МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
КАФЕДРА КОНСТРУКЦІЇ ЛІТАЛЬНИХ АПАРАТІВ

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Завідувач кафедри, д.т.н., проф.
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ДИПЛОМНА РОБОТА
ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ «МАГІСТР»
ЗІ СПЕЦІАЛЬНОСТІ:
«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Прогнозування граничного стану заклепкових з'єднань по експлуатаційним даним пошкодженості літаків Boeing»

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Київ 2021

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
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MASTER DEGREE THESIS
ON SPECIALITY
"AVIATION AND ROCKET-SPACE ENGINEERING"

Topic: "Prediction of riveted joints limiting state using operational damage data of Boeing airplanes"

Fulfilled by:	____________	**Savenok V.V.**
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Kyiv 2021

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Освітньо-професійна програма «Обладнання повітряних суден»

ЗАТВЕРДЖУЮ
Завідувач кафедри, д.т.н, проф.
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«_____» ___________ 2021 р.

ЗАВДАННЯ

на виконання дипломної роботи студента

САВЕНКА ВЛАДИСЛАВА ВАЛЕРІЙОВИЧА

1. Тема роботи: «Прогнозування граничного стану заклепкових з'єднань по експлуатаційним даним пошкодженості літаків Boeing», затверджена наказом ректора від 8 жовтня 2021 року № 2173/ст.

2. Термін виконання роботи: з 11 жовтня 2021 р. по 31 грудня 2021 р.

3. Вихідні дані до роботи: науково-дослідницькі роботи інших авторів за проблематикою роботи, імовірнісна модель багатоосередкового пошкодження заклепкового з’єднання, дані пошкодженості заклепкових швів з технічного обслуговування літаків Боінг.

4. Зміст пояснювальної записки: аналіз актуальності проблеми багатоосередкового пошкодження заклепкових швів старіючого парку літаків Боінг, інформаційний пошук та обробка літературних джерел за проблематикою роботи, представлення експлуатаційних даних пошкодження заклепкових з’єднань з технічного обслуговування, аналіз можливості застосування імовірнісної моделі багатоосередкового пошкодження заклепкового з’єднання, теоретичні розрахунки по прогнозуванн ресурсу.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу презентація.

6. Календарний план-графік:

№	Завдання	Термін виконання	Відмітка про виконання
1	Отримання завдання, підготовка необхідного матеріалу за проблематикою роботи.	11.10.2021–13.10.2021	
2	Обробка та систематизація дослідницьких робіт інших авторів за проблематикою роботи.	14.10.2021–20.10.2021	
3	Вивчення теоретичних засад проблеми багатоосередкового пошкодження заклепкових з’єднань.	21.10.2021–24.10.2021	
4	Вибір математичної моделі для прогнузування ресурсів по експлуатаційним даним.	25.10.2021–15.11.2021	
5	Практичне застосування обраної моделі до експлуатаційних даних з ТО Боінг.	16.11.2021–21.11.2021	
6	Написання розділів з охорони праці та охорони навколишнього середовища.	22.11.2021–29.11.2021	
7	Оформлення роботи та підготовка до захисту.	30.11.2021–31.12.2021	

7. Консультанти з окремих розділів:

Розділ	Консультант	Дата, підпис	
		Завдання видав	Завдання прийняв
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Охорона навколишнього середовища	к.т.н, доцент Тамара ДУДАР		

8. Дата видачі завдання: 11 жовтня 2021 року

Керівник дипломної роботи ___________ Краснопольський В.С.

Завдання прийняв до виконання ___________ Савенок В.В.

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty
Department of Aircraft Design
Educational Degree «Master»
Specialty 134 «Aviation and Rocket – Space Engineering»
Educational Professional Program «Aircraft Equipment»

APPROVED BY
Head of Department,
Dr. Sc., professor
______ Sergiy IGNATOVYCH
«___» _______________ 2021

TASK

for the master degree thesis

Vladyslav SAVENOK

1. Topic: «Prediction of riveted joints limiting state using operational damage data of Boeing airplanes», approved by the Rector's order № 2173/ст from 8 October 2021.
2. Period of work: since 11 October 2021 till 31 December 2021.
3. Initial data: research work of other authors on the issues of work, probabilistic model of multi site damage of riveted joints, riveted joints damage data in the maintenance data of Boeing aircraft.
4. Content: analysis of the urgency of the problem of multi site damage to riveted joints of the aging fleet of Boeing aircraft, information search and processing of literature sources on the issues of work, presentation of operational damage data of the riveted joints, analysis of the possibility of using a probabilistic model resource.
5. Required material: presentation.

6. Thesis schedule:

№	Task	Time limits	Done
1	Obtaining the task, preparing the necessary material on the issues of work.	11.10.2021–13.10.2021	
2	Processing and systematization of research works of other authors on the issues of work.	14.10.2021–20.10.2021	
3	Exploring the theoretical foundations of the MSD problem to riveted joints.	21.10.2021–24.10.2021	
4	Choice of mathematical model for prediction resources on operational data.	25.10.2021–15.11.2021	
5	Practical application of the selected model to Boeing maintenance data.	16.11.2021–21.11.2021	
6	Writing chapters on labor protection and environmental protection	22.11.2021–29.11.2021	
7	Registration of work and preparation for defense.	30.11.2021–31.12.2021	

7. Special chapter advisers:

Chapter	Adviser	Date, signature	
		Task issued	Task received
Labor protection	PhD, associate professor Victoria KOVALENKO		
Environmental protection	PhD, associate professor Tamara DUDAR		

8. Date of issue of the task: 11 October 2021 year

Supervisor: ____________ Krasnopol’skii V.S.

Student: ____________ Savenok V.V.

РЕФЕРАТ

Пояснювальна записка дипломної роботи магістра «Прогнозування граничного стану заклепкових з'єднань по експлуатаційним даним пошкодженості літаків Boeing»:

78 с., 23 рис., 4 табл., 30 джерел

Дана дипломна робота була присвячена проблематиці багатоосередкового пошкодження заклепкових з’єднань авіаційних конструкцій та розвиток втомних пошкоджень в конструкції літака з оглядом на імовірнісну модель багатоосередкового пошкодження.

В роботі було використано імовірнісний розподіл довжин втомних тріщин та відповідна математична модель розрахунку прогнозування ресурсу та визначення надійності заклепкових з’єднань при багатоосередковому пошкодженні.

В результаті чого виконана перевірка практичного застосування математичної моделі імовірнісного розподілу довжин втомних тріщин на основі зібраних параметрів пошкодженості на базі тезнічного обслуговування та отримано аналітичні залежності для функції розподілу ресурсу, визначення імовірності настання граничного стану та імовірності безвідмовної роботи заклепкових зєднань відповідно до реальних даних пошкодженості літаків Боїнг.

Матеріали дипломної роботи магістра можуть бути використані в навчальному процесі та в практичній діяльності конструкторів спеціалізованих проектних установ.

Дипломна робота, MSD, багатоосередкове пошкодження, заклепкове з’єднання, надійність, ресурс, розподіл Парето

ABSTRACT

Master degree thesis «Prediction of riveted joints limiting state using operational damage data of Boeing airplanes»

78 sheets, 23 figures, 4 tables, 30 references

This diploma work was devoted to the problem of multi site damage to riveted joints and the progress of fatigue damage in aircraft structure, taking into account the probabilistic model of multi site damage.

The probability distribution of fatigue crack lengths and the corresponding mathematical model of resource prediction calculation and determination of reliability of rivet joints in case of multi site damage were used in the work.

As a result, were performed the verification of the practical application of the mathematical model of probability distribution of fatigue crack lengths based on the collected parameters of maintenance damage data, analytical dependences for resource distribution function and determination of probability of boundary condition.

Diploma work, MSD, multi site damage, reliability, riveted joints, resource, pareto distribution

CONTENT

INTRODUCTION

A lot of time has passed since the first passenger aircraft was built, and the first and foremost task of any aircraft developer or aircraft maintenance company is flight safety itself, which in turn means increasing the reliability of the aircraft.

According to statistics, a large number of accidents occurred due to damage to the skin of the structure, which caused the need for constant or periodic inspection of the skin condition and riveted joints of the aircraft structure. During the execution of one flight cycle, namely "takeoff-landing", the aircraft is affected by a combination of various negative factors and a set of external loads. And first of all, external loads, taking into account experience and statistics, are concentrated in the joints of structural elements, where over time there are fatigue cracks that are most dangerous, due to the fact that changing the basic characteristics of the skin structure is very difficult observe during flight and line maintenance.

As riveted joints make up about 60% of the total number of joints and are the most widely used in aircraft construction, it is necessary to study more and more the problem of multi site damage in relation to riveted joints. At the moment, special attention is paid to increasing the life time of the aircraft and its systems. It is established that the duration of accident-free operation of the aircraft, its reliability depends primarily on its ability to withstand fatigue failure. Experience has shown that 75-80% of all fatigue failure of the aircraft occurs at the junction of structural elements. Hence the obvious need to increase the life of riveted joints. This applies primarily to joints with hidden rivets, the main disadvantage of which is the low resistance to fatigue when working on repeated and cyclic loads. As a result, cracks often occur in the load concentration zone.

Therefore, the creation of high-level aircraft today is inconceivable without conducting comprehensive research aimed at improving both flight and technical and economic characteristics of the developed facilities.

One of them is the need to predict the occurrence and development of fatigue damage in aircraft design. The development of fatigue cracks in the material is a consequence of the accumulation and combination of defects during operation under the influence of cyclic action of a wide range of damaging factors. It is obvious that the longer the aircraft is operated, the more accumulated damage will be in the elements of its design and the greater the probability of failure.

As most aircraft in Ukraine are currently over 15 years old, ie have been in operation for a long time, so the question of extending airworthiness becomes relevant. Using the collected practical maintenance data show the presence of fatigue cracks in the riveted joints of the skin structure, which is a manifestation of multi site damage in aircraft aged 10-15 years. Therefore, the continuing airworthiness depends on periodic inspections and additional inspections, but the effectiveness of the intervals between periodic inspections should be based on a mathematical description of fatigue damage and a scientific approach to the problem of MSD.

Therefore, this work considers the possibility of applying a mathematical determination of the resource and reliability of riveted joints, based on the probability model of multi site damage, considered in work, in accordance with the actual operational maintenance data of Boeing aircraft.

PART 1. OVERVIEW OF THE PROBLEM.

At present, the development of aircraft has achieved remarkable results, it is fast and quite comfortable, so almost everyone used this type of transport.

Thousands of flights are made around the world every day, and each of these flights is dangerous in its own way. Unfortunately, in history there were cases when before departure planes were completely serviceable, and at the flight revealed some malfunctions which at best ended in an unpredictable plane landing, and at worst - hundreds of victims.

Before departure, the aircraft undergo a series of inspections, after which it is decided whether the aircraft will be able to perform the flight. Including the human factor can be done conclusion that visually some damage can not be detected, so in flight under the influence of some factors these damages can lead to unpredictable consequences. To study the causes of plane crashes an on-board recorder is used, which registers the main indicators flight, crew negotiations, external conditions in which the aircraft is, etc.

After a detailed analysis of these indicators, experts can reconstruct events that occurred with the plane and indicate the causes of the crash. But not always for with the help of these data it is possible to indicate the causes of the aircraft malfunction.

After analyzing a large number of plane crashes can be done conclusion that most accidents occurred due to aircraft malfunctions which proved themselves in flight [1]. Therefore, the period of time that the aircraft spends the flight must be investigated.

The most common forms of damage are all types of cracks or fractures that occur as a result of exceeding the ultimate strength of the element of the aircraft. A significant amount of damage is mainly due to the nature of mechanical and thermal loads (static, dynamic and their combinations). There are factors that a person cannot influence. Repeatedly planes were shot down by enemy missiles due to insufficient fuel the planes did not reach the end point, when taking off the engines were birds that disabled him. Weather conditions play an important role in which the plane gets, because a strong crosswind, rain, hail, snow, lightning can damage the cladding, disable systems, devices and engines. Repeatedly as a result of hit of the plane in a zone turbulence, the aircraft skin was covered with cracks, resulting led to the crash of the plane. During the flight on the plane are dynamic loads which action on the damaged sites of the fuselage can lead to tearing of the cladding sheet. Therefore, to this day the problem reliability of a design and operability of all systems is rather actual.

At present, all aircraft structures are designed for long-term and intensive use in a wide range of possible environmental conditions. This condition is primarily dictated by the issues of economic efficiency of air transport. Modern aircraft construction is a high-tech and science-intensive industry, which uses the latest materials and technologies, as well as highly qualified personnel for the design, production and regular maintenance of aircraft. In order to cover all costs and rational use of resources, as well as in conditions of fierce competition, the world's airlines are increasing the volume of air traffic, which leads to more intensive and long-term use of the existing fleet. On the other hand, due to the increased risks, aircraft and their design elements are subject to stricter safety and reliability requirements than other modes of transport. All these factors together dictate the basic principles and approaches that prevail today in the field of aircraft construction. During operation, the design of the aircraft is affected by a wide range of various factors that affect the strength and structural integrity of the elements of the airframe. Such factors are: loading of the aircraft structure by aerodynamic and mass forces, physical impact of the environment due to sudden changes in temperature, pressure and weather conditions, possible action of aggressive environment during operation in certain climatic zones (deserts, tropics, north). All this causes damage and defects in the material of the aircraft. The accumulation of these damages over time leads to the degradation of the mechanical properties of materials and the onset of the ultimate state [2] of the structure. Since most of these factors are variable or repetitive over time, the long-term operation of the aircraft in its design is significantly dominated by fatigue damage.

A special place among different types of fatigue damage to aircraft structures is occupied by:

- Widespread Fatigue Damage (WFD – such fatigue damage to the structure, characterized by the simultaneous presence in one or more adjacent parts of the structure of many cracks of such size and with such a density that the residual strength of the structure is not maintained at an acceptable level;

- Multi Element Damage (MED) is a condition of a damaged structure that leads to widespread fatigue damage and is characterized by the simultaneous presence of fatigue cracks in adjacent structural elements

– MSD – Multi Site Damage – it is a condition of a damaged structure that leads to widespread fatigue damage and is characterized by the simultaneous presence and development of fatigue defects in one structural element of the aircraft. It should be noted that each of these defects, taken separately, does not pose a danger to the structure as a whole, but in the case of their combination or unfavorable configuration may be a decrease in residual strength below acceptable levels and sudden destruction [1].

Combining scattered fatigue cracks is one of the main mechanisms of destruction in multiple damage. This process occurs in several stages through which the development of damage during loading. Each of these stages is characterized by the presence of damage of different size levels. The transition between these stages is mainly due to the combination of defects when they reach a certain concentration limit until the destruction of the structure. This scheme is typical of almost all construction materials. It manifests itself in different types of loads and in a fairly wide size range. For multi site damage, cracking is even more important. As this type of damage develops in designs with many openings, there is a possibility of simultaneous development of fatigue cracks from the next openings towards each other. This development scenario is particularly dangerous, as it leads to the rapid destruction of the bridge in the structural element, and thus the formation of the nucleus of the main crack and the onset of the boundary state of the structure.

1.1 Analysis of Multi Element Damage and Multi Site Damage during long-term operation of aircraft structures.

Multi Element damage is especially dangerous for aircraft because there is a large number of stress concentrators in the form of holes in aircraft structures. For example, only the holes for riveted joints in the aircraft can be from 40,000 to about 2,000,000. All these holes are potentially dangerous places in terms of the emergence of fatigue cracks.

An example of such damage was the crash of the Comet I on January 10, 1954, the structure of which was destroyed due to the rapid development of fatigue cracks in the rivet joint, which attached square portholes to the receiving antennas of the automatic radio compass. Thus, multi element damage can significantly reduce the design resource laid down in the design of the aircraft. In general, a resource is the total operating time of an object from the beginning of its operation or its renewal after repair to the transition to the limit state, but in aviation the concept of resource can have different interpretations, depending on the choice of initial time, units of duration and justification limit state. However, in any case, the resource is a characteristic of the durability of the structure and should not exceed the allowable operating time in terms of durability and survivability of the structure. Therefore, the decisive influence of fatigue on the safety of aircraft structures in terms of strength was one of the factors in the transition from the concept of safe resource (Safe Life), adopted in the early 50's in aircraft design, to the concept of safety (Fail-Safe).

The main difference between them was that in the concept of safe resource indicators of structural integrity were based on providing static strength over time and improving methods of its calculation and obtaining information on the load of the structure in flight. This provided a certain sufficient level of reliability, but a significant resource limitation for many serviceable structures and premature termination of their use contradicted the commercial aspects of aircraft operation [1].

At the same time, the concept of fracture safety emphasized the multi-element structure and allowed the destruction of its individual parts without reducing the residual strength below the allowable level. This approach allowed to make fuller use of the inherent potential of strength, but not taking into account fatigue damage left a high probability of failure outside the safe resource.

Therefore, in order to extend the period of safe operation and increase the economic efficiency of aircraft since 1958, there has been a gradual transition to a modern approach to damage tolerance (Damage Tolerance). In its current form, it has been used since 1975 and has proven its effectiveness, but a serious challenge was the discovery of a new at the time, but still relevant problem of multi site damage. It was first noticed after the incident with the Boeing 737-200 of Aloha Airlines on April 28, 1988 in Hawaii. The situation was that 23 minutes after takeoff at Hilo International Airport, the plane tore off approximately 35 m^2 of the fuselage over the first six rows of business class (Fig. 1.3). The explosive decompression destroyed the cockpit door and led to the complete depressurization of the passenger compartment. The investigation of the circumstances showed that the cause of this destruction was several factors, among which the main ones were widespread fatigue damage to the rivet seam of the fuselage and corrosion of the metal. And although this incident ended quite successfully: the plane after an emergency reduction landed at the reserve airport Kahului on the island of Maui without casualties among passengers, it became clear that the recurrence of such cases is unacceptable. Fig. 1.3. Destruction of the fuselage of a Boeing 737-200 aircraft due to multi element damage. Following these developments, all major aircraft manufacturers and operators, as well as aviation administrations in various countries and research institutes, launched a large-scale program to study multi site damage. Studies have shown that the destruction of the structure in this type of damage occurs due to the redistribution of loads acting on the connection due to the existing cracks. In addition, it should be noted that in this type of damage, two cracks growing from one hole in different directions in some cases should be considered as one crack with a length that includes the length of these cracks and the diameter of the hole. A defect of this size under cyclic loading grows faster than single cracks, and therefore poses a greater danger.

