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Abstract. *The article deals with contemporary issues of safety of aircraft structures, which are fundamental in the choice of approaches to the continuing airworthiness of aircraft which re fundamental in the choice of approaches to continuing airworthiness of aircraft. The features of the formation methods of technical maintenance of aircraft in view of the design type are considered. Experience of aircraft maintenance has shown that the use of combined operational vitality in a number of cases has helped to prevent the catastrophic destruction of aircraft at a time when high enough qualifications for airline personnel were not satisfied.*

Keywords: aircraft, airworthiness, failure, reliability.

Introduction

In accordance with its purpose civil transport aircraft must perform the following functions:

– itinerant on time and in full safety deliver payload (passengers, their luggage and associated cargo) from the departure to destination airports;

– cybernetic (control and navigation) – control of trajectory of motion and position of aircraft relative to this trajectory;

– protective – protection of the aircraft, crew and payload from excessive mechanical, thermal, electrical and other external damages;

– air support – creating lift and thrust, as well as providing stability and controllability of the airplane;

– ground control – ensuring the operation of aircraft at the airport and control of its maneuverability as well as of loadings depreciation.

To implement these functions according to the most general law of the structure of technical objects (Act of compliance of function and structure) the components of aircraft proper must be: airframe, power plant, airplane control system, takeoff and landing devices (undercarriage), flight and navigation equipment radio, avionics and communication equipment (navigation, communication), electrical equipment, life support and safety systems (including fire-fighting, static electricity discharges, air-conditioning, utility equipment).

Every of above-mentioned components is realized through its structure, i.e. a set of mutually oriented material elements forming a single organized material system.

Any design in addition to its functions in the process of operation must withstand the current loads without destruction, i.e. the strength of any construction is it's the most important function.

Aircraft airworthiness standards require that the analysis of structural strength of parts and the quality of their manufacture showed the absence of an emergency or catastrophic failure due to fatigue, corrosion or accidental damage. This analysis should be conducted for each part of the aircraft structure, destruction or damage of which may result in emergency or catastrophic failure of the aircraft (for such units as the wing, the tail unit, control surfaces and their systems, the fuselage, engine mounting, landing gear and main mountings of these units).

The strength of airframe is its most important property which provides safe operation of aircraft as a whole. Therefore the further consideration of aircraft structure strength will be considered on the example of its airframe construction though it is applicable to the construction of other aircraft components as well.

Analysis of strength should be based on a typical spectrum of loads, list of critical sites destruction of which may cause disaster of catastrophic damage of aircraft; results of tests which are as a rule natural, and calculation of critical sites of aircraft design.

Thus, there are two main principles in analyzing structural strength: where the weakest (critical) sites of construction are and what condition of critical site must be considered its failure.

Problem Solving

Any design may be divided into two parts: main power part and “secondary structural” part.

Main power structure is a part of design intended for taking the stress loads effecting the aircraft in the course of its operation. Requirements of strength and minimum weight determine its sizes and consequently minimum aircraft reserve factor. “Secondary structural” part also takes the stress loads (but differing from main load part its sizes are not chosen on conditions of strength but other conditions) for example constructive or technological conditions) which leads to multiple redundancy in its strength.

Among the elements of the main power structure the main power elements stand out which took a significant part of actual stress loads and “secondary structural” parts take the remaining part of loads. But essential difference between these elements of the main power construction is that the strength of the main power elements is the most important for preserving the overall integrity of airplane construction. Namely, the strength of these elements determines the overall strength of airplane. Airworthiness standards specifically require that the major force elements and individual units of a design, the destruction of which can result in emergency or catastrophic failure of the airplane, were by all means included into the list of structures subjected to the strength analysis.

Structurally the main power elements can be made in a single transmission path load (the design of a single track loading) or in the form of several parallel paths of load transfer (the design of multi-path loading).

Single-path loading is realized if the applied loads are transmitted by a singular element, destruction of which results in loss of structure strength, i.e. its failure. Airworthiness standards admit but not recommend the structures with the only way of transferring loads.

The structures with a single –track loading are:

– the design with a secure resource;

– the design with single-track loading but permitting the damage of a certain size.

