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

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри, д.т.н., проф.
___________ Сергій ІГНАТОВИЧ
«_____» ___________ 2021 р.

ДИПЛОМНА РОБОТА
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«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Реалізація вимоги імпортозаміщення в конструкціях сучасних українських літаків»

Виконавець: __________ **Михайло ЯВОРІВСЬКИЙ**

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Київ 2021

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
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DEPARTMENT OF AIRCRAFT DESIGN

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MASTER DEGREE THESIS
ON SPECIALITY
”AVIATION AND ROCKET-SPACE ENGINEERING”

Topic: « Substantiation of import substitution in the designs of modern Ukrainian aircraft according to the criteria of resource characteristics of metals »

Fulfilled by: ____________ **Mykhailo YAVORIVSKYI**

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Kyiv 2021

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

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ЗАВДАННЯ

на виконання дипломної роботи студента

ЯВОРІВСЬКОГО МИХАЙЛА ВОЛОДИМИРОВИЧА

1. Тема роботи: «Реалізація вимоги імпортозаміщення в конструкціях сучасних українських літаків», 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: маса комерційного навантаження 45000 кг, дальність польоту з максимальним комерційним навантаженням 7000 км, крейсерська швидкість польоту 750 км/год, висота польоту 11 км.

4. Зміст пояснювальної записки: Визначення типових конструктивних елементів планера літака, на прикладі яких вирішується задача імпортозаміщення конструкційних матеріалів; проведення аналізу даних, що стосуються відповідності функціональних властивостей.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: креслення загального виду вантажного літака.

6. Календарний план-графік

№	Завдання	Термін виконання	Відмітка про виконання
1	Огляд літератури за проблематикою роботи. Аналіз проблемних частин літака з точки зору імпортозаміщення	8.10.2021–12.10.2021	
2	Проведення досліджень частин та матеріалів, які потребують заміщення	13.10.2021–16.10.2021	
3	Дослідження недоліків та переваг матеріалів для імпортозаміщення	17.10.2021–22.10.2021	
4	Визначення матеріалів для імпортозаміщення та їх інтеграція в процес побудови літака	23.10.2021–15.11.2021	
5	Виконання частин, присвячених охороні навколишнього середовища та охорони праці.	16.11.2021–21.11.2021	
6	Підготовка ілюстративного матеріалу, написання пояснювальної записки.	22.11.2021–29.11.2021	
7	Перевірка, редагування та виправлення пояснювальної записки	30.11.2021–08.12.2021	

7. Консультанти з окремих розділів:

Розділ	Консультант	Дата, підпис	
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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
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«___» ________________ 2021

TASK

for the master degree thesis

MYKHAILO YAVORIVSKYI

1. Topic: « Substantiation of import substitution in the designs of modern Ukrainian aircraft according to the criteria of resource characteristics of metals », approved by the Rector's order № 2173/ст from 8 October 2021 year.
2. Period of work execution: from 11 October 2021 year to 31 December 2021 year.
3. Initial data: payload 45 tons, flight range with maximum capacity 7000 km, cruise speed 750 km/h, flight altitude 11 km.
4. Content: determination of typical structural elements of the glider, on the example of which the problem of import substitution of structural materials is solved; analysis of data related to the compliance of functional properties
5. Required material: drawings of the general view of the cargo aircraft.

6. Thesis schedule:

№	Task	Time limits	Done
1	Review of the literature on the issues of work. Analysis of problematic parts of the aircraft in terms of import substitution	8.10.2021–12.10.2021	
2	Carrying out research of parts and materials that need replacement	13.10.2021–16.10.2021	
3	Research of disadvantages and advantages of materials for import substitution.	17.10.2021–22.10.2021	
4	Identification of materials for import substitution and their integration into the aircraft construction process	23.10.2021–15.11.2021	
5	Execution of the parts, devoted to environmental and labor protection.	16.11.2021–21.11.2021	
6	Preparation of illustrative material, writing the report.	22.11.2021–29.11.2021	
7	Explanatory note checking, editing and correction.	30.11.2021–08.12.2021	