Another feature of MSD is the possibility of the presence of counter cracks in the joint, which grow from adjacent holes. Such cracks can coalesce and destroy the bridge between the holes, forming a defect of a higher dimensional level and being a potential localization of the future main crack (leading crack). Such cracks are very dangerous because they grow very fast and cause sudden destruction of the structure, as happened with the Boeing 737-200. Therefore, as a limiting state of the structure in the case of multi-site damage, it is advisable to take the destruction of at least one bridge joints between two rivets.

Thus, the problem of MSD has clearly shown that it is not enough to simply calculate the design life of the aircraft given the current loads. It is also very important to monitor the condition of the structure in operation. This is one of the provisions of the concept of admissibility of damage. The basic principles of this approach are the provision of the presence of defects in the structural element at any time, even in the newly manufactured part, and the need to monitor the condition of the structure during operation to monitor the development of defects. This allows you to use the part as efficiently as possible to the point of destruction and save resources (natural, time, financial) on irrelevant inspections. 28 The experience of using this approach at the end of the XX century has shown its extraordinary effectiveness in ensuring the safety of aircraft structures, for example, the number of failures of the fuselage structure has decreased by about 80% [2].

However, in the practical application of this concept there are a number of problems, the solution of which is fundamentally important for its effective application. Some of these problems are related to the mechanics of fatigue failure and are as follows:

- determination of operating time (number of cycles) to the formation of a fatigue crack of a certain initial length;
- prediction the kinetics of fatigue crack growth under operating load;
- substantiation of limit states of critical structural elements with cracks;

- determination of the residual strength of the structure as a function of crack length.

The first two problems are related to the probabilistic nature of MSD. In fact, the origin of fatigue cracks occurs under the action of flight loads, which are variable and unpredictable, and therefore the origin of cracks and their growth are accidental events.

The third problem is the need to clearly identify and justify the critical size or configuration of the defects that will lead to failure. This causes difficulties due to the inability to predict the development of MSD, both in terms of the development of a single crack and in the case of merging adjacent cracks. In addition, for different parts of the structure, the critical configuration will also be different due to the different load and importance of the considered elements.

The fourth problem is related to the first three, and although it is obvious that there must be some correlation between crack length and residual structural strength, a mathematical description of this phenomenon requires a large number of independent random factors. Therefore, the construction of any mathematical models of this type of damage is quite a difficult task.

Other problems of the concept of damage tolerance relate to the control of the technical condition of aircraft structures in operation, namely:

- ensuring the maximum controllability of the structure;

- substantiation of the methodology of non-destructive testing of the technical condition of the structure;

- the choice of strategy for monitoring the technical condition of the structure. These problems lie exclusively in the practical plane and are related to the methodological and technical support of the design and maintenance of aircraft.

And if the fifth point is only a design task to ensure accessibility for inspections of those places of construction where multi site damage can occur, the sixth is directly related to the technical feasibility of detecting defects by non-destructive testing (NDT) and justifying the minimum size of the defect. can be reliably detected. The latter problem is also related to the random nature of multi element damage and is to justify the periods of technical inspection of the structure, given the speed of defects and timely prevention of the onset of the boundary condition. It is obvious that these tasks are not separate and need joint consideration and solution. For example, a reliable determination of the operating time before the formation of a crack of the initial length is impossible without an appropriate methodology of non-destructive testing, and without this it is difficult to choose a strategy for monitoring the technical condition. At the same time, this strategy is concerned with predicting the kinetics of fatigue crack growth. An understatement of the number of inspections will increase the risk of not detecting a dangerous defect, and an overestimation will lead to unnecessary time and resources for outdated inspections. On the other hand, substantiation of the limit state of structural elements and the ability to determine its residual strength will directly affect the nature of maintenance, which will optimize its cost. The current vision of the principles of damage tolerance for aircraft currently in operation in the United States is set out in a publicly available manual [3].

1.2 Concepts of time to fatigue crack initiation description in structure with holes.

With the beginning of the approach of damage tolerance appeared the need to predict the ultimate state of structures in order to economically sound and timely control and repair. This is a task solved by analytical description of the patterns of growth of fatigue cracks [4]. An important aspect is reliable and reliable detection the fact of the origin of the crack in the structure, which mainly depends on accepted initial defect size (initial flaw size - IFS). Others an important factor for calculations is the time (number of cycles) before the formation of the crack with this size (time to crack initiation - TTCI). Today there are two main ones the concept of describing the initial stages of fatigue failure.

In the first concept the position on existence in details of defects is accepted at any stage of operation and even before its beginning. Such defects are common small in size and present in large numbers. Their existence is not explained ideal structure of the crystal lattice of the material and imperfect technology of production of details. When applying this concept to aircraft designs, it is called the equivalent of the original quality (equivalent initial quality - EIQ) [4]. Its quantitative indicator is size initial defect at (equivalent initial flaw size - EIFS). There are such defects conditional rather than physically expressed because their size is too small for methods of non-destructive testing (0.004 ÷ 0.055 mm). They are determined calculated by inverse extrapolation of crack growth curves and are adjusted according to the results of fractographic studies.

The EIQ fatigue failure model is based onusing the EIFS probability distribution f(ai). Because to get such distribution in practice by means of measurements is difficult enough, apply an artificial method of inverse extrapolation of crack growth curves a (t) to value t = 0 and convert the time distribution to crack formation length a0 - f (TTCI) in the EIFS distribution f(ai) (Fig. 1.1)

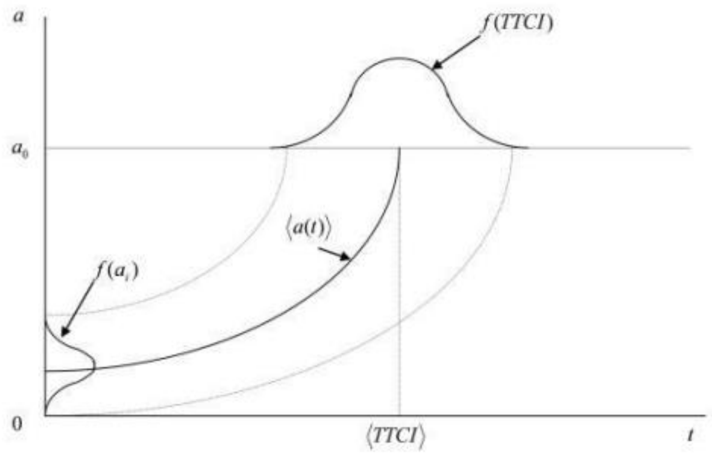


Fig. 1.1. Scheme for determining the statistical distribution of EIFS f(ai) on the distribution of TTCI by the method of inverse extrapolation of the dependence of the crack length on time.

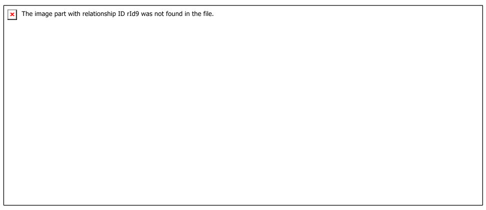
The resulting distribution of EIFS is extrapolated to the entire period of crack growth, then on its basis parameters of durability at MSD are defined [5]. The application of this approach extends to the simulation of the MSD method Monte Carlo.

However, it is worth emphasizing the artificiality of inverse extrapolation crack growth curves, because it does not take into account the features behavior of small (short) cracks, as well as their behavior in the boundary stress intensity factor Kth.

The second concept (the concept of TTCI) involves the registration of work parts to form a crack with a given initial size a_0 . This size in this concept is a deterministic quantity, the time will be random before occurrence of such a crack (TTCI).

The main problem with the TTCI concept is the rationale for size initial crack a_0 , because it depends on the relevant experience. Very large values of this size are dangerous in terms of reliability as well very small cannot be measured by non-destructive testing field conditions during the operation of aircraft. For rivet holes in aircraft designs for a0 values from 0.25 to 1.5 mm are used [6, 7, 17]. However, most often this size is accepted a_0 = 1.27 mm (0.05 inches)

According to experimental data on the destruction of structures aircraft random value of time (number of cycles) to crack formation initial length a0 in the holes for rivets is well described two-parameter Weibull distribution [8, 9, 10, 11, 17], whose function has appearance:



Where Fi (N) - is the generalized Weibul probability distribution function;

N - operating time in flight cycles;

α - is the shape parameter;

β - is the scale factor.

It should be noted that in some cases for TTCI is also used logarithmically normal distribution [5], which is taken as the baseline in the assessment the emergence of MSD and the development of inspection programs for the Boeing fleet.

In this distribution for aluminum alloys of aircraft structures usually take α = 4 [8,10], but in practice these values can differ depending on the structural element under consideration and conditions its load (Table 1.1)

Table 1.1 - value of the parameter α for different conditions.

The value of the parameter α for different conditions		
	Pressure load	External load
Aircraft	5	4
Component WFD	6	5
Part	8	6

Determination of the scale factor β possible in several ways that are to conduct full-scale fatigue tests or using the corresponding S-N diagrams of a typical alloy [3,12]. Elementary the method is to determine the parameter β due to the fatigue life of the aircraft that is laid down at designing for the set level of reliability. For aluminum aircraft structures, the value of the design resource is assigned to the minimum level of reliability is 0.95. Applying the Weibull distribution to value of design resource 20,000 flights parameter β can be determined from the ratio:

$$1-\exp\left[-\left(\frac{20000}{\beta}\right)^{4}\right]=0{,}05\,.$$

Solving equation with respect to β, was obtained the value 42026 flights, which roughly corresponds to double the project resource.

1.3. Features of the association of fatigue cracks in structures with holes.

The union of scattered fatigue cracks is one of the main mechanisms destruction with multiple damage. This process takes place in several stages through which the development of damage during exercise. Each of these stages is characterized by the presence of damage different dimensional level. The transition between these stages occurs mainly by due to the combination of defects when they reach a certain limit concentration until the destruction of the structure. Such a scheme is characteristic practically all construction materials. It is manifested in different species load and in a fairly wide size range [13].

For multi-site damage, there is still the issue of cracking more relevant. Because this type of damage develops in structures with many holes, there is a possibility of simultaneous development of fatigue cracks from adjacent holes towards each other. This development scenario is special dangerous because it leads to the rapid destruction of the bridge in constructive element, and hence the formation of the nucleus main crack and the onset of the ultimate state of the structure.

The fact of fatigue cracks is determined on the basis of several possible criteria. For example, Newman's criterion is calculated through an angle opening the ends of the crack. Each material has its own critical values of this angle, which are determined experimentally. Definition of conditions fracture in materials that are both elastic and plastic deformation is possibly one of the methods of nonlinear fracture mechanics with using the J-integral. Under the conditions that the body should be homogeneous, the volumetric forces are zero, the edges of the crack are free from loads, the deformation must be elastic or elastic-plastic and be described the theory of small elastic-plastic deformation, the J-integral will not be depend on the integration circuit. The values of the J-integral are calculated methods of Beagle and Landes [14, 15], Reiss or finite element methods [16].

In modern practice, Swift's criterion is most often used is calculated through the size of the zone of plastic deformation at the crack tip (Fig. 1.3). The union of two adjacent cracks in this case occurs in the moment when two zones of plasticity near the crack tips touch. It is experimentally established that at different types of loading the propagation trajectories of nearby cracks deviate from initial when their vertices converge (Fig. 1.4) [7].

a) b)

Fig 1.2. – Length between two rivets at: a – wings; b – fuselage;

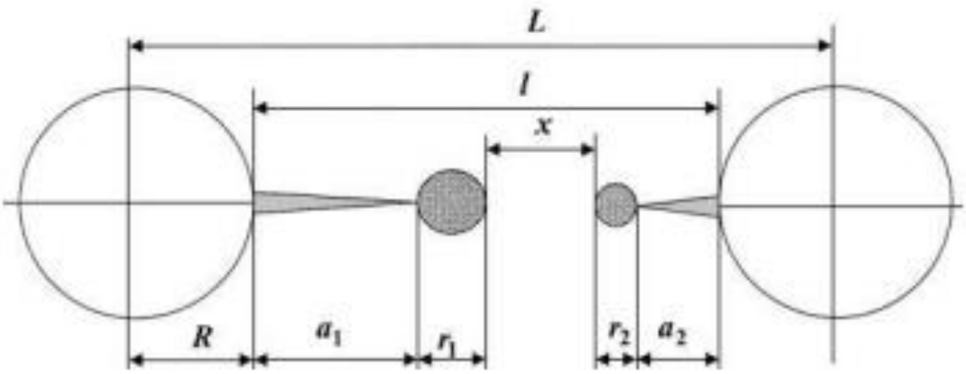


Fig. 1.3. Zones of plastic deformation at the top of cracks.

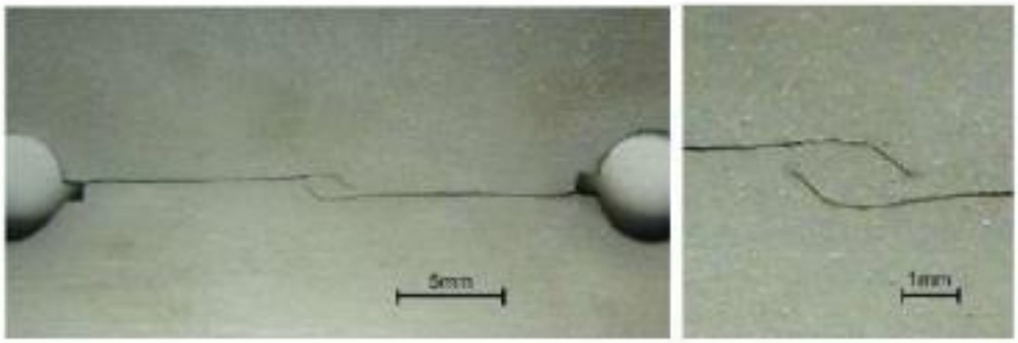


Fig. 1.4 Features of the association of fatigue cracks.

This suggests that the interaction of adjacent quasicollinear cracks is carried out through certain zones of influence near their tops, and the union of cracks is realized due to the unstable shift of the material bridge when touching and overlay of these zones. The size of the impact zone increases with increasing length cracks and loads [17, 18]. Therefore, it is assumed that it is a local area plastic deformation at the crack tip. The size of such a zone can be determined in different ways. Mainly used for this purpose Irwin's equation.

$$r = \frac{K^2}{2\pi\sigma^2},$$

where K is the load intensity factor;

σ - current macroscopic stress;

Due to the fact that the presence of a zone of plastic deformation determines increasing the length of the crack, compared to its "actual" length, take, that its length is equal to the "real" plus the fraction of the zone of plastic deformation [5]. In quality of the first approximation, Irwin equated this increase with the radius of the zone plastic deformation. In fact, the size of this zone is larger, which is due to redistribution of stresses in the vicinity of the zone of plasticity. After further assessments the size of the plastic deformation zone was calculated to be its actual size twice as large as the first assumption. Later, this value was named Irwin's amendment to plasticity. Khan and Rosenfeld studies regarding the shape of this zone, it was experimentally confirmed that it corresponds shown in Fig. 1.6.

Significant influence on the interaction and union of cracks in the structural materials has a number of other factors: the method of applying the load, type of stress-strain state, physical and mechanical properties of materials and features of their structure, type, location, size and concentration of defects. In general, there are two main approaches to modeling a merger scattered cracks - geometric and force.

In the first approach, the determining factor is the relative position damage when two ship defects accidentally found next to each other are possible considered united without taking into account the forceful interaction between them. Such the joining mechanism may be characteristic of plastic materials and defect, the stress concentration range of which is small compared to the size of the defect itself.

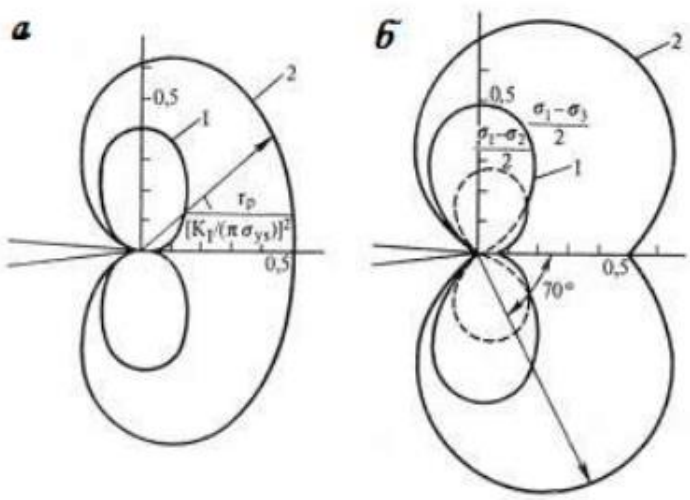


Fig. 1.5. The shape of the zones of plastic deformation at the top of the crack:

a - Mises criterion; b - Cod criterion; 1 - flat deformation; 2 - flat

tense state.

In the second approach, the merging process is described taking into account stress-strain interaction between adjacent lesions. Worth note that the problem of collective interaction of cracks is very complex. Ago when modeling the joint, taking into account the interaction of cracks make certain simplifications and assumptions [5].