Designs with single-track loading will be illustrated in general in a rather simplified form with the elementary example. Let us suppose that the structure must withstand the limit load of 100 kg during its operation. Considering the standards of airworthiness, the estimated static failure load is 150 kg. Considered design, structure and materials are such that the appearance of cracks of any size in it would mean its failure. When you assign a secured resource, it is assumed that in the process of its operation not a single aircraft practically will have fatigue cracks. All the critical areas for fatigue must be identified during laboratory studies of strength and eliminated.

Safe resource (life) of the design is achieved by means of establishing the permissible operating time, during which the damages will not appear in the construction, reducing its strength below an acceptable level. At the same time life service may be calculated thin a number of flights, landings, flight hours, cycles of operation, in years, as well as other units that may characterize the rate of decrease of strength due to degradation processes (fatigue, corrosion, etc.). In the example the safe resource is 15,000 hrs.

The main drawback with the design of safe resource is that the majority of units (accessories) may be written off prematurely before their individual longevity is over. Besides the design with high value resource requires a low level of allowable stresses during operation which adversely affects the weight and consequently economic data of aircraft.

The main advantage of the safe resource design is its simplicity and low costs for maintenance as such a design provides the possibility of beforehand planning for replacement of units that have worked out their resource.

The design with acceptable damage is a plate static strength of which without the crack is the same 150 kg. Allowable crack size is determined by the following condition: the residual strength should be sufficient to with stand maximum operating load (100 kg) i.e. not less than two thirds from the initial load (airworthiness requirements). The material and structure of the design must provide low rate of crack advance as the possibility of its detect it during maintenance.

The key to the safe design with a single crack of loads transference permissible damage is a slow speed of crack growth, its easy detection and inspection program based on estimate of the limit damage, ensuring reliable detection and monitoring of damagem growth.

In accordance with standards of airworthiness of civil aircraft main power components with a single-track loading, individual failure (destruction, damage) of which causes emergency or catastrophic situation are classified as particularly significant and responsible elements.

Multi-path loading is realized in the design, in which applied loads are safely redistributed destruction among the remaining elements due to their more complete loading after the destruction of one of the elements. Such designs are the designs that implement the principle of safe destruction; their static strength should be such that during the fracture of one of the elements the remaining ones should withstand the limit load. The key to their safe operation is the sufficient magnitude of residual strength after the complete destruction of one of the elements.

Thus in the design of the airframe (as well as in the design of other components), there are parts, elements, zones, local places, longevity and operational viability of which determine the level of security under the terms of structural strength as a whole. Such places of design are called critical location. There are between seven dozens to several thousands of critical locations in the airframe of a civil aircraft. Thus, the safety of design due to strength in the conditions for long-term operation is determined by failure free time, longevity, and operational (maintenance) technological effectiveness of critical locations of the design, i.e. by its reliability.

Failure of design is an event which consists in breaking down its serviceability. The simplest example of design failure is its physical destruction (separation into two or more parts) or its acquisition of irreversible residual deformation.

Figure shows enlarged block diagram of a failure appearing based on energetic approach [1; 2].

In the process of aircraft operating its construction and other components are affected by various types of energy (mechanical, chemical, etc.). Theirs certain is necessary for appearing of degradation processes. If this level is not exceeded, prerequisites of failure will be absent. But if the degradation process appeared, it will change the initial properties of the materials of which the product is made.

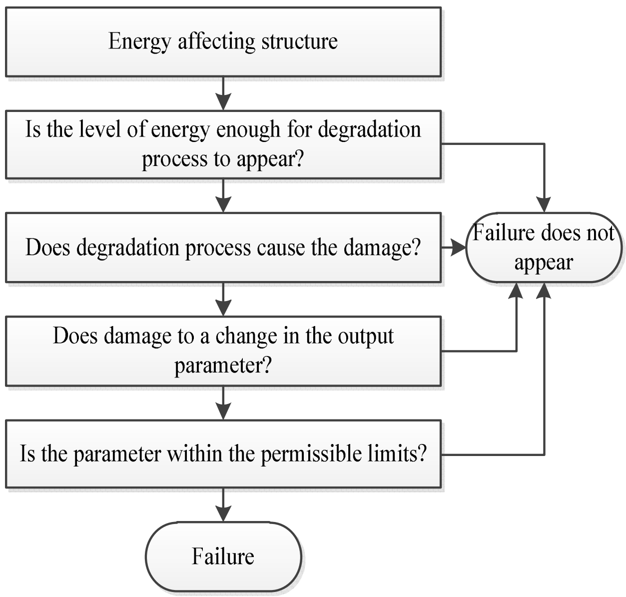
Under the effect of various types of energy such processes as fatigue, corrosion etc. may appear and enlarge. These processes may cause the damage of construction. Damage is understood as defection of controlled parameters (strength) from initial ones obtained during manufacture of construction.

