The refined method of risk assessment of the technical condition determination of the aviation equipment critical elements

G I Korshunov¹,², S L Polyakov¹, E T Nurushev¹ and V O Smirnova¹

¹State Autonomous Educational Institution of Higher Education "Saint-Petersburg State University of Aerospace Instrumentation" (SUAI), ul. BolshayaMorskaya, 67, lit. A, St. Petersburg, 190000, Russian Federation
²Peter the Great St. Petersburg Polytechnic University (SPB STU), 29, Polytechnicheskaya St., Saint-Peterburg, 195251, Russian Federation

E-mail: ksi@pantes.ru

Abstract. The accuracy of the critical systems assessment of aviation equipment is paramount importance. The paper proposes a method of risk assessment, based on combined statistical methods, in the technical condition determination of the aircraft critical systems. The application of FMEA-analysis technology is considered in order to improve the accuracy and reliability of the obtained values. This technique can be useful for refining the resulting indicator in the presence of different emissions in total set of estimates.

1. Introduction

The process of repair aircraft systems and components is one most time-consuming and technically complex in the operation of aircraft, requiring a high level of diagnostic accuracy and reliability of its indications for further decision-making. At the same time, the timeliness and quality of repairs leads to a decrease in the occurrence of accidents and improve the performance of aircraft as a whole. According to the ICAO Safety Report 2019 Edition, the downward trend in aviation incidents in 2017 has changed its direction to an increase [1]. In this regard, the task of assessing the state of systems and components of aircraft in order to predict possible failures, is one of the main in the modern aircraft industry.

The effectiveness of predicting possible failures in aviation equipment will always be important both during operation and at the design stages of aircraft equipment, and in this case the accuracy and reliability diagnosis state is key for aircraft components. The existing nomenclature of operational technical characteristics (OTC) allows the calculation and experimental methods for assessing the values of OTC indicators at the stages of development, testing and operation of aircraft equipment [2].

Full assessment of the technical condition of aircraft equipment, as a rule, is made when performing major repairs (or when performing D-check), while most of the characteristic refusals of components and assemblies refers to the design and production deficiencies made during the design or production. Prediction of aging-related refusals is particularly difficult [3]. Based on the degree of impact on flight safety, the main systems of aviation equipment were identified, the prediction of failures of which is most important:

- Landing gear;
- The airframe including the flight control elements (ailerons, flaps, speed brakes, elevators and rudders);
- Power plant;
- Onboard equipment.

Thus, the operation steering control system is critical for the landing gear, as well as the regular operation of limit switches and the integrity of the electrical wiring, failures of which are possible when moisture enters and foreign objects (FOD – foreign object damage) on the airstrip, taxiways and apron.

For the airframe, the most important is to predict the occurrence of cracks during their design. Quite often the manifestation of fatigue phenomena (WFD - Widespread fatigue damage) is a serious factor in major accidents [4]. In the operation of flight control elements, timely and adequate shifting and deflection of the controlled planes is critical [5].

Power plant are characterized by mechanical and thermal fatigue cracks, irreversible ultimate deformation of parts, burnouts and peeling of coatings, wear of friction pairs. So fatigue failure of the disk stages of compressors of low and high pressure (CLP and CHP) is caused by high-frequency vibrations of turbine blades (figure 1) and the level of residual stresses in the material of the rotor discs is above the calculated.

![Figure 1. The destruction of the working blades of high pressure turbine.](image)

For onboard equipment, the reliability of the angle of attack sensors and the inadequate operation of the software, due to which two consecutive Boeing - 737MAX air crashes occurred, are of particular concern.

High reliability of the above elements of the aircraft will provide an acceptable level of safety. A measure of parametric reliability is the probability that the parameters determining the state of the system under consideration do not go beyond the stipulated limits [6]. In this regard, the analysis and evaluation of the parameters obtained in diagnosis requires a high degree of accuracy and reliability. In order to expand the tools for assessing the state of aircraft equipment and improve the quality of both repair and maintenance of aircraft systems, components and assemblies, a methodology for assessing the accuracy and reliability of the parameters obtained, based on a combination of analysis causes of refusal [7].