1.4. Analysis of research works and materials devoted to riveted joints.

To completely understand the state of the problem of the reliability of riveted elements aircraft designsneed to review the work of other authors on the topic of research.

- In the [5] development and substantiation of the method of resource prediction and determination of reliability of riveted joints of aircraft structures in case of multi site damage. safe operation of the fleet of aging aircraft. The main scientific result of the work is a new solution of the scientific and technical problem of determining the reliability and service life of riveted joints of prefabricated aircraft structures in case of multi element damage. This problem is solved by scientific substantiation and development of new mathematical software for modeling the processes of formation and growth of fatigue cracks in structures with holes made of aluminum alloy D16AT, taking into account experimentally established patterns.

As a result, it was found:

A new mathematical model of stochastic formation of fatigue crack sizes is developed, taking into account the randomness of their formation and growth. Based on this model, it was confirmed for the first time theoretically and experimentally that the probability distribution of fatigue crack length corresponds to Pareto's law.

A new probabilistic model of combining counter cracks in multi site damage has been developed, taking into account that the length of these cracks has a Pareto distribution.

The mathematical model of multi element damage is developed and on its basis the new method of prediction of a resource and definition of reliability of riveted connections of aircraft designs at multi site damage is offered.

- In [19], the crack growth and were experimentally investigated fatigue behavior of the riveted joints of the aircraft skin when changing the compression force rivets. For the study, three sheets of aircraft skin with different were selected thickness (1.9 mm, 1.2 mm, 0.8 mm.) when using round rivets head and rivets with compensator.

As a result, it was found:

1. The onset and growth of fatigue cracks in riveted joints depend from the expansion of the rivet hole, from the type of rivet and force rivet clamp, as well as the thickness of the sheet. Fatigue cracks always begin on the surface of the sheet in one of the outer rows rivets.

2. For relatively low rivet compression forces, crack path close to the cross section along one of the outer rows rivets. At high compression forces, cracks may begin and grow outside the rivet hole. Material fatigue increases as the compression force of the rivet increases and it is always larger for rivets with a compensator than for rivets with a round head.

3. Rivets with a compensator are not suitable for fastening thin sheets, as significant local defects under the manufactured head cause premature destruction in this place.

-In [20] the topical in scientific and practical was solved in terms of the task of prediction the life of aircraft structures made of aluminum alloy D16AT with a riveted connection at polyhedral damage. The research conducted in this work is based on the methods of mechanic fatigue failure, numerical simulation, crack mechanics, physical basics of optical microscopy, methods of mathematical statistics and regression analysis, methods of non-destructive testing and image processing. At experimental studies used methods fatigue tests and digital photography. When conducting measurements and data processing used automatic methods control, programming, computer technology. [23].

As a result, it was found:

1. It is established that the number of cycles to the formation of fatigue cracks in the studied samples are described by the Weibull distribution law. Definitely parameters of this distribution for samples with multiple holes and with riveting connections.

2. It is shown that the riveted connection increases the resistance to multifaceted damage to the aluminum alloy D16AT. Earnings before education cracks in the riveted joints by 10% more than in the absence rivets. The duration of the stage of growth of cracks in the riveted joints inthis stress range increases by 45 ... 55% compared to free holes.

3. A numerical experiment of multifaceted damage for samples with multiple holes of riveted joints. Comparison of results laboratory tests and numerical experiment showed satisfactory result. The accuracy of predicting the minimum values of the number of cycles to destruction in a numerical experiment is (91.2 ... 98.0) %, and prediction the minimum values of the number of cycles before the formation of cracks - (91.7 ... 96.8) %.

-In [21], the growth of long tiring cracks is investigated components of aircraft. A deterministic model capable is presented to simulate the growth of fatigue cracks on riveted holes. She too includes criteria for assessing the connection of collinear adjacent cracks. For model testing was conducted a campaign to test fatigue on riveting specimens with riveted connection to obtain experimental the results of crack growth. Accurate measurements of natural cracks on surfaces were performed automatically by image analysis that allowed testing 24 hours a day. Comparison experimental tests and numerical simulations confirm that the model is a useful tool for estimating the fatigue life of rivets connections in aircraft.

-In [22] the results of research on development are presented methods and diagnostic control of riveted joints by the method of free oscillations in automatic mode. This kit consists of a system recording and signal processing systems. The registration system includes device for positioning tested products. Excitation of oscillations in carried out by means of the calibrated blow. Signal processing system consists of a sixteen-year-old analog-to-digital converter and computer. Acoustic signals of vibration oscillations are recorded on hard disk, and their processing is performed using a software package DetectFault software created in LabVIEW. Software providing controls the movement of the guide wheel and rod, providing recording and converting signals from analog to digital form with a given number of samples and the value of the sampling interval. Adoption or deviation of the riveted connection is made depending on the results of comparing the reference and current spectrum using Spearman's correlation coefficient. In the formation of the reference spectrum a reliable weighing algorithm is used. The result of the work was data reproducibility when monitoring riveted connections.

-In [23] the built-in diagnostic system for monitoring the growth of fatigue cracks in aviation structures. SMART system The Layer consists of piezoelectric sensors, a diagnostic unit and Software. Fatigue damage were the subject of the study aluminum sheet. This system was designed on a critical surface areas of riveted joints. Using the software, the diagnostic unit generated pre-selected diagnostic signals from piezoelectric drive to its adjacent sensors. Relevant signals sensors were registered and compared with the previously recorded database. Since this system is in the process of improvement, the monitoring results are not accurate.

Therefore, the disadvantages of classical rivets include the need for access to the two ends of the rivet and the difficulty of riveting. The disadvantages hollow rivets can be attributed to the possibility of use only in places with low mechanical load and the need for access to two ends of the rivet. The main disadvantage of embedded rivets in them use is the need for great axial force.

The most common forms of damage to structural elements Aircraft have all kinds of cracks, or destruction, that result exceeding the ultimate strength of structural elements. A significant number damage is mainly related to the nature of mechanical and thermal loads (static, dynamic and their combinations).

Any assembly unit consists of separate parts, of which the simplest is a part. ‘A set of several parts connected together is called a node. Connections of parts are divided into:

- collapsible - are made with the help of fasteners (bolts, nuts, dowels, screws, bolts, etc.). If necessary, this connection of parts can be disassembled without damaging their parts;
- non-demountable - are performed by welding, soldering, riveting, etc.;
- movable - allow mutual movement of the connected parts of the assembly unit;
- fixed - the position of the elements remains unchanged.

Non-demountable joints are widely used in the construction of industrial structures, which cannot be disassembled without damaging the integrity of at least one part. A connection made with a group of rivets is called a rivet. This connection is strong and reliable. The most famous riveted structures are the Eiffel Tower in Paris, the Shukhov Tower in Moscow, the Darnytsky Bridge in Kiev, and the Harbor Bridge in the Gulf of Sydney.

The rivet joints are widely used in aircraft construction. In aircraft designs made of aluminum alloys, riveted joints make up about 60% of the total number of joints. Welded joints are more widely used in aircraft made of titanium and steel alloys. The choice of the type of connection is determined by the purpose and condition of the unit or unit, the loads acting on the structure, the materials used. Rivet joints must be designed so that the rivet works on the cut. If the current load causes the head to detach, the rivets are replaced with bolts.

Currently, special attention is paid to increasing the life of the aircraft and its system. The resource of a passenger plane should be increased from 30 thousand to 40-60 thousand people. It is established that the duration of accident-free operation of the aircraft, its reliability depend on primarily its ability to withstand fatigue failure. Experience has shown that 75-80% of all fatigue failure of the aircraft occurs at the junctions of structural elements. Hence the obvious need to increase the life of riveted joints. This applies primarily to joints with hidden rivets, the main disadvantage of which is the low resistance to fatigue when working on repeated and cyclic loads. As a result, cracks often occur in the load concentration zone.

The creation of the highest level of aviation equipment today is inconceivable without conducting comprehensive research aimed at improving both flight technical and economic characteristics of the developed facilities. The experience of aircraft development has shown that the creation of serious competitive equipment is associated with modeling: the interaction of aircraft with the oncoming flow; the work of the propeller and jet and their interaction with the elements of the aircraft; behavior of the device in critical modes; modeling and analysis of the features of the flow of tens or even hundreds and thousands of variants of aerodynamic layout.

It is known that modeling is the study of phenomena, processes, objects or systems of objects by constructing and studying their models; use of models for definition or specification of characteristics and rationalization of ways of construction of earlier constructed objects. The need for modeling in the creation of new models of aircraft and elucidation of their operational capabilities is determined not only by the relatively high cost of these samples, but often the physical impossibility of reproducing the real conditions of their work during testing. Due to the wide range of tasks that must be solved when creating any aircraft and other models of aircraft (aerodynamics of the aircraft and its individual parts, 12 flight dynamics, the operation of onboard equipment and other tasks) in each area used its own characteristics. methods and means of modeling. Along with the use of composite materials in order to reduce the weight of the aircraft structure, new solutions are used in the control systems of its main units. Possibilities of transition from rather difficult and expensive in operation hydraulic systems to electric are tested. In particular, electric motors are proposed to be used to control the elements of the wing and tail, the release and cleaning of the landing gear, the movement of the aircraft from the passenger seat to the runway [1].

=All operating conditions of the aircraft can be reproduced and investigated using simulation, which is a powerful tool for scientific research.

1.5. Aircraft damage and their occurrence factors.

Aircraft damage is a destructive event that involves change element of the aircraft from the state of airworthiness to partial airworthiness suitability, and in extreme cases - non-volatile. This condition occurs due to exceeding the permissible limits [1, 24]. Damage to the aircraft can arise both in the whole object and in its individual elements and units. Thus thus, damage leads to repair or replacement of the element or unit for the flight period. Identifying the causes of damage plays an important role in maintaining a high level of reliability of aircraft operation. Appearance damage depends on the factors inside the object, the environment environment, operating technologies and maintenance personnel. Importantly determine when the damage occurred, in what period of use of the aircraft.

Detection of damage can be divided into 3 phases:

The first phase represents the phase of initial damage - in this phase the failure rate small. In the second stage - the normal period of operation - the frequency failure is constant. The third stage - intensive wear - is characterized increasing the failure rate. The probability of damage is greater in the beginning period of operation of the aircraft and after a long period of operation or at the end resource calculated, for example, by the 88. 7/number of working hours or resources for the calendar. In the first stage, errors that occur at the stage are detected design and execution, and in the second case the elements and are revealed total wear of the element. Both of these factors are random. The period is complete [24].

The reliability of the aircraft usually ends quickly, but the transition period normal operation occurs more slowly. At this range it is possible observe the longest reliable operating time with the least probability the appearance of damage. The probability of damage over time aircraft operation is growing slowly.

Aircraft damage is the result of the influence of various factors that can be grouped as follows [24]:

- Operation - the impact on the aircraft as a result of the flight task aircraft;
- External factors - characterizes the impact of the environment on plane;
- Anthropo-technical - human impact on the aircraft.

In addition, the factors that cause the formation of damage are possible divided into internal - related to the aircraft itself, as well as external - associated with its environment (Fig. 1.7).

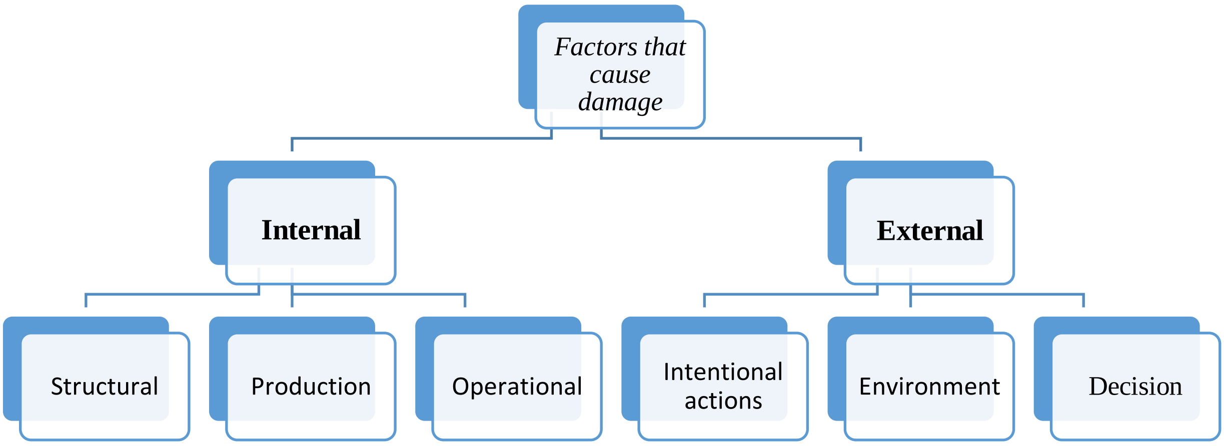


Fig. 1.6. – Damage factors

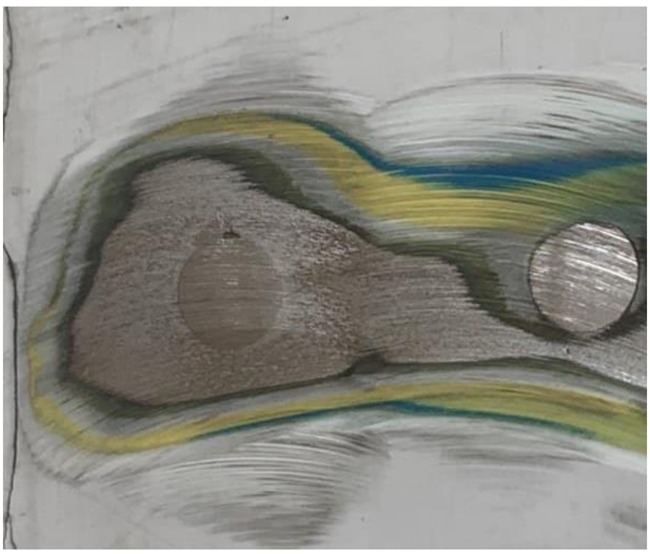


Fig. 1.7. – Initial crack formation in the rivet joint.

Problems related to the impact of damage on air safety vessels are solved using the theory of reliability. Due to very high requirements to the safety of the product in aviation, an accurate damage assessment based on knowledge of the physics of damage formation (Table 1.2) [24].

Table 1.2 - General characteristics of aircraft damage

Type of damage	Description of damages
Construction mistakes result	Damage that occurred during the process construction of aircraft
The result of the wear process	The process of systematic physical changes properties of system elements
Primary damage	Damage to a system element that was not direct or indirect caused by damage to others elements of the system
Secondary damage	Damage to a system element that was not direct or indirect caused by damage to others elements of the system
Sudden damage	Damage to a system element that was not direct or indirect caused by damage to others elements of the system
Gradual damage	Damage that is possible anticipate in the process

Twin-type damage	Damage that is from a physical point of view vision has the same set characteristics or the same set reasons
Irreversible	Damage resulting in impossible repair

The most common forms of damage are all types of cracks, or destruction resulting from exceeding the ultimate strength element of the aircraft. A significant number of damage are related to the main way with the nature of mechanical and thermal loads (static, dynamic and their combinations). Damage to civilian aircraft most often occurs under take-off and landing time' [24]. However, in military aircraft damage occurs during the flight when the crew is carrying out missions, which often leads to significant overload of the airframe and drive elements.

During the flight it is impossible to conduct inspections for detection defects, damages and malfunctions of the aircraft. However, the influence of the majority Factors that affect flight safety can be investigated using geometric and simulation modeling.

1.6. Ways of damage detection in aircraft structure during operation.

Each system and each element of the aircraft as well as the actions of the crew or pilot may cause the aircraft to crash. On the human factor it is impossible to influence, so for a safe flight all systems must be serviceable. Therefore, the aircraft must be serviced after a certain time or a certain flight of hours.

There are the following types of checks: transit check (before each departure), daily check, 48-hour check, A-check, C-check and D-check. A-check is simple (easy) verification, while C and D-check is a difficult form of technical service. For some types of aircraft, the composition of the works included in the form of maintenance, determined by the regulations review, which is developed by the manufacturer in conjunction with representatives of aviation owners and representatives of operators (all together they form working groups).

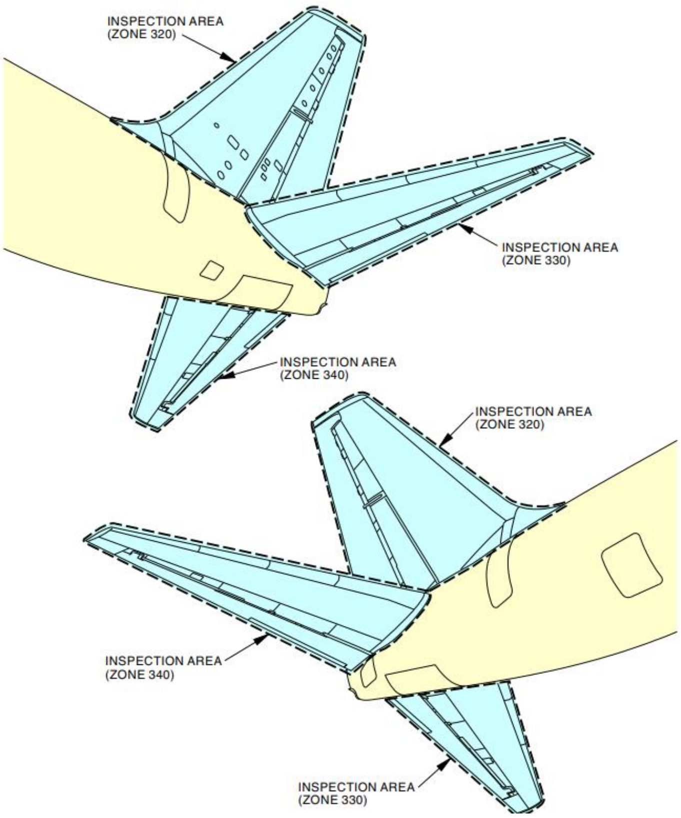
There is no single regulation for more modern types of aircraft and the operator is required to develop a maintenance program for a specific aircraft on the basis of guidance documents, recommendations plant and government instructions (directives, bulletins, etc.). Forming forms maintenance in this case should be carried out by the operator in accordance with the policy applied by them. Yes, if the airline carries out only daily flights, it will be advisable to conduct maintenance at night. Redistribution of work between nocturnal forms ideally may exclude medium-weight checks (A-check). Since many factories abandoned the letter numbering of the checks then, the names of the forms maintenance remain at the discretion of operators but how as a rule, use the conventional ones.