The damage may or may not affect the output parameters of the design which are the indications of its strength.

The fails are of design are classified as gradual and sudden ones; as functioning and parametric fails; as actual and potential ones.

Gradual fails appear as a result of the progress of some degradation process (fatigue, corrosion and other degradation process), which worsen the initial structural strength. The main sign of gradual construction failure is that of probability of its occurrence $F(t)$ during specified period of time from t_1 to t_2 depends on duration previous work of construction was in operation, the higher is the probability of its failure, i. e. $F(t_2) > F(t_1)$, if $t_2 > t_1$. Fatigue and corrosion of the design are typical examples of processes causing gradual failures.

Sudden failures of the design appear as a result of unfavorable factors and random affecting loads exceeding the possibility of design to their perception. In MOC to АП 25.571 such impacts are defined as random effects of discrete character. For example, the strike of a bird mass of which is greater than estimated mass, against a windshield of a cockpit. The main sign of sudden failure of design is that the possibility of its happening $F(t)$ during the given period of time from t_1 to t_2 does not depend on the duration of the previous work of the construction.



Scheme of a fault structure

Sometimes it is believed that the appearance of sudden failures usually happen after concealed changes of design properties which are not always defected during maintenance, that is why the division into sudden failures is conventional. This is a misconception because the division into gradual and sudden failures is determined by the nature of their occurrence and not by the fast if the cause of the failure is or is not determined. Sudden failure of the design during the operation of aircraft due to hidden destruction process does not still mean that the failure can be closing as a sudden one. The criterion here is the dependence of the probability of failure occurrence $F(t)$ on time (service life) of a design.

At the result of functional failure the design cannot fulfill its functions. For example it is possible in case of physical destruction of the design.

Parametric failure leads to exceeding the parameters (characteristics) of the design its permissible limits. For example, fatigue damage of the design (the length of fatigue crack) exceeded the permissible amount. In complex constructions parametric failures may lead to its functional failure.

Let us consider the general scheme of forming parametric construction failure, given below. The failure will occur when the discussed parameter of functioning Y (for example the length of fatigue crack) will reach its limiting value Y_{max} .

As a result of various degradation processes taking place in the design. So as the time of reaching the limiting value is a random magnitude, its main characteristics will be the law of distribution of this time t, for example density $f(Y = Y_{max}, t)$. Knowing of this law allows to some tasks estimating reliability of design, product and aircraft as a whole because in any fixed value of time of design operation $t = T$ it is possible to determine the probability of failure which is quantitatively characterized by the integral:

$$\int_0^T f(Y = Y_{max}, t)dt .$$

Main stage of forming the law $f(Y = Y_{max}, t)$ consist in the following. First it is necessary to take into consideration scattering of parameters of a design (product) $f(Y)$ in relation to its mathematical mean value Y_0. It is connected with scattering of the initial indications of a new design (product) as well as with such processes as vibration, deformation etc. which show themselves immediately during the work of the design (product). Then the parameters of a design (product) are worsened in the process of operation slowly taking place processes like fatigue, corrosion, wear, ageing etc. It's necessary to point out that in general the process of changing parameter may begin through some period of time τ which is also a random value and associated with accumulation of damage (for example fatigue).

Speed γ of the process of parameter Y – change is also a random value and depends on changing of parameters of separate elements of design (product).