2. Description of the method and problem statement
The proposed method is an analysis of the system, disaggregated to a certain extent allowing to identify different types of potential refusals, their causes and consequences, as well as the assessment of the impact of failures on the functioning of the system. According to the results of the analysis, the most critical systems are identified, the state of which directly affects the functioning as a whole. Based on results of the evaluation, a decision is made to repair or decommission a single element or the entire system, as well as proposals for changes in the design or production technology of the object in question.

The assessment reliability of all systems can be represented as a set of (equation 1).

\[ P = P_1 \cdot P_2 \cdot P_3 \cdot P_4. \]  

\[ P_1 \] – the reliability landing gear;
$P_2$ – the reliability control system;
$P_3$ – the reliability power plant;
$P_4$ – the reliability avionics.

Assessing the reliability systems under consideration is quite a complex task, which must take into account a large number of different factors and conditions, in this regard, it is possible to use FMEA-analysis technologies and Shewhart cards, followed by reducing the impact maximum deviations of estimates on the final figure. The evaluation process is carried out by a group of experts together on the basis of the submitted data, recommended number of experts varies from 4 to 8 [8]. Experts have high requirements for experience in a particular field and the presence of an appropriate coefficient of concordance between experts in the field which is defined by the equation (2).

$$W = \frac{12 \cdot S}{n^2 \left(m^3 - m\right)};$$

(2)

$S$ – sum squared deviations of all rank estimates of each object;
n – number of experts;
m – number objects of expertise.

The main indicators for risk assessment in determining the technical condition critical elements of aviation equipment are: the impact on functioning aviation equipment or a separate element in event refusal ($S$); the probability refusal ($O$); the technical level of equipment enterprise in the diagnostic process ($D$). Each of these indicators is evaluated on a ten-point scale. For the first two criteria, this scale is increasing, i.e. the higher significance or frequency of refusal, the higher corresponding estimates. For the third criterion, the scale decreases – the higher possibility of detecting this refusal, the lower corresponding score. Comprehensive risk assessment ($K$) in determining the technical condition of critical elements of aircraft equipment is defined by equation 3.

$$K = S \cdot O \cdot D.$$  

(3)

The acceptable upper limit value of $K$ is between 110-125. Performing assessment experts put points on three main indicators, and the result is reflected graphically. In this case, the upper and lower limit lines are marked, as well as signal lines at a distance of ±2δ, where δ is the standard deviation of expert opinions.

3. Refined risk assessment methodology
Based on different combinations of estimates, the graphs will have a different display relative to the midline. When summarizing the judgments of experts, a deviation from the result set will always take place. In this case, the total area $f$ bounded above and below the curves of the graph and the height of the area "rectangle estimates" conditionally located along the middle line may vary depending on the set of estimates. At the same time, it should be borne in mind that with the maximum deviations of the estimates of individual experts, the estimates of others will compensate and the resulting area may be unchanged. In order to reduce the impact of maximum deviations from the mean value of estimates, we apply this technique [9].

| Experts | 1   | 2   | 3   | 4   | 5   | 6   | 7   |
|---------|-----|-----|-----|-----|-----|-----|-----|
| Ratings | 1   | 6   | 5   | 7   | 2   | 9   | 6   |
| Average | 5,139 | 5,139 | 5,139 | 5,139 | 5,139 | 5,139 | 5,139 |
| The trend line | 3,213 | -   | -   | 5,139 | -   | -   | 7,065 |

Using equations to calculate the area from known coordinates, for a triangle by equation 4.
\[ F = \frac{1}{2} \left[ (x_1 - x_3)(y_2 - y_3) - (x_2 - x_3)(y_1 - y_3) \right], \]  
(4)

for polygon equation 5.

\[ F = \frac{1}{2} \left[ \begin{array}{cc} x_1 & y_1 \\ x_2 & y_2 \\ \vdots & \vdots \\ x_n & y_n \end{array} \right], \]
(5)

where, \((x_1, x_2, x_3, x_n \text{ and } y_1, y_2, y_3, y_n)\) coordinates points outlining the shapes to calculate the area figures located from the middle line up and down, getting the total area \(F_U = 5.46\) of all areas figures above CL and the total area \(F_L = 4.06\) of all areas figures under CL.

In this case, the height of the upper area \(h_u\) will be equal to the ratio of \(F_U\) to the length middle line \(CL\) equal to 7 in the number of experts, thus determining the height of the deviation lower edge area \(h_l\).