1.6.1. Line Maintenance.

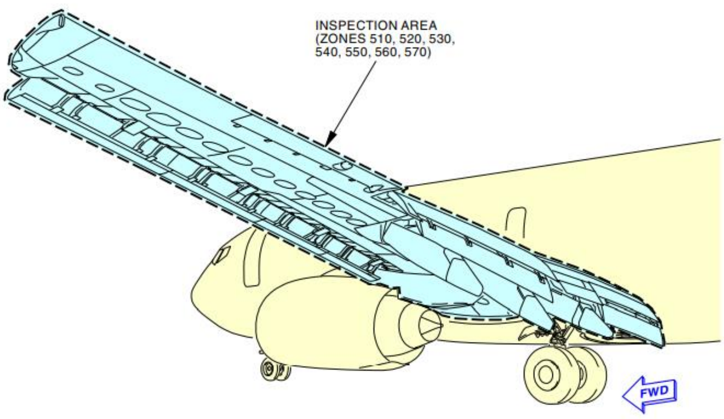
Inspecting things like wheels, brakes and fluid levels (oil, hydraulics) are done during transit checks. Plus, any running repairs that the aircraft tells us it needs through thousands of on-board sensors. Most aircraft would receive about 12 hours of line maintenance per week. These happen around the world and around the clock.

1.6.2. The A Check.

Every eight to 10 weeks, filters will be changed, key systems (like hydraulics in the ‘control surfaces’ that steer the aircraft) will be lubricated and a detailed inspection of all the emergency equipment (like inflatable slides) is completed. A typical A Check on B737 takes between six and 24 hours. This is performed approximately every 400-600 flight hours or 200–300 cycles. (takeoff and landing is considered an aircraft “cycle”), depending on aircraft type. It needs about 20–60 man-hours and is usually performed overnight at an airport gate. The actual occurrence of this check varies by aircraft type, the cycle count, or the number of hours flown since the last check. The occurrence can be delayed by the airline if certain predetermined conditions are met.



a)



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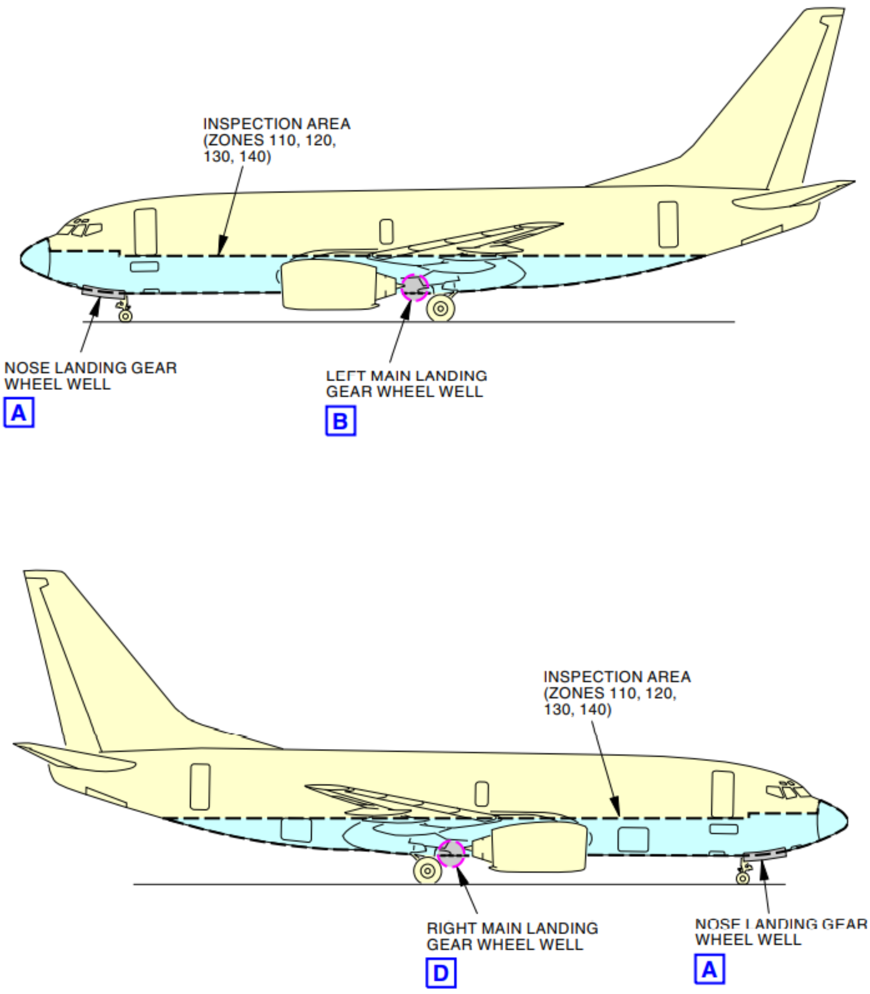


c)

Fig. 1.8 a,b,c – external zonal inspection included in line maintenance& A checks.

1.6.3. The C Check.

Happens every 18 months to two years (depending on type of aircraft) and takes three weeks. We recently took the opportunity when a number of our A330s were undergoing C Checks to upgrade the cabin interior at our Heavy Maintenance Base in Brisbane. The same thing is happening with some of our B737s. It is, therefore, usually carried out in a hangar at a maintenance base. The time needed to complete such a check is generally 1–2 weeks and the effort involved can require up to 6,000 man-hours. The schedule of occurrence has many factors and components as has been described, and thus varies by aircraft category and type.

Aircraft Type	Check Equivalent	Intervals			Remarks
		Hours	Cycles	Calendar (month)	
B733 & B735	1C-check	4000	N/A	24	Whichever occur first
B738 & B739	C1-check	7500	3000	24	Whichever occur first
B763	1C-check	6000	N/A	18	Whichever occur first
B772	1C-check	7500	N/A	N/A	N/A
E190	B1-check	7500	N/A	N/A	N/A

Table 1.3 – example of time intervals between aircraft check.

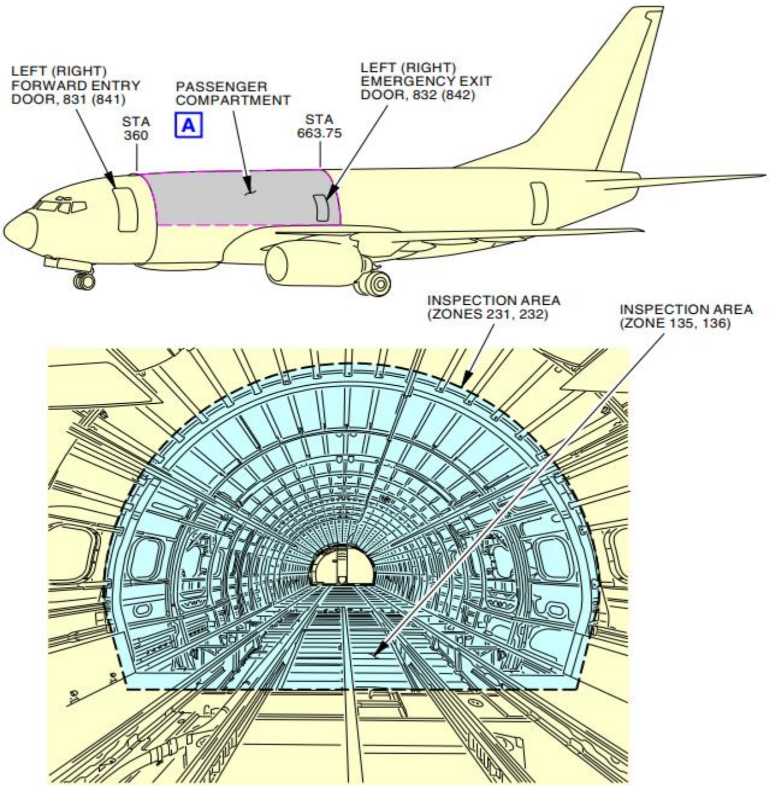


Fig. 1.9. – Inspections areas from STA360 up to pressure bulkhead, included in MPD during performing C checks.

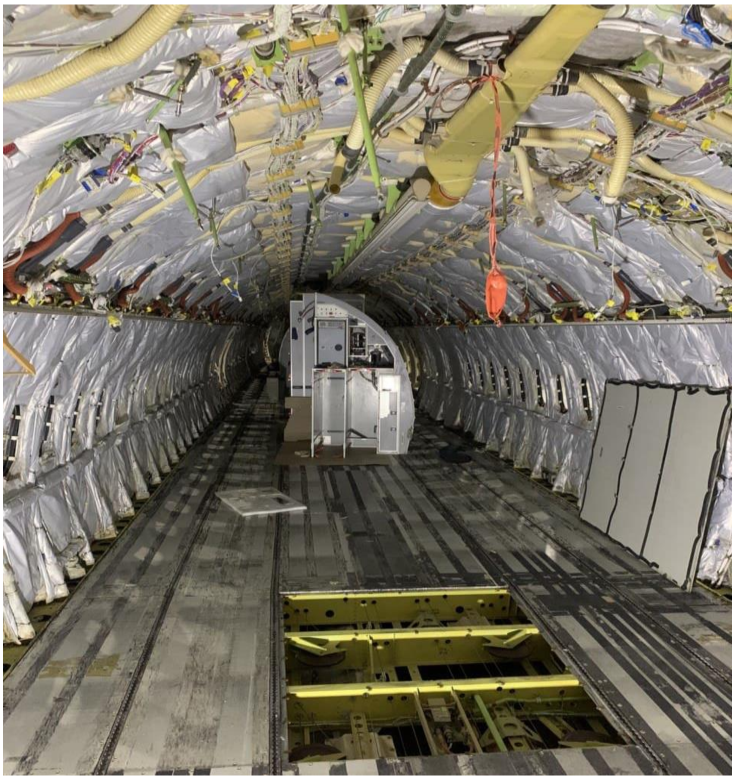
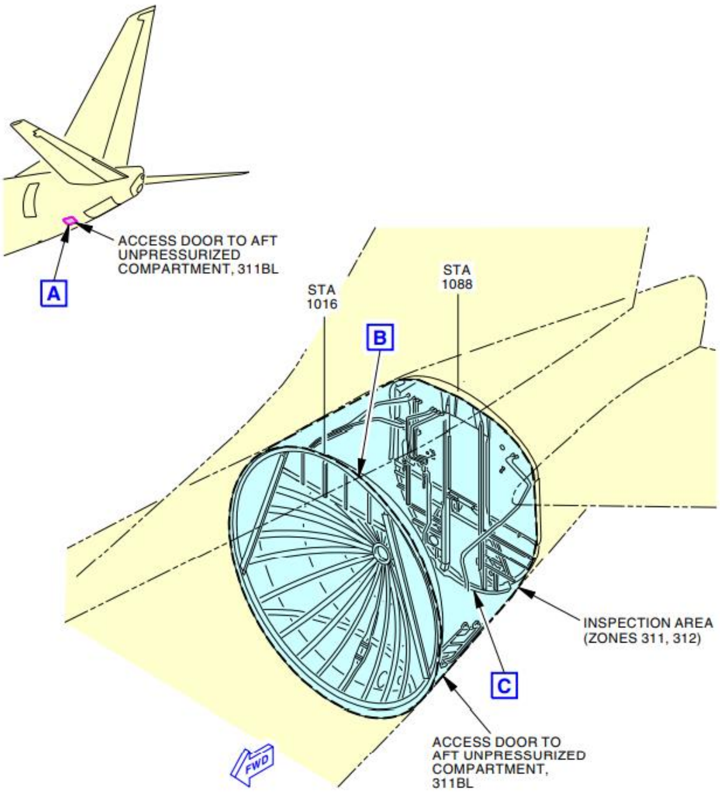


Fig. 1.10 - Inspections areas from STA360 up to pressure bulkhead on practice

.

Fig. 1.11. – inspection of cargo compartment area.


ACCESS DOOR TO AFT UNPRESSURIZED COMPARTMENT, 311BL
A
STA 1016
STA 1088
B
INSPECTION AREA (ZONES 311, 312)
C
ACCESS DOOR TO AFT UNPRESSURIZED COMPARTMENT, 311BL
FWD

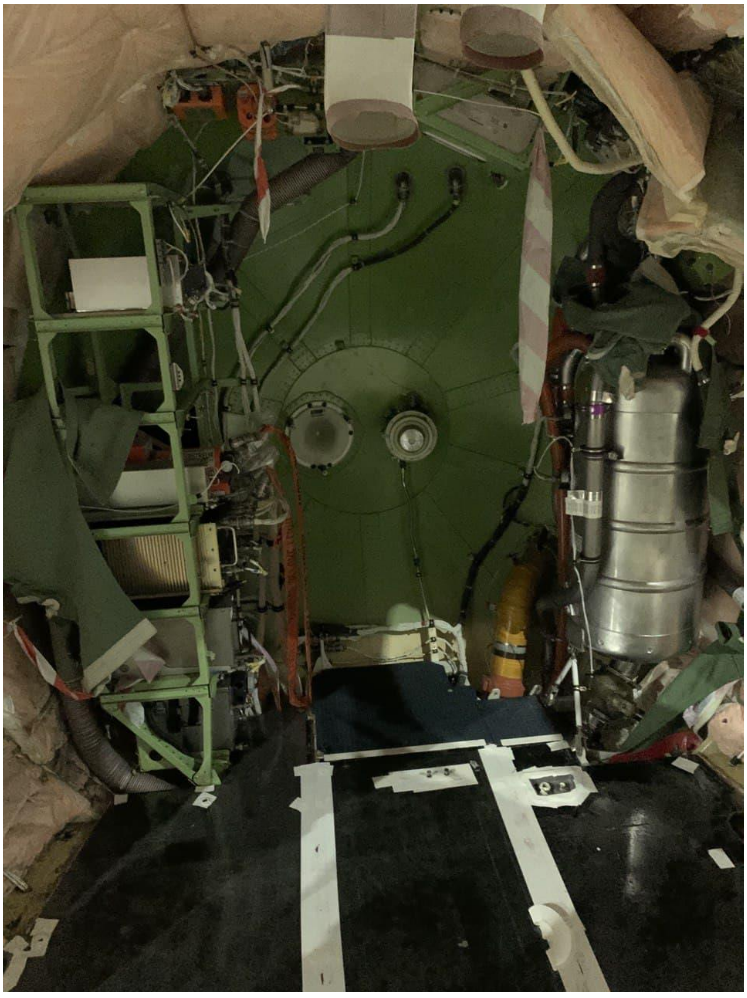


Fig.1.12. – inspection of aft pressure bulkhead.

1.6.4. The D Check

This is also known as a C4 or C8 check depending on the aircraft type. This is by far the most comprehensive and demanding check for an airplane. It is also known as an IL or "heavy maintenance visit" (HMV). This check occurs approximately every 6 years. It is a check that more or less takes the entire airplane apart for inspection and overhaul. Even the paint may need to be completely removed for further inspection on the fuselage metal skin. Such a check can generally take up to 50,000 man-hours and 2 months to complete, depending on the aircraft and the number of technicians involved. It also requires the most space of all maintenance checks, and as such must be performed at a suitable maintenance base. The requirements and the tremendous effort involved in this maintenance check make it by far the most expensive, with total costs for a single visit ending up well within the million-dollar range.

Because of the nature and the cost of such a check, most airlines — especially those with a large fleet — have to plan D checks for their aircraft years in advance. Often, older aircraft being phased out of a particular airline's fleet are either stored or scrapped upon reaching their next D check, due to the high costs involved in comparison to the aircraft's value. On average, a commercial aircraft undergoes three D checks before being retired. Many maintenance, repair and overhaul (MRO) shops claim that it is virtually impossible to perform a D check profitably at a shop located within the United States. As such, only a few of these shops offer D checks.

The landing gear is removed and overhauled with the aircraft supported on massive jacks. All of the aircraft systems are taken apart, checked, repaired or replaced and reinstalled. Each D Check costs several million dollars and takes about three to six weeks, but it's almost like a brand new plane by the end of it.

As technology improves, aircraft are being designed to need less maintenance. For instance, the Boeing B787 only needs a D Check every 12 years compared with every six years for older aircraft.

Given the time requirements of this check, many airlines use the opportunity in order to also make major cabin modifications on the aircraft, which would otherwise require an amount of time that would have to put the aircraft out of service without the need for an inspection. This may include new seats, entertainment systems, carpeting, etc.

1.6.5. Control Limitations (CDCCLs)

Design features that are CDCCLs are defined and controlled by Special Federal Aviation Regulation (SFAR) 88, and can be found in Section 9 of the Maintenance Planning Data (MPD) document. CDCCLs are a means of identifying certain design configuration features intended to preclude a fuel tank ignition source for the operational life of the airplane. CDCCLs are mandatory and cannot be changed or deleted without the approval of the FAA office that is responsible for the airplane model Type Certificate, or applicable regulatory agency. A critical fuel tank ignition source prevention feature may exist in the fuel system and its related installation or in systems that, if a failure condition were to develop, could interact with the fuel system in such a way that an unsafe condition would develop without this limitation. Strict adherence to configuration, methods, techniques, and practices as prescribed is required to ensure the CDCCL is complied with. Any use of parts, methods, techniques or practices not contained in the applicable CDCCL must be approved by the FAA office that is responsible for the airplane model Type Certificate or applicableregulatory agency.

