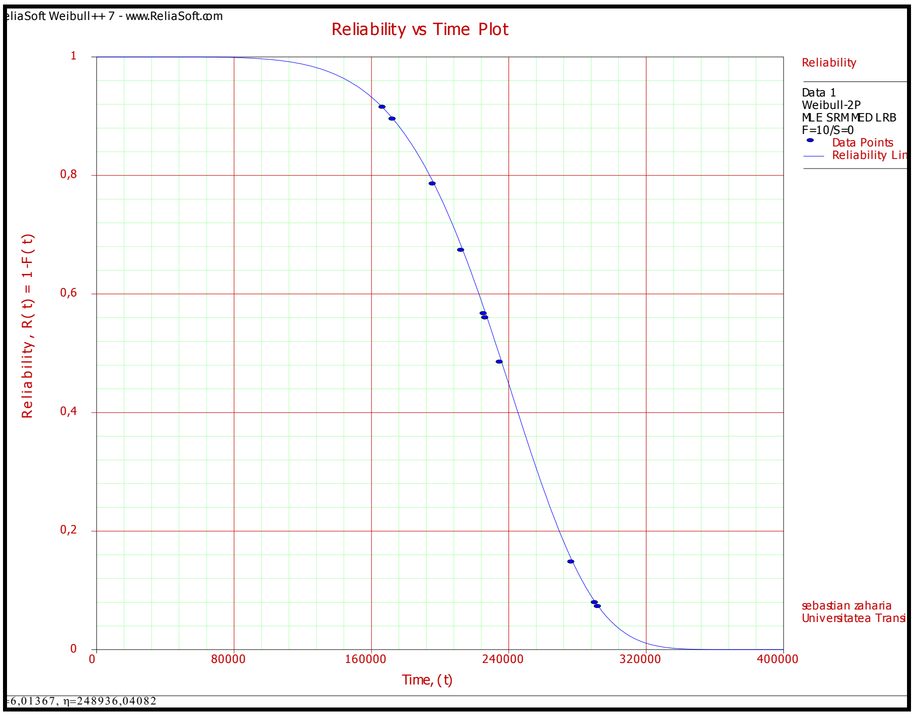
Fig. 5. Graphical representation of degradation as a function of the time of inspection of compressor blades

Using the Power model, the data from the analysis of degradation were extrapolated to the failure times, for the ten compressor blades. Using statistical data processing, the reliability indicators were determined (Table 2) corresponding to the ten times of failure (in cycles) [11]. For determining the specific reliability indicators for the ten compressor blades, the Weibull bi-parametric distribution and maximum likelihood method were used. The value for the shape parameter was β=6.013 and for the scale parameter η=248936.04.

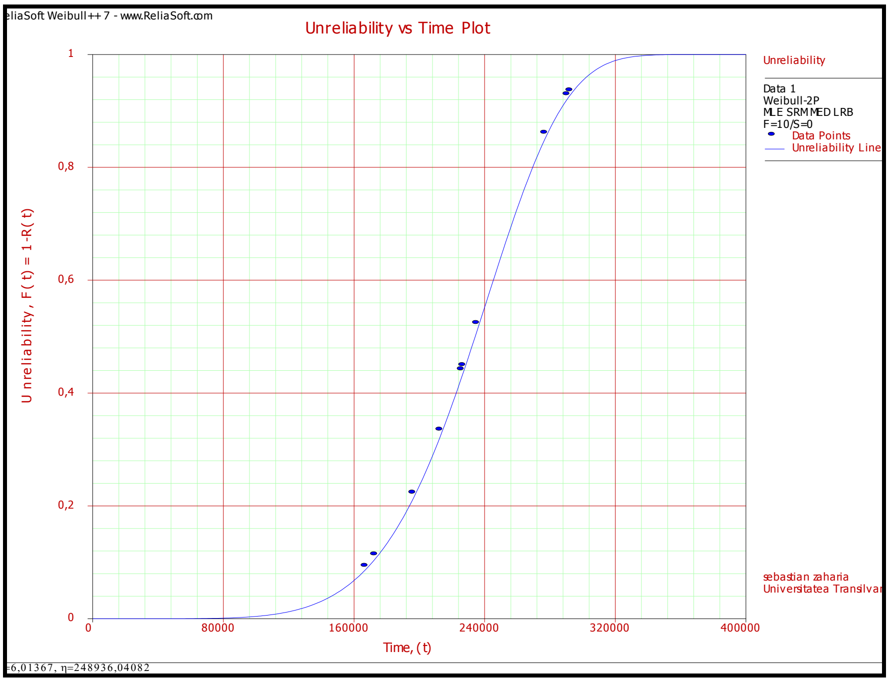
Table 2. Dependence of the number of cycles and reliability indicators