As a result of these phenomena forming of laws of scattering of parameter Y take place: $f(Y = Y_{max}, t)$ or $f(Y, t = T)$ which determine probability of parameter Y exceeding the limit Y_{max} i. e. probability of failure of the design (product) $F(t)$.

Probabilistic nature of changing parameter Y in practice stipulate an individual approach to the problem of establishing (continuing) resource and service life of aircraft. For example, operation of a product for ever life service T, for which actual nature of changing parameter Y, may turn out practically impermissible because of nearness of this parameter to limiting value of Y_{max}.

Division of failures into actual and potential ones is connected to the fast that during damage of the design i. e. fatigue corrosion etc., only in comparatively rare cases failure is admitted (for example, destruction of one of the ways of transferring the load in a design with multi-track loading). In the majoring of cases failures are prevented beforehand, i. e. during maintenance and repair. In this case failure is seen as a potentially possible event.

In view of this, when me discuss design failures, the main category of reliability theory.

We mean mainly potentially possible, but not only actual failures.

Thus, failure of aircraft is its destruction in a narrow and broad understanding of this term. Destruction in the narrow sense means separation of construction into several parts (minimum two). Destruction in a broad sense is appearing impermissible deformations; loss of stability by compressed elements, violation of design integrity (for example, fatigue crack, corrosion). In other words, failure of design element is words, failure of design element is reaching of limiting condition, i.e. under which the further use of design element according to its purpose is inadmissible and/or inacceptable either restoring of its serviceable condition or serviceability is impossible or inacceptable.

Three types of limiting states are distinguished in modern practice of operation of products (elements):

– Limiting state determined by permissible service life (resource) of a product;

– Limiting state corresponding to state of a product;

– Limiting state corresponding to the failure of a product.

These types of limiting state are the basis of these methods maintenance corresponding to them:

– Restoration (writing off) after service life is over – operation on resource;

– Restoration after reaching before failure state (parameters control);

– Restoration (writing off) after failure – operation before failure.

Methods of maintenance before failure occurs and the state before failure are referred to methods of maintenance on condition.

In maintenance on resource the moment of beginning the works of maintenance and repair (including replacement of the element) is set the same common day for the entire fleet of typical elements and regulated by service life. Such elements must have set resources before the first repair, between the repairs period and writing off.

During maintenance before failure state the elements are operated without limiting there resource (except the resource before writing off, which may be set for elements in necessary cases) with continuous or periodic control of technical condition of every element during maintenance. While the defining (and hence monitored) parameters (for example, the length of a fatigue crack) achieve the state before failure established by operational documentation for every type of the elements, it means their breakage and indicates the necessity of their restoring (repairing) or replacement.

During maintenance before failure every element separately is operated without limiting the resources (as an exception the resource before writing off may be established). Maintenance of every element consists mainly in clearing of fault detected while using respective indication or monitoring which is performed with necessary periodicity.

A certain construction corresponds to every limiting state as well as every method of maintenance:

– with safe resource;

– with permissible damage;

– with safe destruction.

Conclusions

Thus, method of maintenance and type of construction must correspond to each other. Nowadays the method of aircraft maintenance on condition is the main method which determines the main operating principle of the design and its type – operational viability, which (by definition of MOC to АП 25.571) includes both the constructions with possible damage and the constructions with safe destruction. The experience of operation of domestic aircraft has shown that the use of combined principle of operational viability helped in a number of cases prevent catastrophic destruction of aircraft in the conditions when rather high demands to qualification and experience of employees in the services of defectoscopy in some airlines turned out unfulfilled.

Thus, operational viability is a leading principle of design performance of the modern civil aircraft.

References

1. *Костерев, В.В.* Надежность технических систем и управление риском. –М.: МИФИ, 2008. – 280 с.

[*Kosterev, V.V.* 2008. Reliability of engineering systems and control of risk. Moscow. MEPhI. 280 p.] (in Russian).

2. *Байхельт, Ф.; Франкен, П.* Надежность и техническое обслуживание. Математический подход / пер. с нем. – М.: Радио и связь, 1988. – 392 с.

[*Baihelt, F.; Franken, P.* 1988. Reliability and maintenance service. A mathematical model approach: the lane with it. Moscow. Radio and communication. 392 p.] (in Russian).

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