1.6.6. Airworthiness Limitation Instructions (ALIs)

Inspection features that are ALIs are defined and controlled by Special Federal Aviation Regulation (SFAR) 88, and can be found in Section 9 of the Maintenance Planning Data (MPD) document. These ALIs identify inspection features related to fuel tank ignition source prevention which must be done to maintain the design level of safety for the operational life of the airplane. These inspection features are mandatory and cannot be changed or deleted without the approval of the FAA Oversight Office that is responsible for the airplane model Type Certificate. Strict adherence to methods, techniques and practices as prescribed is required to ensure the ALI is complied with. Any use of methods, techniques or practices not contained in these ALIs must be approved by the FAA Oversight Office that is responsible for the airplane model Type Certificate or applicable regulatory agency.

1.6.7. Enhanced Zonal Analysis Procedure (EZAP) and associated Electrical Wiring Interconnection System (EWIS)

Enhanced Zonal Analysis Procedure (EZAP) is an analytical procedure required by Part 25, Appendix H, Section H25.5(a)(1) that identifies the physical and environmental conditions contained in each zone of an airplane, analyzes the effects of these conditions on electrical wiring and components, and assesses the possibilities for smoke and fire. The end result of the analysis are inspection and restoration tasks in the form of EWIS ICA. Electrical Wiring Interconnection System (EWIS): means any wire, power feeder, wiring device, or combination of these, including termination devices, installed in any area of the airplane for the purpose of transmitting electrical energy, including data and signals, between two or more intended termination points. EWIS is defined in full by 14 CFR section 25.1701.

The Zonal Inspection Program includes a general visual and, if required, physical check of the general condition and security of attachment of the accessible systems and structures items contained in defined zones. This includes checks for degradation such as chafing of tubing, loose duct supports, damage to wiring and connected EWIS, cable and pulley wear, fluid leaks, electrical bonding, general condition of fasteners, inadequate drainage, etc., and general corrosion, not covered in the MSG-3 analysis. The zonal inspection is not intended as a quality assurance after maintenance check for determining proper reassembly of systems, components, structures, or powerplants.

The zonal program packages a number of General Visual (GV) Inspections into one or more zonal inspections. The program includes any GV inspection tasks required to assure security of attachment and general condition of any system or structural items within the zone.

CONCLUSION TO PART 1.

From the considered material concerning damage of riveted joints and their reliability, it becomes clear that the Multi Site Damage (MSD) is a serious and important problem in the world of the aviation industry and aircraft maintenance.

In accordance with other scientific works, we see that there is no 100% solution to this problem today, given that this problem has been approached by scientists from different angles and using different methods and approaches. The problem of MSD still needs further study.

Given the analysis of the operation of Boeing aircraft, which shows in practice the real problem of damage to riveted joints, during scheduled and unscheduled inspections of aircraft structure, confirming the danger of MSD on the reliability of aircraft.

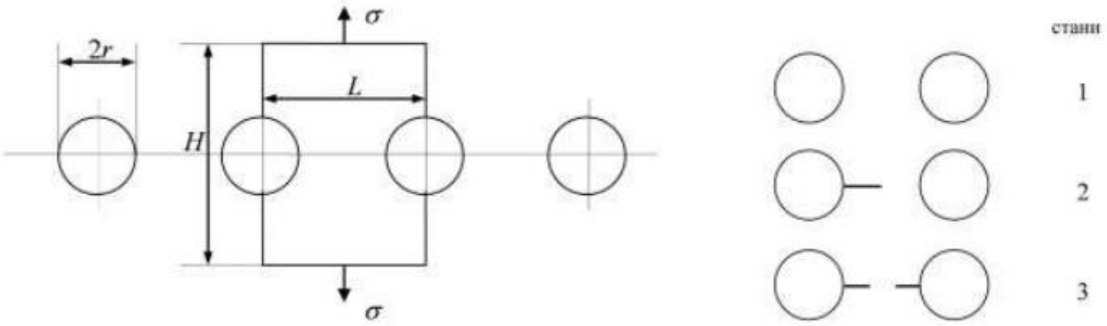
Thus, this work is devoted to an attempt to test one of the existing methods of predicting MSD using real operational data on the damage of Boeing aircraft.

PART 2. SERVICE LIFE PREDICTION OF AIRCRAFT RIVETED JOINTS USING OPERATIONAL DAMAGE DATA OF BOEING AIRPLANES.

2.1. Deterministic mathematical model for service life prediction of riveted joints.

The model developed in [5] was used as a basis for calculations.

This model predicts the reliability of the connection using 3 key functions. In this work [5], it was considered that for n rivets the number of such elements will be n = 1, and the bridge of any of them at time t can be in three possible states (Fig. 2.1. B): 1) no cracks ; 2) there is one crack; 3) there are two cracks.



a) b)

Fig. 2.1. Scheme of the riveted joints element between adjacent holes for rivets (a) and indication of possible states of damage of such element (b);

Taken into account 3 main functions have been used in [31]. They are:

$$1.\ \Omega = 2 - F_a^{(n-1)P_{1(t)}}(a_*; t) - [1 - G(t)]^{(n-1)P_2(t)} \qquad (2.1)$$

- Ω – the probability of occurrence limit state at a given operating time

- $G(t)$- the probability of combining two cracks in the bridge at operational time;

- $F_a(a_*; t)$ - crack length distribution function at time t;

- n - number of rivets (or holes) in a row of connections;

- a_* - the maximum length of the crack, which corresponds to the limit state;

- $P_{1,} P_2, P_3$ — the probability of the state of the bridge between the holes;

$$2.\ R(t) = [1 - \Omega(t) + \Omega(t)P_0(t)]^{n-1} \qquad (2.2)$$

- $R(t)$ - the probability of trouble-free operation (reliability) of the rivet joint;

- $\Omega(t)$ — the probability of realization of the limit state of the rivet joint;

$$3.\ F_T(T) = 1 - [1 + \eta(T)]e^{-\eta(T)} \qquad (2.3)$$

- $F_T(T)$ - is the distribution of the operating time of the connection to destruction;

- $\eta(T)$ - resource allocation parameter;

In accordance with the practice of Boeing as a function of the distribution of the number of cycles to the formation of a crack of a certain initial size, we accept the two-parameter Weibull's distribution:

$$F(N_0) = 1 - \exp\left[-\left(\frac{N_0}{\beta}\right)^{\alpha}\right]; \qquad (2.4)$$

where N_0 - is the number of cycles before the formation of a crack of the initial length a_0; β = 40000FC - scale parameter; α = 4 - a form parameter.

For calculation this formulas need to find out unknown parameters, such as:

-

Pareto distribution:

$$F_a(a;N) = 1 - (\frac{a_0}{a_*})^k$$

(2.5)

- a_0 - initial crack length;
- a_* - the maximum length of the crack, which corresponds to the limit state;
- k - Pareto distribution parameter, which will be determined at fig. 2.2.;

Functions values of 3 states of riveted joints (fig. 2.1.):

- no cracks

$$P_0 = [1 - F_i(t)]^2$$

(2.6)

- there is one crack

$$P_1 = 2F_i(t)[1 - F_i(t)$$

(2.7)

- there are two cracks

$$P_2 = F_i^2(t)$$

(2.8)

The distribution of the length of fatigue cracks at a fixed operating time and the probability of combining cracks growing towards adjacent holes, as shown in [5], may correspond to the Pareto distribution, then the probability of combining cracks will be as follows:

$$g(z) = \frac{2k}{z}\left[\frac{a_0}{z(z-a_0)}\right]^k \left[(z-a_0)^k {}_2F_1\left(-k;k;1-k;\frac{a_0}{z}\right) - a_0^k {}_2F_1\left(-k;k;1-k;1-\frac{a_0}{z}\right)\right]$$

$$G(z) = 1 - \left(\frac{a_0}{z - a_0}\right)^k - \left(\frac{a_0}{z}\right)^k {}_2F_1\left(-k; k; 1-k; \frac{a_0}{z}\right) +$$

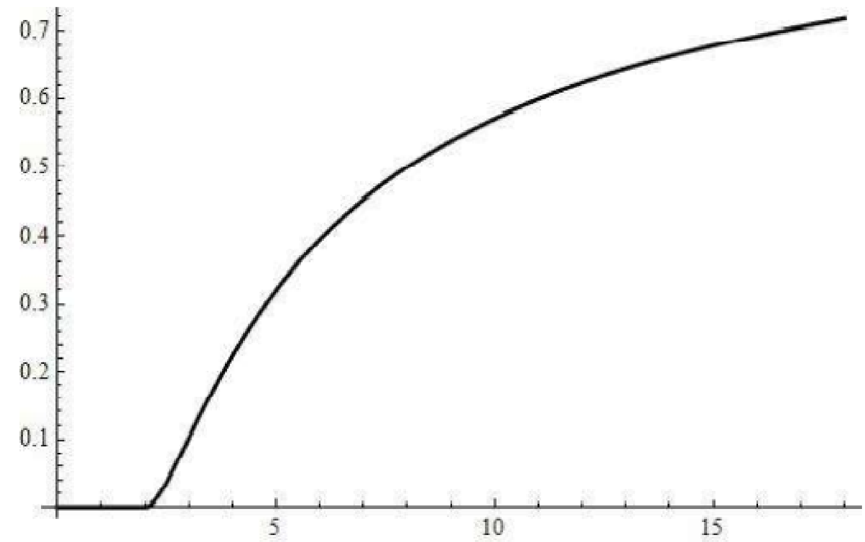
$$+ \left[\frac{a_0^2}{z(z - a_0)}\right]^k {}_2F_1\left(-k; k; 1-k; 1 - \frac{a_0}{z}\right). \qquad (2.9)$$

where z - is a random variable, which is the length of the "conditional" crack, composed of the lengths of two opposing cracks;

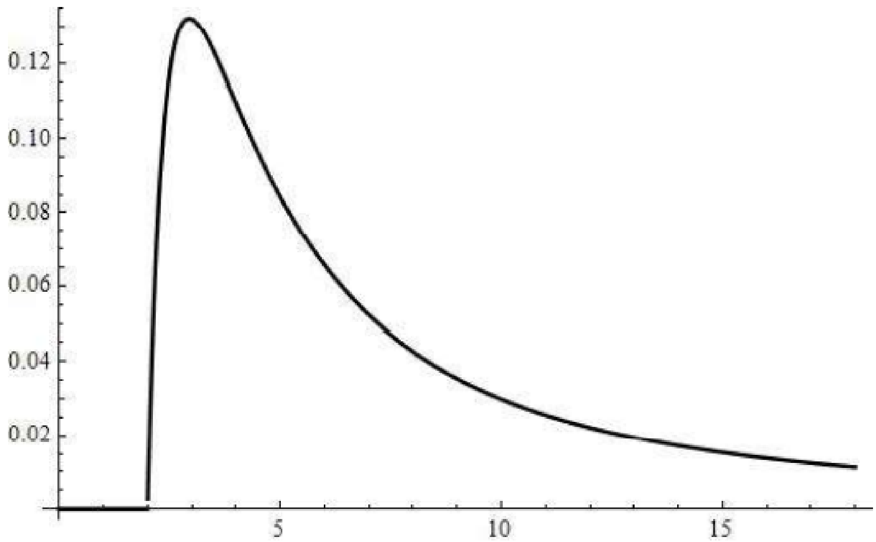
a_0 – the minimum size of the "conditional" crack z, which is 1 mm. This follows from the physical content of the value of a_0 Pareto distribution. Indeed, if we take two cracks measuring a_0 = 1 mm and fold them, we obtain a length of $2a_0$. Since for the Pareto distribution the size a_0 is the minimum possible for which the distribution exists, for the distribution of the sum of the crack lengths, a value less than 2 a_0 = 2 mm is impossible;

k – an indicator of the degree that characterizes the growth of cracks that are part of z.

Graphical representation of the dependences of the Pareto distribution is derived in [5], has the form:



a



b

Fig. 2.2. - Function a) and density b) Pareto distributions

Thus, to apply the model in practice, we need six of these parameters to build a function of distribution of crack lengths at a fixed operating time. According to the work [5], this includes the following steps:

1. Set a number of values of operating time N from 0 to the value of the order β;

2. Calculate the value of the distribution function F_i (N) based on found values α and β and Weibull distribution;

3. Calculate the values of functions $P_0(N)$, $P_1(N)$, $P_2(N)$;

4. Calculate the parameter γ at fixed operating times *N*;

5. Calculate the distribution function of crack lengths $F_a (a; N)$ for relevant γ;

6. Calculate the probability function of the union of counter cracks $G (a; N)$ for appropriate γ;

7. Calculate the probability of destruction of at least one damaged bridge $\Omega_*(N)$;

8. Calculate the probability of failure of the rivet connection $R(N)$;

9. Calculate the resource allocation parameter $\eta(N)$;

10. Calculate the connection resource allocation function $F_T (N)$;

11. Plot graphs of dependencies $\Omega(N)$, $R (N)$, $F_T (N)$;

Thus, according to the algorithm described above, you can find all six parameters and obtain graphical dependencies, which is the end result of this model.

By analyzing them, it is possible to predict with some probability the resource of the connection in question and draw conclusions about its reliability. So, that function $\Omega_*(N)$ can be interpreted as the probability of reaching the limit state at a given time, the function R(N) – as the probability of failure on the appropriate number of cycles and change the residual strength of the structure, and the function $F_T (N)$ is the distribution of the operating time of the connection before failure.

This data can also be used to justify and assign periodicity maintenance inspection program.

2.2. Operational damage data.

The necessary parameters and data for the calculation of the model using real data on the damage of Boeing aircraft were taken during inspections of aircraft, A and C checks at MAUtechnik for the past two years. All data is kept in the AMOS system, which retains all defects for 3 years.

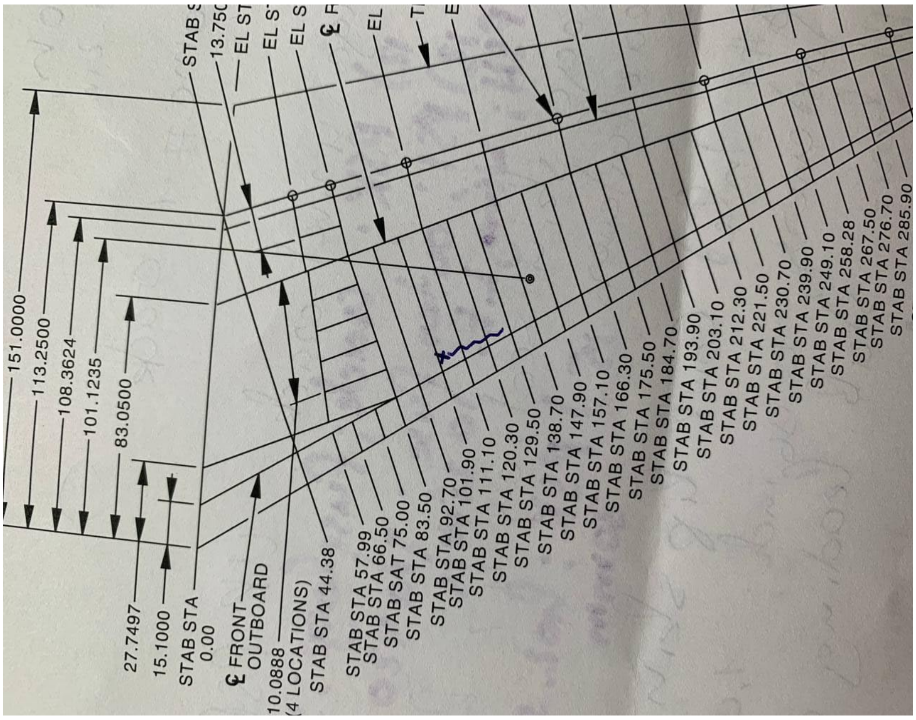
The main companies served by MAUtechnik are UIA, SkyUp and Azur, which have the majority of B737NG aircraft. The average age of the aircraft of the 3 above-mentioned airlines is as follows: UIA - 11.7 years, SkyUp - 11.5 years, Azur - 21.2 years.

The obtained data can be summarized according to the data in table 2.1., and the main places of damages are shown in fig.2.3.-2.4(a, b, c). Which will be the source data for the calculations in the next section.