Cycles to failure	Reliability R(t)	Unreliability F(t)	Failure rate λ(t)	PDF f(t)
168111	0.909	0.091	0.0000034	0.0000031
174079	0.890	0.110	0.0000040	0.0000036
197393	0.780	0.220	0.0000075	0.0000059
213963	0.668	0.332	0.0000113	0.0000076
227152	0.561	0.439	0.0000153	0.0000086
227985	0.554	0.446	0.0000155	0.0000086
236467	0.479	0.521	0.0000187	0.0000090
278108	0.142	0.858	0.0000421	0.0000060
291788	0.074	0.926	0.0000536	0.0000040
293512	0.067	0.933	0.0000552	0.0000037

The reliability function, R(t), is the probability for the compressor blades to operate without faults, for the time t (Fig. 6a). Unreliability or cumulative reliability of fails, F(t), is the percentage of compressor blades who suffered a fails in the interval 0-t (Fig. 6b) [12].



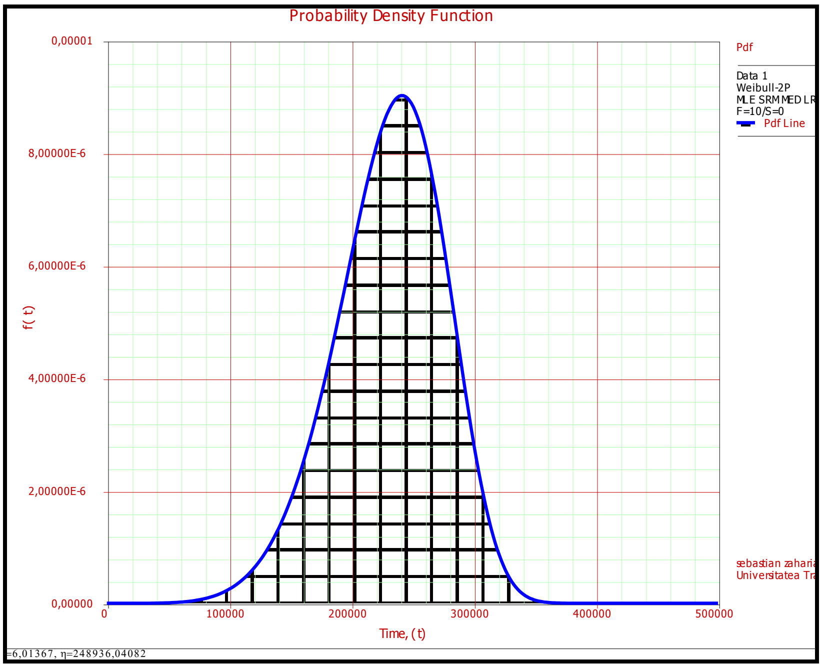
a) reliability function



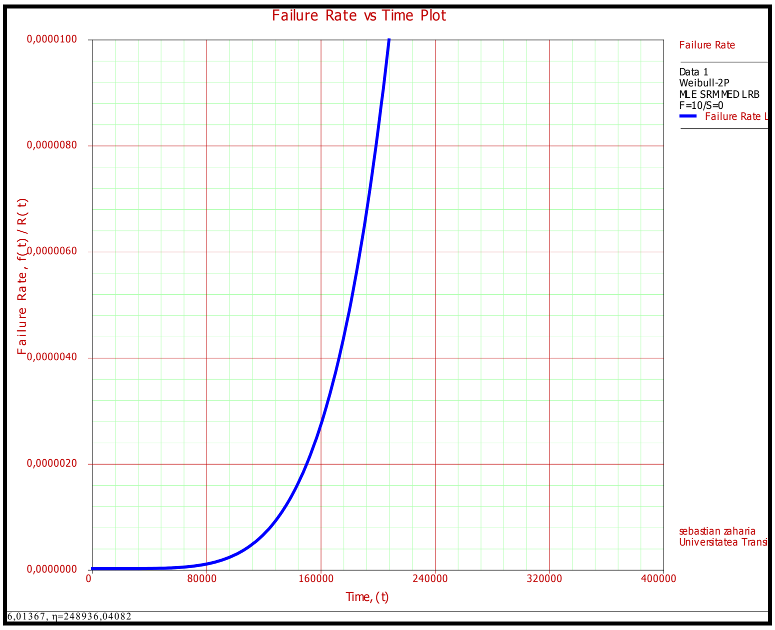
b) unreliability function

Fig. 6. Reliability indicators of compressor blades

In Figure 7a, the probability density function is described and Figure 7b presents the failure rate, which is the ratio between the number of failures within a certain time and the total running time of the compressor blades.