As a result, the upper boundary area is located above the average line by 0.78 points and the lower by 0.57 points below the average, to determine the value location in points, use the equations: \(UCL = CL + 0.78\), \(LCL = CL - 0.58\). The values are shown in table 2.

| Experts | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|----------|---|---|---|---|---|---|---|
| Ratings  | 1 | 6 | 5 | 7 | 2 | 9 | 6 |
| Average  | 5.139 | 5.139 | 5.139 | 5.139 | 5.139 | 5.139 | 5.139 |
| LCL (- 0.57) | 4.569 | 4.569 | 4.569 | 4.569 | 4.569 | 4.569 | 4.569 |
| UCL (+ 0.78) | 5.919 | 5.919 | 5.919 | 5.919 | 5.919 | 5.919 | 5.919 |

On the basis of figure 2, deviations upper and lower boundaries occupied areas have different values and are directly proportional sign and value maximum and minimum points exhibited by experts.

**Upper and lower boundaries of the areas**

![Figure 2](image)

**Figure 2.** Location of the upper and lower edges of \(F_U\) and \(F_L\) squares.

We define the relation of the maximal positive bound \(L_{\text{max}}\) to UCL using the equation (6),

\[ k_U = \frac{UCL - CL}{L_{\text{max}} - CL}, \]  
(6)
Get the value $k_U = 0.202$. In the same way we evaluate the ratio value $L_{\min}$ to the value LCL using the equation (7).

$$k_L = \frac{CL - LCL}{CL - L_{\min}} \tag{7}$$

Get the value $k_L = 0.137$. Calculate the resulting averaged coefficient of deviation from the mean line using the equation (8).

$$k_{CL} = (k_U + k_L)/2 = 0.1695 \tag{8}$$

| Experts | Ratings | 1   | 2   | 3   | 4   | 5   | 6   | 7   |
|---------|---------|-----|-----|-----|-----|-----|-----|-----|
| CL      | 5.139   | 5.139 | 5.139 | 5.139 | 5.139 | 5.139 | 5.139 | 5.139 |
| New CL  (CL-0.1695) | 4.9695 | 4.9695 | 4.9695 | 4.9695 | 4.9695 | 4.9695 | 4.9695 | 4.9695 |

If we take this value as an amendment to the location average line of experts estimates, the specified location of the CL line will be lower than the existing one by the value of CL-0.1695. The resulting line is shown in figure 3.

### Table 3. CL values based on the correction.

![Midline correction](image)

**Figure 3.** CL level offset based on correction.

4. Conclusion

In order to improve the accuracy average result of evaluations, the evaluation of decisions in relation to maximum and minimum scores was carried out, taking them as erroneous, due to their significant deviation from the average score. The presented method of risk assessment of the technical condition determination of critical elements of aviation equipment allows to reduce the degree of influence of the maximum deviations of estimates on the resulting indicator of expert assessments, which leads to an increase in the accuracy and reliability of the values obtained. In addition, the presented calculations allow us to determine the clarifying correction depending on the ratio of the maximum estimate.

References

[1] SafetyReport 2019 (ICAO)
[2] OST 1 02785-2009 Aviation standard. Civil aircraft. Operational and technical characteristics. General requirements 29
[3] MacLean L, Richman A and Hudak M 2018 Failure Rates for Aging Aircraft. Safety 4(1) 7
[4] Molent L, Jones R 2016 A stress versus crack growth rate investigation (aka stress—cubed rule). Int. J. Fatigue 87 435-43
[5] Ogunvoul B D, Balanchuk E A and Kandyba K S 2017 Failure modeling in an automated aircraft control system Scientific Bulletin of MSTU GA 20 4
[6] Vinogradov A S 2011 Reliability of aircraft engines and power plants Textbook (Publishing house of Samara state aerospace university, Samara) 73
[7] GOST 27.310-95 2002 Reliability in technology. Analysis of the types, consequences and criticality of failures. Basic Provisions (IPK Standards Publishing House, Moscow) 12
[8] Basili M and Pratelli L 2014 Aggregation of not independent experts’ opinions under ambiguity. Structural Safety
[9] GOST R 50779.42–99 2000 Statistical methods. Control cards of Shekhart (IPK publishing house of standards, Moscow) 37