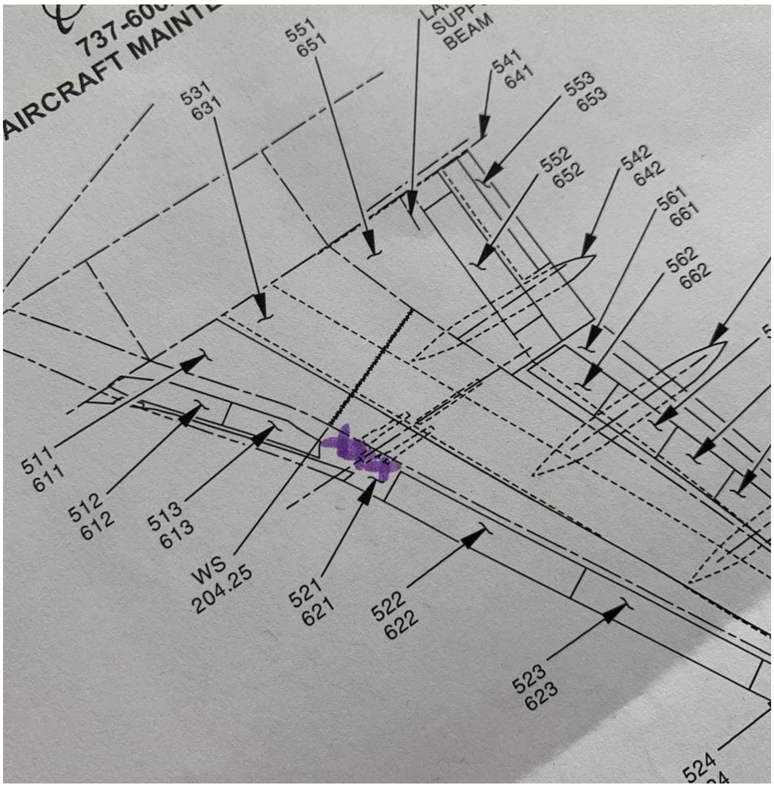
Table 2.1. – Maintenance damage data

<table>
<tr><th colspan="2">WINGS</th><th colspan="2">FUSELAGE</th></tr>
<tr><th>Length a, [mm]</th><th>Cycles, N</th><th>Length a, [mm]</th><th>Cycles, N</th></tr>
<tr><td>1.9</td><td rowspan="14">4000</td><td>5.334</td><td rowspan="14">8000</td></tr>
<tr><td>2.5</td><td>5.588</td></tr>
<tr><td>12</td><td>4.3</td></tr>
<tr><td>30</td><td>1.2</td></tr>
<tr><td>2.2</td><td>3.1</td></tr>
<tr><td>2.7</td><td>1.2</td></tr>
<tr><td>3.1</td><td></td></tr>
<tr><td>2.9</td><td></td></tr>
<tr><td>3.7</td><td></td></tr>
<tr><td>4.1</td><td></td></tr>
<tr><td>13.3</td><td></td></tr>
<tr><td>3.2</td><td></td></tr>
<tr><td>2.9</td><td></td></tr>
<tr><td>3.1</td><td></td></tr>
</table>

Fig. 2.3. – the distance between two riveted joints.


151.0000
113.2500
108.3624
101.1235
83.0500
27.7497
15.1000
STAB STA 0.00
℄ FRONT OUTBOARD
10.0888 (4 LOCATIONS)
STAB STA 44.38
STAB STA 57.99
STAB STA 66.50
STAB SAT 75.00
STAB STA 83.50
STAB STA 92.70
STAB STA 101.90
STAB STA 111.10
STAB STA 120.30
STAB STA 129.50
STAB STA 138.70
STAB STA 147.90
STAB STA 157.10
STAB STA 166.30
STAB STA 175.50
STAB STA 184.70
STAB STA 193.90
STAB STA 203.10
STAB STA 212.30
STAB STA 221.50
STAB STA 230.70
STAB STA 239.90
STAB STA 249.10
STAB STA 258.28
STAB STA 267.50
STAB STA 276.70
STAB STA 285.90

a)


551 651
531 631
BEAM
541 641
553 653
552 652
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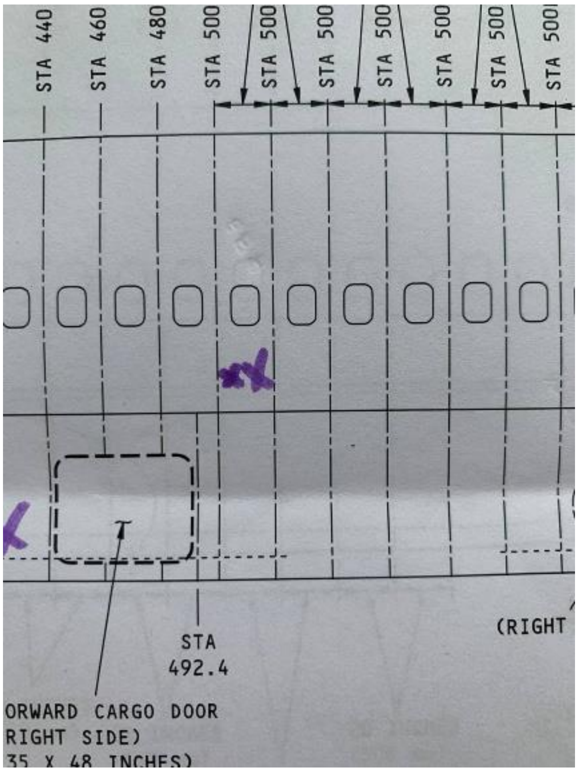
513 613
WS 204.25
521 621
522 622
523 623

b)



c)

Fig. 2.4. – the main damage location of riveted joints, a) – horizontal stabilizator; b) – wings; c) – fuselage;

2.3. Calculation of reliability parameters of riveted joints using operational damage data of Boeing aircraft.

For the practical application of the model, 6 necessary parameters were determined according to the actual practical data of maintenance:

- initial crack length $a_0 = 1$;

- N operating time in flight cycles, taken intervals between inspections 4000-8000FC;

- the number of rivets in a row: wings n = 23; fuselage n = 21;

- according to [8] for aluminum alloys of aircraft structures, the shape parameter is taken as $\alpha = 4$;

- double design resource, for aluminum aircraft structures the value of the design resource is assigned with a minimum level of reliability $\beta = 0{,}95$;

- γ is a Pareto distribution parameter that we must define. Based on this, we need to find out if our Pareto data match. Therefore, in order to solve this problem and find the coefficient k according to the data obtained from maintenance data, the distribution functions and the density of the crack length distribution were constructed. These data were approximated by the Pareto distribution. The value of the initial crack length a_0 = 1 mm was selected.

To find the coefficient $k = \gamma - 1$ the transformation and logarithmization of the Pareto distribution was performed. This dependence in logarithmic coordinates is a straight line. Therefore, according to the sample data, the natural logarithms of the corresponding values were calculated and the approximation was performed according to Figure 2.2:

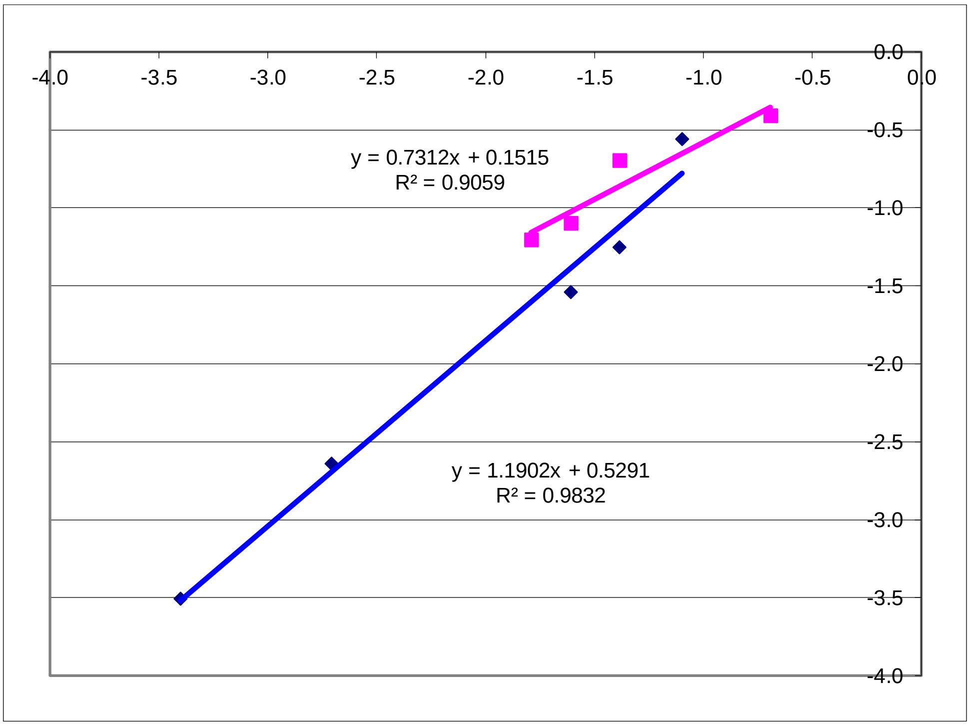


Fig. 2.5 – Approximation by a linear crack length distribution function using maintenance data.

From these graphs it is determined that k = 1.902 with the corresponding correlation coefficient R^2 = 0.9832 for wing and k = 0.731 with the corresponding correlation coefficient R^2 = 0,9059 for fuselage. This error does not exceed 5%, which allows us to conclude that the real data really correspond to the Pareto distribution. Using the calculated Pareto distribution coefficients, the crack length distributions for all stress levels were constructed and presented in Fig. 2.6 and Fig. 2.6.

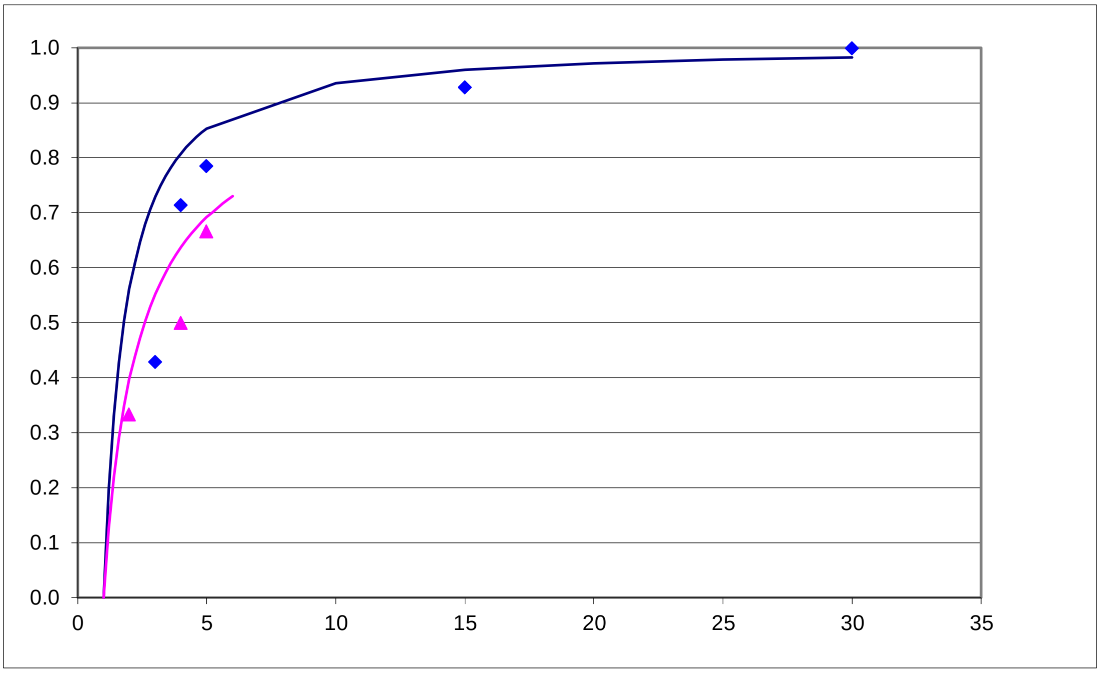


Fig. 2.6 - function of crack length distribution (points) and Pareto distribution (line) for the wing (blue line) and fuselage, respectively (red line)

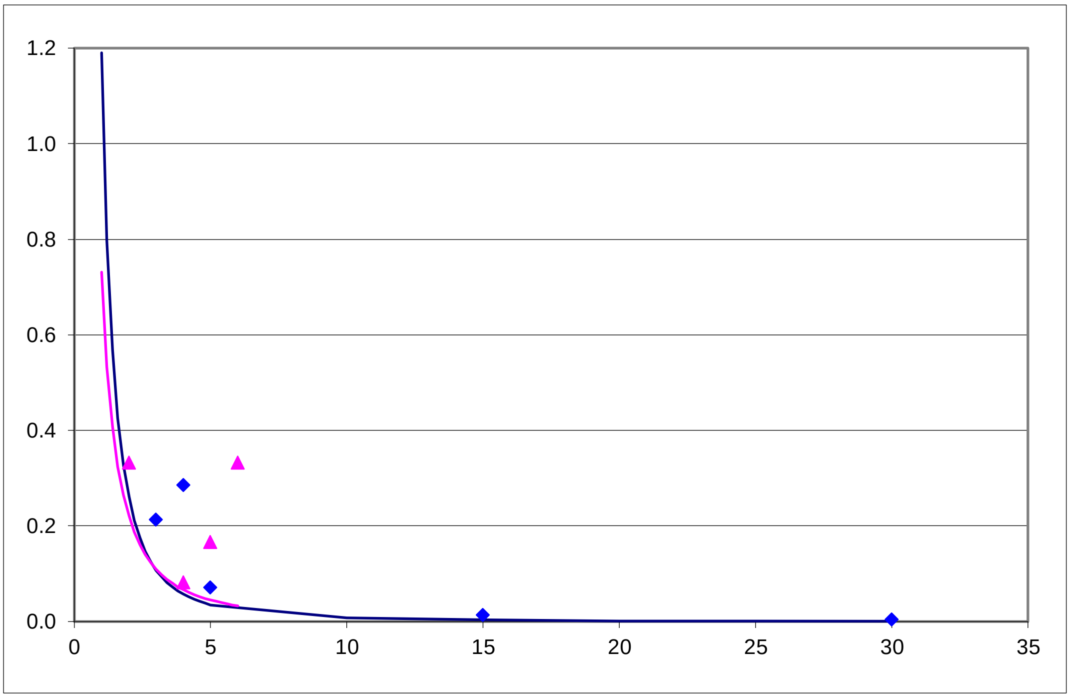


Fig. 2.7 - function of crack length density distribution (points) and Pareto distribution (line) for the wing (blue line) and fuselage (red line)

We now have everything we need to apply the model in accordance with practical real data on the damage of Boeing aircraft. Based on all the above data, the probability of destruction of at least one damaged bridge was calculated $\Omega_*(N)$, the probability of failure of the rivet joints *R(N)* and resource allocation function $F_T(N)$ respectively for the fuselage and wing. The vast majority of calculations and plotting the graph were performed in Microsoft Excel. The following results are shown in Fig.2.9-2.10.

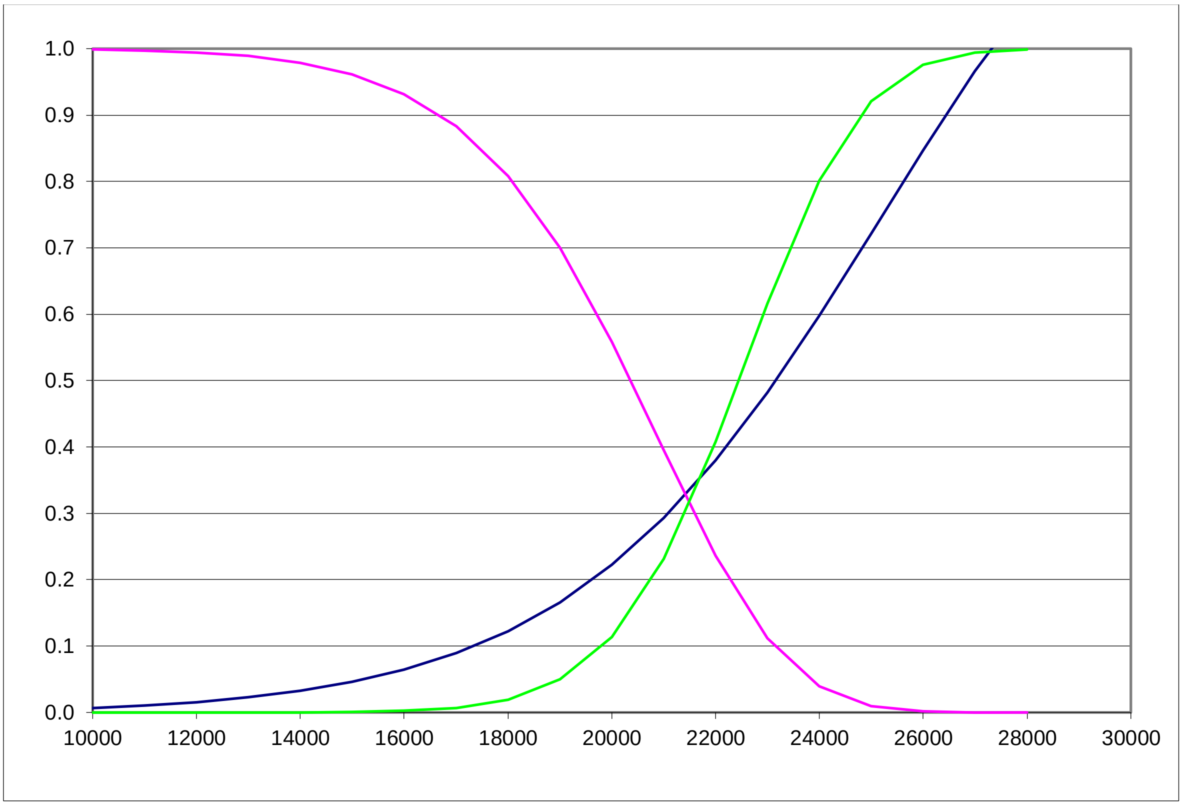


Fig. 2.8. Changing the reliability of the rivet joints from the number of flight cycles for the wing: red line - *R(N);* blue line - $\Omega_*(N)$; green line - $F_T(N)$;