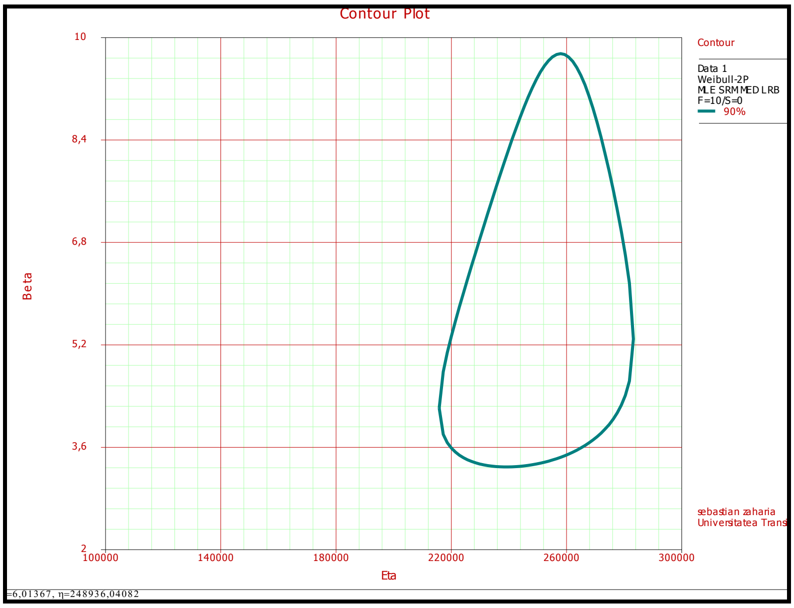
a) probability density function



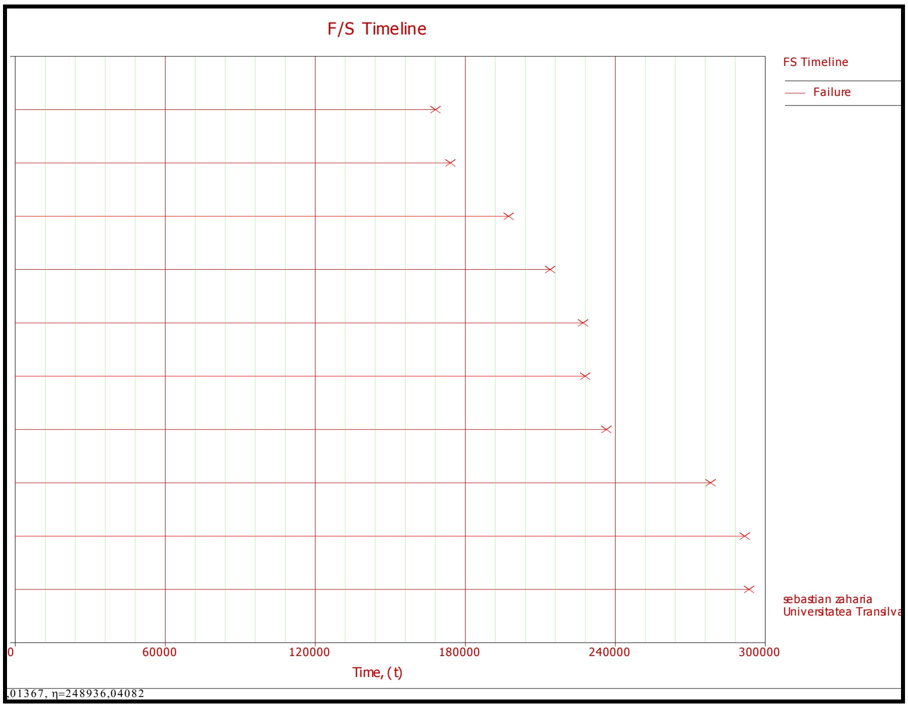
b) failure rate

Fig. 7. Reliability indicators of compressor blades

The contour Plots (Fig. 8a) is an option of the Weibull ++7 software and it is specific to Weibull bi-parametric and tri-parametric distribution, representing the variation of the shapes function for the scale parameter. Figure 8b represents the failure times for the ten compressor blades.



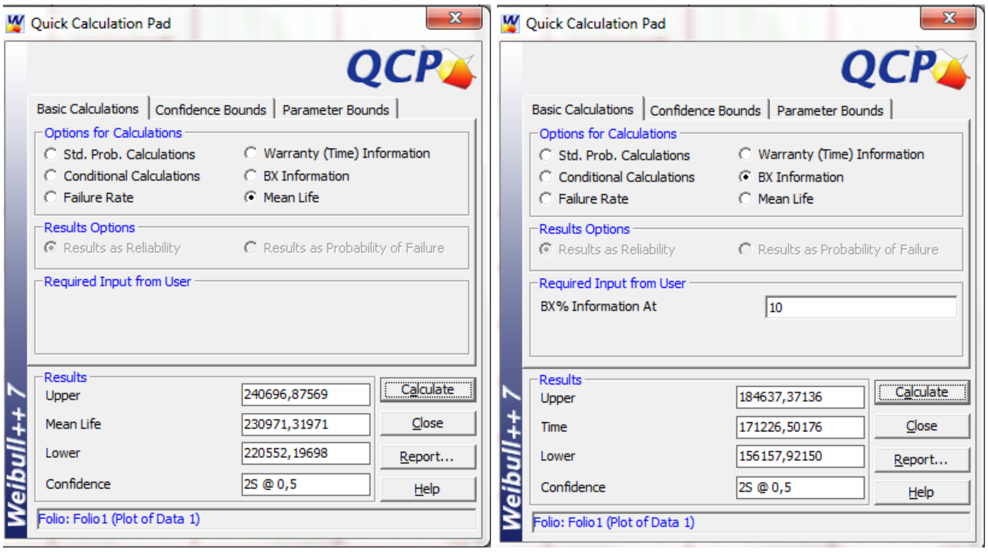
a) contour plot



b) failure time

Fig. 8. Reliability plot

Mean life (Fig. 9a) is the most important indicator of reliability for the analysed case because it represents the resource of the compressor blade. B10 life (Fig. 9b) is the estimated time when the probability of failure of compressor blade [13] will reach a specified point (10%).



a) mean life b) B10 life

Fig. 9. Reliability indicators of compressor blades

4. CONCLUSION

The level of reliability of an aeronautical product is determined by finding the probability after the number of occurrence of defects, resulting in the loss of functional qualities. Related to this, through the reliability analysis, a significant attention is given for studying the causes of defect occurrences and their possible consequences. Knowing the service lifetime of jet engine components, the occurrence and intensity of defects can be reduced by replacing them during operation, without removing the engine. The right choice of deadlines, the volume of maintenance activities and the sustainability of the replaceable parts are the premises for the resource growth of the turbojet engines.

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