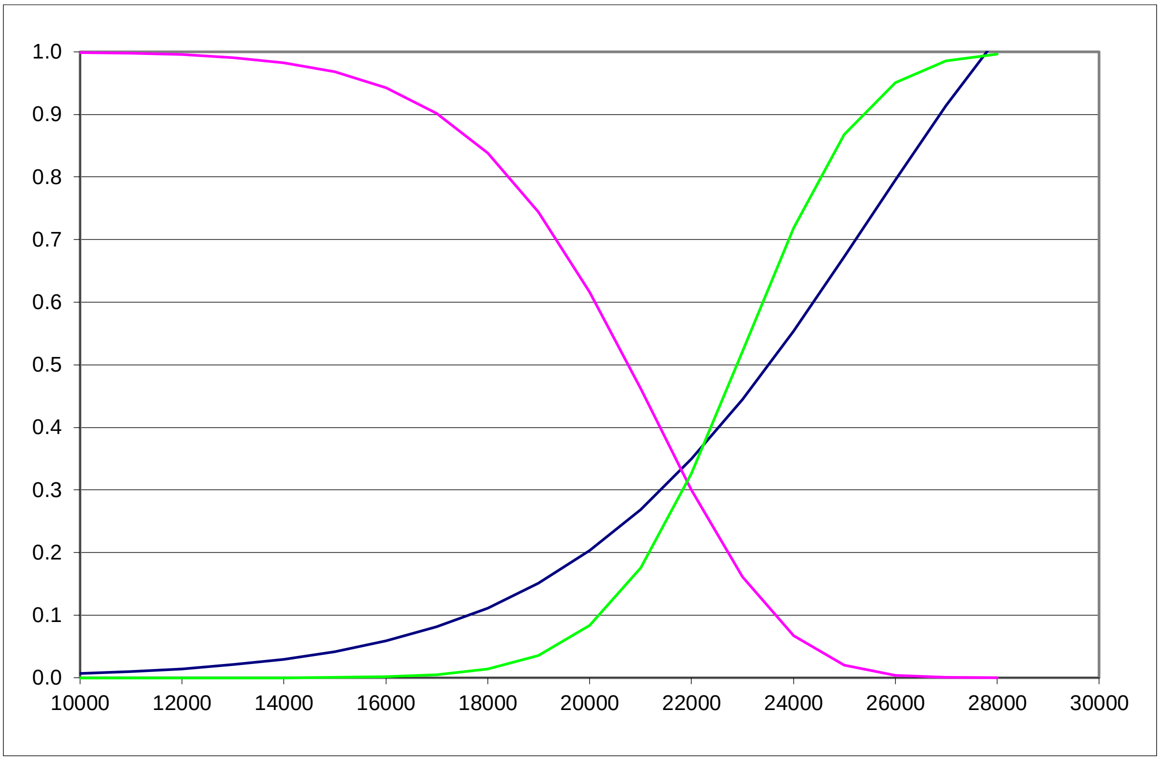


Fig. 2.9. Changing the reliability of the rivet joints from the number of flight cycles for the fuselage: red line - *R(N);* blue line - $\Omega_*(N)$; green line - $F_T(N)$;

The nature of the dependencies on the graphs fully confirms all expectations. The probability curve of the destruction of at least one damaged bridge $\Omega_*(N)$ starts from zero and maintains this value until a certain time when fatigue cracks begin to appear. After that, the probability increases and reaches unity with the number of cycles, which is close to the destruction of the sample. The probability curve of the rivet joints R(N) on the contrary, it starts with one and retains this value until cracks appear. Then it gradually decreases and when the sample is destroyed reaches zero. Resource allocation function $F_T(N)$ also starts from scratch and begins to increase only at those developments when the destruction of the sample becomes theoretically possible due to the presence of fatigue cracks.

From the obtained graphs we can draw a number of conclusions: first, it is possible to predict the resource of the connection using the probability of failure, secondly, it is predicting the occurrence of the limit state on the probability of failure of the bridge in the connection, and thirdly resource to determine the probability of failure at a given time. The second approach should be noted separately: the ability to predict all of the above by changing the value of the degree k of the Pareto distribution.

CONCLUSION TO PART 2.

1. The method of calculating the relevant values of the parameters of the model of multi site damage of riveted joints is tested, and it is applied in accordance with the real data of damage to the rivet joints of Boeing aircraft.

2. Processing of Boeing rivet damage data showed compliance with the Pareto crack length distribution with a correlation of more than 90%.

3. The considered mathematical model can be applied in operation according to maintenance data for prediction of a resource of riveted joints in the conditions of MSD.

PART 3. ENVIROMENTAL PROTECTION

3.1 Peculiarities of the Boeing aircraft impact into enviroments.

The problem of the state of the planet's ecology as a whole remains an open and topical issue today. As a result of the scientific and technological revolution, humanity is suffering from excessive pollution of the environment with harmful substances: air, water and land resources. In particular, civil aviation is not the last link that poses a real threat to the atmosphere from the standpoint of emissions and the formation of "holes" in the ozone layer of our planet. The issues of assessment and reduction of the adverse impact of civil aviation objects on the state of the atmospheric air are inextricably linked with the solution of the problems of ecological safety in Ukraine. In this regard, there is a need to address pressing environmental issues across the spectrum of transport, production, intellectual and social activities through state and industry systems of environmental management [25].

Analysis of sources shows that soil, water and air pollution occur during the operation of aircraft. The author of showed that the specifics of the impact of air transport on the environment is found in significant noise exposure and significant emissions of various pollutants. Emissions from aircraft engines and stationary sources are an important aspect of the impact of air transport on the environmental situation. In addition, aviation has a number of differences compared to other modes of transport: the use of mostly gas turbine engines determines the different nature of the processes and the structure of exhaust emissions; the use of kerosene as a fuel leads to changes in the components of pollutants; high-altitude flights cause the scattering of combustion products in the upper atmosphere and over large areas, which reduces the degree of their impact on living organisms. Labor analysis revealed that aircraft contaminate the surface layers of the atmosphere with exhaust gases from aircraft engines near airports and the upper atmosphere at cruising altitudes. Gases account for 87% of all civil aviation emissions, which also include atmospheric emissions from special vehicles and stationary sources. As you know, in recent years there has been a significant burden on the environment, accompanied by an increase in air traffic by 4-5%. This process is irreversible and occurs both globally and locally. Studies of the factors that determine the level of environmental safety in the vicinity of airports have shown that aviation noise and the emission of pollutants by aircraft engines, electromagnetic radiation have the greatest impact on the quality of the environment. It is also known that stratospheric ozone is a natural filter that absorbs ultraviolet radiation from the sun. As a result of human activity, some compounds enter the atmosphere, destroying the balance between the processes of creation and destruction of ozone [25-28].

The most important of these compounds are chlorofluorocarbons (freons), halogens, carbon tetrachloride and methyl chloroform. All of them remain chemically inert in the lower atmosphere and move into the stratosphere. Exposure to ultraviolet rays releases chlorine and bromine, which act as a catalyst for ozone depletion. The author of showed that a modern first-class airport emits several tens of tons of NOx into the atmosphere annually. The calculation of NOx emitted by aircraft engines during the flight of aircraft on the routes is a significant difficulty, but it is known that the NOx emission index of engines in service is from 10 to 40 in takeoff mode and from 5 to 20 in cruising mode (in grams of NOx per kilogram of fuel). Thus, the total annual emission of NOx into the Earth's atmosphere by air is hundreds of thousands of tons, which does not give grounds to neglect the impact of these emissions on the ozone content. When determining the total amount of harmful substances, aviation specialists have to sum up nitrogen oxides with hydrocarbons, sulfur oxides, carbon monoxide and even with soot particles. But in my opinion, from the ecological and chemical point of view such summation of harmful waste substances is incorrect.

It is known that the main components that pollute the environment are: carbon monoxide, unburned hydrocarbons, nitrogen oxides and soot. At idle and when driving on taxiways, during landing in the exhaust gases significantly increases the content of carbon monoxide and carbohydrates, but reduces the amount of nitric oxide. In steady-state mode, when the engines run without overloading 35-50% of their power with optimal parameters, the content of carbon monoxide and carbohydrates decreases, but nitrogen oxide emissions increase. The greatest emissions of soot and smoke occur during takeoff and ascent, when the engines operate with an overload of 1.1-1.2 times relative to its rated power and, as a rule, on an enriched fuel mixture. Also, according to sources [25-27], the greatest environmental pollution occurs in the area of airports during the landing and takeoff of aircraft, as well as during the warming of their engines. It is estimated that at 300 takeoffs and landings of transcontinental airliners per day, 3.7 tons of carbon monoxide, 2 tons of hydrocarbon compounds and 1.7 tons of nitrogen oxides enter the atmosphere. At the same time, pollutants do not enter the atmosphere evenly, but depending on the schedule of the airport. During the operation of engines on takeoff and landing in the environment receives the largest amount of carbon monoxide and hydrocarbon compounds, and during the flight - the maximum amount of nitrogen oxides. A jet liner performing a transatlantic flight requires from 50 to 100 tons of oxygen. But the most dangerous is that during the flight in the lower stratosphere, the engines of supersonic aircraft emit oxides of nitrogen, which lead to the oxidation of ozone, which acts as a shield against the negative effects of ultraviolet sunlight [26-27].

3.1.1 Harmful CO2 emissions from Boeing aircraft

In addition to carbon dioxide, aircraft emissions include water vapor and nitrous oxide. According to experts, the fault of aircraft in man-made global warming is three percent.

Gaseous emissions from aircraft contain two main components: carbon dioxide (CO2) and water vapor. In addition, they include nitrogen oxides. Both CO2, water vapor, and ozone are gases that are able to actively absorb infrared radiation and then give it back to the atmosphere. Therefore, air transport also causes the atmosphere to heat up, explains Ulrich Schumann, director of the Institute of Atmospheric Physics at the German Center for Aviation and Cosmonautics. He estimates that the contribution of aviation to man-made climate change is about three percent.

Kerosene is 86 percent carbon and 14 percent hydrogen. Because carbon combines with oxygen in the air during combustion, each kilogram of kerosene burned by an aircraft accounts for 3.15 kilograms of CO2 from turbines. "Because CO2 stays in the atmosphere for a long time, it is evenly distributed over the Earth," says Schumann [28].

Carbon dioxide can pass from one layer of the atmosphere to another, so it does not matter at what altitude the emission occurred - 10 thousand meters above the Earth or on its surface. Thus, it is quite easy to calculate the extent to which air transport affects climate change - about 2.2 percent of human-caused CO2 is produced by aircraft, street transport provides 14 percent of CO2, and the rest of transport, such as ships and railways, by 3.8 percent. of the total.

It is more difficult to unambiguously calculate the impact of water vapor on the climate. When burning one kilogram of kerosene is released 1, 23 kilograms of water vapor. When hot and humid gases mix with cool atmospheric air, water vapor condenses and small water droplets appear. In cold air with a temperature of about minus forty degrees Celsius, these droplets freeze, forming small ice crystals that we can see in the form of airplane stripes in the sky.

The stratosphere is very dry. The content of water vapor in the air there is less than 0.01 ppm. Therefore, ice crystals from condensation traces evaporate very quickly. In the troposphere, instead, where air can be saturated with water vapor, the behavior of condensation tracks depends largely on the weather.

"If the air is humid, the ice cubes absorb further moisture from the environment. Then the ice cubes grow, and condensation traces in the sky can turn into clouds," says the atmospheric researcher. This is exactly what happens in 10-20 percent of all flights. "So, in this way, air transport really intensifies the clouds on Earth with its condensation tracks," Schumann said.

The impact of these clouds on the climate, however, is ambiguous. On the one hand, condensation bands during the day reflect short solar waves back into space. "It's a bit simplistic: condensation strips cast a shadow on the Earth, and it's always cooler in the shadows." On the other hand, the ice particles in these clouds absorb long infrared rays, which are partially directed to the Earth. This effect is important day and night. Which of the two effects prevails is still an unresolved issue for condensation strip researchers. However, Schumann asserts that, according to research conducted so far, "the warming effect of condensation strips prevails."

Emissions from aircraft also contain small amounts of soot. Their size is only from 5 to 100 nanometers. It is known that the hot water vapor behind the aircraft turbines, condensing, partially settles on these particles. However, even without condensation bands, soot particles remain in the atmosphere for many days. Therefore, scientists suggest that they can influence the formation of clouds over time, forming a condensation nucleus for their formation. Soot particles also compete with other particles, such as desert dust or acid droplets formed when ice cubes freeze in the atmosphere.

3.2. Modern ways to reduce the negative impact of aircraft.

The problem of air pollution by air transport is not limited to the study and assessment of the impact of gaseous and aerosol combustion products of aircraft engines on the ozone layer. There are several aspects of the manifestation of the consequences of such pollution: - photochemical: expressed in the change in the ratio between the concentrations of small but important components of atmospheric air due to photochemical reactions. That is, the growth of some atmospheric gases (as well as aerosols) is accompanied by a decrease in other gaseous components of air; - radiation: fluctuations in the composition of greenhouse gases (carbon dioxide CO_2, water vapor H_2O, ozone O_3, methane CH_4, etc.), aerosols and especially the formation of cirrus clouds lead to changes in thermal and radiation balances of the Earth-atmosphere system, and hence to changes in air temperature in the atmosphere and on the earth's surface; - biological: expressed by the influence of the flux of biologically active ultraviolet radiation at the level of the Earth's surface, the intensity of which depends on the thickness of the ozone layer. Ultraviolet radiation is known to be dangerous to human and animal health and to reduce the productivity of some plant species. Thus, the fact remains that emissions from aircraft engines affect vital elements of the ecosystem: air quality, its temperature, atmospheric circulation and climate, the flow of ultraviolet radiation.

3.2.1. The main direction of environmental activities of European airports.

The main direction of large airports in the world, including large airports in Ukraine, now and in the near future - reducing aircraft noise (AS). In some cases, the problem of noise prevents the increase of airport capacity (PS). Aviation noise has a negative impact not only on the population living on the outskirts of the airport, but, above all, on the airport staff directly involved in the operation of the airline. Thus, noise is both an environmental and a production adverse factor. The problem of the impact of AS on the outskirts of the airport is exacerbated by the continued approach of residential areas to airports, the expansion of existing and the introduction of new routes of aircraft (PC) in the aerodrome area, which are often located above residential areas. At the same time, the socio-economic significance of the problem is constantly growing due to the growing number of people working under the influence of AS, and the seriousness of the consequences of this impact, which is manifested in occupational morbidity, reduced productivity, increased risk of wrongdoing, in harmful working conditions. Solving the problem of protection of the population and airport staff from harmful effects is relevant for Ukraine in the context of insufficient financial support for measures for labor protection and emergencies and should be one of the priority areas of state activity [17].

3.2.2. The International Civil Aviation Organization (ICAO) requirements.

ICAO currently setting requirements for aircraft in the field of environmental protection. Regulatory documents governing aircraft noise and aircraft engine emissions include:

– Annex 16 to the Convention on International Civil Aviation "Environmental Protection";

– aviation rules "AP-36. Certification of aircraft on noise in the field ";

- ICAO document DOC 8168. "Regulations - Aircraft Flight", Volume I, Part 5, Appendix to Chapter 3 "Guidance material on noise reduction during take-off at take-off".

Environmental protection is a very important issue and on June 8, 2010 the second international conference Greener Skies Ahead 2010 was held within the framework of the Berlin ILA, dedicated to the issues of reducing the environmental impact of future air transport. The conference addressed issues of improving the environmental efficiency of air transport, achieving environmentally neutral development of air transport, reducing harmful emissions and compliance with restrictions on harmful effects on the environment while maintaining the technical and economic performance of aircraft [29].

3.2.4. Boeing aims to reduce negative impact.

The world's leading manufacturers of aviation equipment are constantly working to reduce the impact on the environment in the following main areas:

- reduction of emissions of harmful gases (carbon dioxide, nitric oxide);
- noise reduction for passengers, crew and settlements;
- reducing the use of harmful materials;
- reduction of waste in aircraft production.

Thus, the Airbus A380 consumes 20% less fuel than the largest modern aircraft. At the same time, less than 75 grams of carbon dioxide are emitted per passenger, which is almost twice less than the same figure for European cars in 2008.

Boeing on its 787-8 Dreamliner reduced carbon dioxide (CO_2) emissions by 20% and engine noise by 60%.

3.2.4.1. The purpose of converting Boeing aircraft to environmentally friendly aviation fuel.

By 2030, all aircraft of the aircraft corporation will be refueled with biofuels.

The American aircraft company Boeing, following the European competitor Airbus, promised to make all its aircraft as safe as possible for the environment. The corporation will produce parts from recycled materials and will convert the fleet to biofuels, according to Reuters.

Aviation accounts for about 12% of global emissions from transport. The industry has committed to halving its carbon footprint by 2050 compared to 2005, and now its key players are developing new technologies. Airbus, for example, has already promised to produce a hydrogen-powered aircraft by 2035.

Boeing has decided to emphasize something else - in the former configuration of aircraft more widely use environmentally friendly aviation fuel (sustainable aviation fuel, or SAF), which is produced from waste vegetable oil and animal fat. Mike Sinnett, Boeing's vice president of product development, said that by 2030, all of the company's aircraft will be refueled with environmentally friendly aviation fuel. Now it is added to conventional jet fuel, but in small concentrations - many aircraft engines do not provide a share of SAF above 50% [30].

CONCLUSION TO PART 3

The problem of air pollution by aircraft engines is analyzed, as a result of which: - the global and local character of the problem is determined (global - associated with changes in the chemical composition of atmospheric air, local - with a high level of noise pollution); - generalized ways to solve this problem. It is established that the solution to the problem of air pollution by air transport should be comprehensive. The analyzed areas of reducing air pollution by aircraft solved only a specific problem and did not reduce the harmful effects of all factors.

As a result, it is proposed to comprehensively and simultaneously solve this problem in the following four areas of improving the environmental performance of aircraft engines: chemical, structural, economic and the introduction of alternative types of energy in air transport. The chemical direction is based on the improvement of the hydrocarbon composition of the fuel and the addition of certain additives and additives. Structural - to improve the process of fuel combustion in the combustion chamber and to improve the combustion chamber itself. Economical - to reduce fuel consumption by reducing takeoff weight, aircraft resistance, increase engine cleanliness, reduced separation, as well as efficient piloting of aircraft in the airport area.

PART 4. LABOUR PROTECTION

4.1. Introduction

This diploma work is based on practical and experimental investigations at aircraft maintenance based in the hangar. Persons not younger than 18 years of age who have undergone special training in aircraft maintenance, medical examination, established occupational safety training and are licensed to perform aircraft maintenance are allowed to work on aircraft maintenance. Engineering and technical personnel must perform only the work specified in the job description, current technology, instructions of the head of the department. When maintaining the aircraft, only the equipment that is designed for this type of aircraft is used. The equipment must be in good condition.

4.2. Analysis of working conditions.

The root cause of all damage and diseases is the labor factors impact on the human organism. This influence depends on the presence of a factor, its potentially unfavorable properties for the human body, the possibility of direct or indirect action on the body, the nature of response of the organism depending on the intensity and duration of action of this factor.

Depending on the intensity and time of action these factors can be dangerous or harmful. The former can lead to damage, including death; other lead to diseases, including increasing existing ones.

4.2.1 Workplace organization

General plan of MRO hangar in Boryspil is design to be a working place for 50-60 persons and 4 aircrafts. Its total area is equal to:

$$A = 4800\ m^2$$

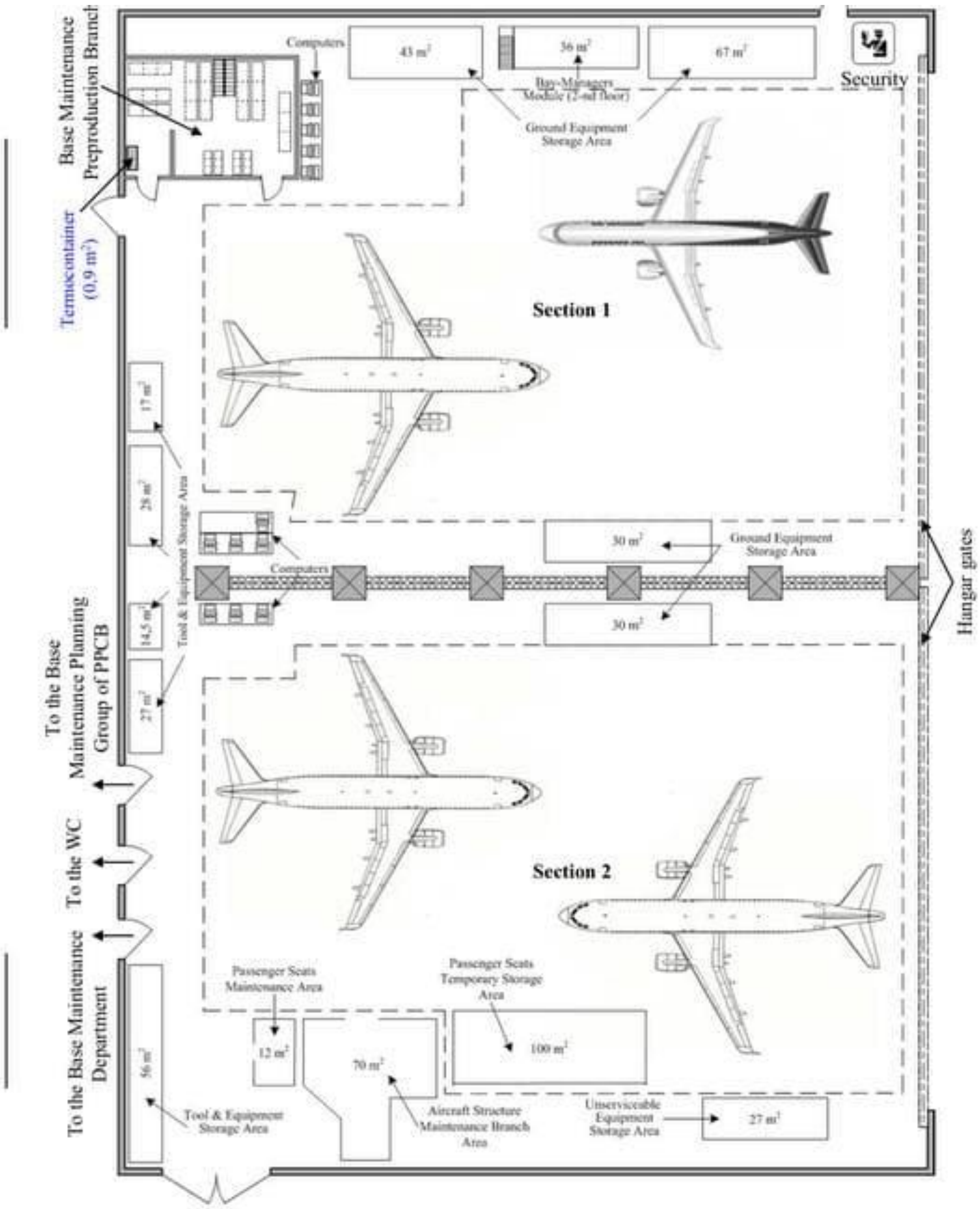


Fig.4.1 - General plan of MRO hangar

The working area of one person is approximately equal to:

$$A_{person} = A/n\ [m^2];$$

$$A_{person} = 4800 / 50 = 96\ m^2;$$

where **n** is number of workers.

The MRO uses an appropriate hangar that meets Part-145 requirements, with sufficient space for basic maintenance.

The upper third of the side walls of the hangar is glazed. In addition to natural light, the hangar has artificial light sources mounted on the ceiling.

The hangar consists of two sections. The gates of each section are 15 m high and 48 m wide when fully open. Their opening and closing can be done electrically or mechanically (manually). The floor is made of concrete-metal 60 cm thick and heated if necessary.

There is power supply: 115V-400Hz and 380 / 220V-50Hz AC and 28V DC, water supply and compressed air.

These premises provide:

- Protection against documents, office equipment, furniture, stored materials and components, dust, precipitation, foreign objects that can cause damage;

- Protection against harmful effects of the environment: noise, wind, etc;

- Temperature mode for normal work of personnel. The air temperature is maintained within the limits set by Maintenance Organisation Exsposition ;

- Sufficient light. The rooms are equipped with artificial lighting.

All dimension listed are approved by building codes Ukraine ДБН Б.2,2-12-2018 "Administrative buildings"

4.2.2. The list of harmful and hazardous factors, ensure that affect the employee during the maintenance of the aircraft.

- work with mechanisms, ladders, supports, equipment;

- moving parts of the aircraft, doors, entrance ladders, hoods, flaps, rudders, interceptors, chassis doors;

- noise, ultrasonic vibrations, radiation of onboard and aerodrome radar systems, radio transmissions in the ultrahigh frequency bands;

- work at height;

- increased fbo reduced air temperatures;

-increased voltages in electrical networks;

- insufficient lighting;

- chemicals and special fluids used in maintenance;

-physical overload;

4.3. Calculation of the multiplicity of air exchange during industrial ventilation rooms.

The production process during the maintenance of aircraft often involves the release of various harmful and unpleasant-smelling substances. As this is life-threatening for workers, these substances should be eliminated. The elimination of these substances is the responsibility of industrial ventilation, which provides the necessary microclimate in the room and the work of production.

Ventilation of industrial premises must ensure the removal of waste air (exhaust ventilation) and its exchange for fresh purified air (supply ventilation).

Given that the closed hangar space has a lot of dangerous fumes and is ventilated only by supply ventilation (natural), it is necessary to improve the flow of polluted air through additional exhaust ventilation.

4.3.1 Calculation of ventilation equipment for the production room by multiplicity

The multiplicity is calculated by the formula:

$$L = k \times S \times H, \ [m^3/hour]$$

Where L - amount of air (flow), m3 / h; k - is the multiplicity of air exchange, which is indicated in the normative literature ДБН В.2.5-67:2013**;** S, H - the size of the room;

K – in according with ДБН В.2.5-67:2013 7.1.6 and 7.2.15, flow of air supplied to the sluice, should be taken for calculation to create and maintain in it excess pressure of 20 PA when the door is closed (relative to the pressure in the room, for which the vestibule-gateway is intended), but not less than 250 m3/ hour

$$L = 250 \times 4800 \times 15 = 18 \times 10^6 \ [m^3/hour]$$

4.3.2. Calculation of ventilation of industrial premises according to the norms per person

In according with ДБН В.2.5-67:2013 the rate of air exchange per person is

n = 40 - 60 m3 / hour *person

We consider the calculation for the number of staff of 50 people. Hence, air exchange is equal to:

$$L = 50 \times 60 = 3000\ [m^3/hour]$$

The high-rise building according to DBN B.2.5-67: 2013 7.3.9 should be divided into separate ventilation zones, which are limited by the specified maximum height. The vertical distance **D** between the lowest and highest openings of outdoor air receiving devices in the same zone should not exceed the following value:

$$D_{max} = \frac{600}{\Theta_a - \Theta_{out,min}}$$

D_{max} – vertical distance, m

$\Theta_{\boldsymbol{a}}$ – indoor air temperature

$\Theta_{\boldsymbol{out,min}}$ – estimated outdoor temperature for the cold period of the year in the coldest five days with a security of 0.92 according to ДСТУ-Н Б В.1.1-27, ˚С

$$D_{max} = 21{,}4\ [\mathrm{m}]$$

In other cases, cut-offs should be provided to prevent traction air valves or similar devices.

The location of the air outlets should be taken into account characteristics (quality) of exhaust air, depending on the type of room and conditions of its use. The release of air to the outside is usually carried out in the highest place of the roof vertically upwards. The height of the ventilation pipe of the natural ventilation system that located at a distance equal to or greater than the height of the solid the structure protruding above the roof should be taken:

- not less than 0.5 m above the flat roof;

- not less than 0.5 m above the roof ridge or parapet

- at the location ventilation duct at a distance of up to 1.5 m from the ridge or parapet;

- not below the ridge of the roof or parapet

- at the location of the ventilation channel at a distance of 1.5 to 3 m from the ridge or parapet;

- not lower than the line drawn from the ridge down at an angle of 10 ° to horizon

- when the ventilation duct is located at a distance from the ridge more than 3m.

The ventilation pipe of the natural ventilation system should be removed above the roof of the tallest building to which the building is attached natural ventilation system.

The ventilation pipe of the natural ventilation system should be removed not lower than a line drawn at an angle of 10 ° to the horizon and tangent to the contour the tallest building, located next to a building with a natural system ventilation.

The height of the ventilation pipe located next to the chimney is required take one equal to the height of this pipe.

4.4.1 Safety requirements in emergency situations

- In case of an accident, provide first aid to the victim, immediately report to the responsible manager and send the victim to a medical institution.
- In case of fuel spill near the aircraft, immediately stop refueling, de-energize the aircraft, report to the responsible manager.
- In case of fire on the aircraft, turn off the power supply and immediately notify the fire brigade by phone: 101, on the radio station "MOTOROLA". Report this to the responsible head of the department. Take immediate action to extinguish the fire.
- In the event of a fire in the area of the fuel tank, immediately stop the supply of fuel to the engine or auxiliary power plant. Immediately notify

the fire brigade by phone: 101, on the radio station "MOTOROLA". Report this to the responsible head of the department. Take immediate action to extinguish the fire.

In cases that endanger the health and lives of employees, take advantage Emergency evacuation scheme of staff and aircraft.

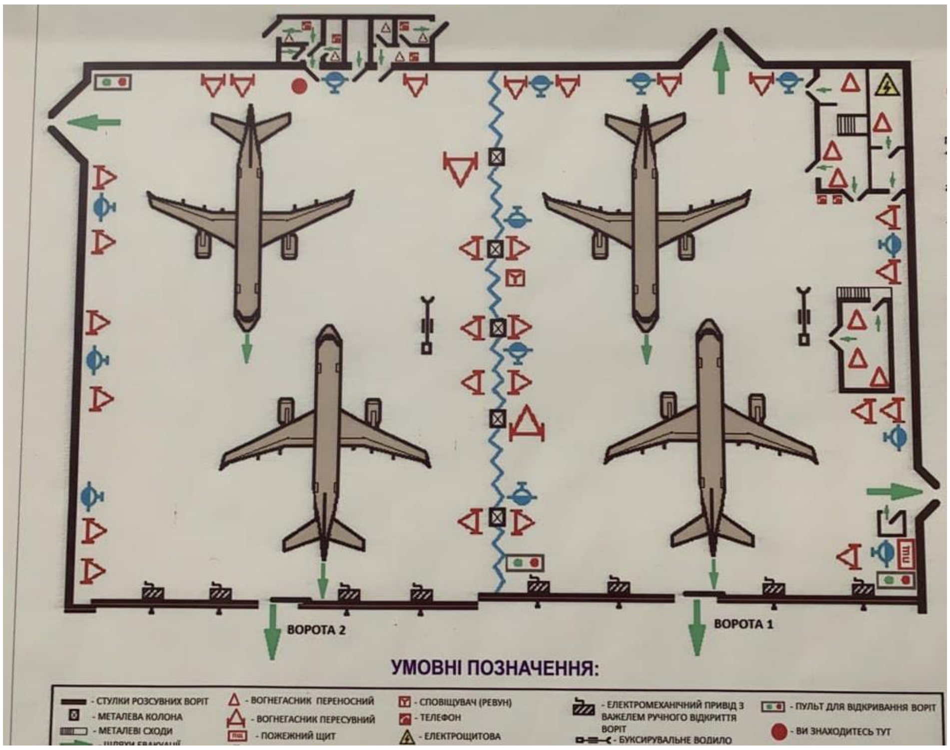


Fig. 4.2 - Emergency evacuation scheme of staff and aircraft.

4.4.2 Fire safety of production facilities

The causes of fires in hangar during maintenance can cause careless use of fuels and lubricants, failure to follow instructions when working in FTS fuel tanks

At enterprises with 50 or more employees plans (schemes) of evacuation of people in case of fire should be developed and posted in visible places and in addition to the schematic plan of evacuation the instruction defining actions of the personnel concerning maintenance of safe and fast evacuation of people should be developed and approved. practical training of all involved employees should be held once every six months. For facilities where people are expected to stay at night, the instructions should also include actions at night. (Абзац другий пункту 5 розділу

ІІ із змінами, внесеними згідно з Наказом Міністерства внутрішніх справ № 657 від 31.07.2017*)*

For rooms of categories A, B, C (combustible gases and liquids) the distance between the locations of fire extinguishers should not exceed 15 meters.

Fire extinguishers should be installed in easily accessible and visible places, as well as in fire-hazardous places where fires are most likely to occur. It is necessary to ensure their protection from direct sunlight and the action of heating and heating appliances. Accordingly, the hangar room must be equipped with 28 fire extinguishers of different types. 9 points of internal fire water supply, fire alarm system, corner bucket and sand.

4.4.3. Safety requirements before starting work

- put on overalls and, if necessary, obtain and prepare for use personal protective equipment.- check the serviceability of working tools, devices and other equipment.

- make sure that the workplace is safe to work with and equipped with fire extinguishers.

4.4.4. Safety requirements during operation

- when performing work at a height of 1.3 m or more from the ground surface from a ladder or other equipment to use safety belts and special cables;

- it is forbidden to perform work at height during a thunderstorm, ice, at a wind speed of 15 m / s and more;

- use only serviceable portable luminaires with a protective grille and a maximum operating voltage of 24 V DC;

- to exclude and prevent contact of hot oils on skin;

- do not spill oil, hydraulic mixtures, synthetic oils, etc. on the ground;

- when working in the area of interceptors, flaps, ailerons and other moving elements of the aircraft structure, make sure that the movement area of the controls is free and installed warning instructions for work on other aircraft systems;

- if it is necessary to check the on-board equipment, the supervisor must take measures to prevent workers from entering the radiation area (according to FAA Advisory Circular # 2068B, hazardous area 15 meters);

CONCLUSION TO PART 4

In this section, the hangar area has been examined to satisfy labor protection norms. Dangerous factors of influence on the person during performance of maitenance are considered and requirements concerning use of the equipment, work with dangerous liquids are established, requirements of fire safety are fulfilled and the plan of evacuation during an emergency situation is executed.

Multiplicity of air exchange during industrial ventilation rooms was calculated according to which ventilation system must be assure a minimum 3000 m^3/hour of air exchange in the hangar area and not less then 250 m^3/hour of input air flow multiplicity.

GENERAL CONCLUSIONS

This work was assigned in accordance with negative statistics due to the large number of accidents that occurred as a result of damage to the aircraft skin, which at one time caused the problem of multi site damage to the riveted joints of aircraft structures.

Since modernity requires the latest approaches to aircraft diagnostics and maintenance, scientific works with different methods and approaches to the important problem of riveted damage were considered and based on a mathematical model for determining the reliability and life prediction of riveted joints.

The practical indicators of the problem with damage to riveted joints, which were collected from maintenance on the basis of MAUtechnik for the last two years, were taken into account and analyzed.

A number of actions taken during the work, allows us to conclude that the main result of the work - the mathematical model for determining the reliability and service life of riveted joints of aircraft structures can really be used in operation on the collected real maintenance data in multi site damage. This problem was solved by comparing the maintenance data of riveted joints damage according to the Pareto distribution.

Given that all the necessary data on the damage of riveted joints were obtained in the hangar room, that is why the hangar area was inspected for compliance with labor protection standards, took into account the hazards of human impact during maintenance and set requirements for handling hazardous liquids. safety and an emergency evacuation plan.

The problem of air pollution by aircraft engines was analyzed, as a result of which: - the global and local nature of the problem was determined, and on this basis the ways of solving this problem were generalized.

Thus, to improve the working process, the air exchange rate was calculated for industrial ventilation rooms, according to which the ventilation system must provide at least 3000 m3 / h of air exchange in the hangar area and at least 250 m^3/h of intake air multiplicity.

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