7. Special chapter advisers:

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

8. Date of issue of the task: «___»___________2021 year.

Supervisor: ____________ Mykhailo KARUSKEVICH

Student: ____________ Mykhailo YAVORIVSKYI

«Substantiation of import substitution in the designs of modern Ukrainian aircraft according to the criteria of resource characteristics of metals»

Table of content

INTRODUCTION

Modern aircraft industry is characterized by a high level of international cooperation. This ensures the rapid implementation of progressive technical solutions, scientific developments, promotes social progress, prevents monopolization of individual production associations and countries.

The presented master's work considers the problem of continuous provision of the production process of Ukrainian aircraft on the basis of diversification of the supply of structural materials, in particular aluminum alloys and steels.

Among the functional properties of materials when choosing them for the production of the aircraft, first of all, it is necessary to highlight: static strength, fatigue durability, viability of destruction, specific strength, corrosion drainage. It is these indicators that are sold out when searching for analogues of traditional materials, which for decades have been used in domestic aircraft construction.

Consequently, **the purpose of the work** is a reasonable choice of structural materials of foreign production, which can ensure the diversification of sources of metal supplies necessary for the production of a modern medium-range transport aircraft. To achieve the goal of the study, **the following tasks** were performed:

Typical structural elements of the aircraft airframe are determined, on the example of which the problem of import substitution of structural materials is solved; an advance project of a mid-range cargo aircraft was developed in order to determine the technological tasks of import substitution; the list of materials requiring the search for analogues and criteria for their compliance are determined; analysis of data relating to compliance with functional properties is carried out. The aircraft's avanproject was carried out in accordance with international and national airworthiness requirements, first of all, of the European CS-25 rules relating to transport category aircraft.

The Ukrainian Antonov-70 aircraft was used as a basic design for which the possibility of import substitution was considered. This made it possible to maximally ensure the specification of the decisions taken, in addition, it is this choice of the basic design that determines **the practical value** of the work.

The results can be useful in the educational process, because the materials of the analysis expand the information on the use of structural materials in the world aircraft industry.

The project contains an analysis of the technical characteristics of prototype aircraft, the choice and substantiation of geometric, mass characteristics, design solutions; calculation of the geometry and mass of the main parts of the new aircraft; calculation of aircraft centering options for standard loading options and configurations. Calculations were carried out according to the method of automated determination of the parameters of the aircraft at the stage of the out-of-project. When performing the graphical part of the work, automated design systems were used.

PART 1. FACTORS DETERMINING THE CHOICE OF STRUCTURAL MATERIALS IN THE DESIGN OF THE AIRCRAFT

The choice of materials has evolved from the implementation of the minimum mass requirement with sufficient strength to a complex of various properties that provide minimal weight, sufficient static strength, fatigue durability, viability of destruction, the possibility of using non-destructive testing, and other indicators of functional suitability.

1.1 .Loads of the main structural elements of the aircraft in flight and on the ground

Structural materials must withstand loads that affect the aircraft design in flight and on the ground. In accordance with international regulations relating to airworthiness

[Federal Aviation Regulations, PART 25. Airworthiness standards. Transport Category airplanes. Federal Aviation Administration, Department of Tran-sportation. USA, 2004. – 220 p, Certification Specifications for Large Aeroplanes CS-25, European Aviation Safety Agency, EASA,2007] strength calculations require determining the values of operational loads and calculated loads. Operational loads are the maximum loads that an aircraft can meet in operation. Calculated loads are these operational loads multiplied by the safety factor. The safety factor value is assumed to be 1.5 for most structural elements. Consider the effect of the main types of loads that determine the choice of structural materials. When performing calculations for the strength of force acting on the design of the aircraft is divided as surface and mass. Surface forces are applied directly to the surface of the aircraft design. These forces include: aerodynamic forces, engine thrust, resistance forces. Mass forces are gravitational forces and forces of inertia. The aircraft is in balance when the equilibrium of mass forces is equal to the equilibrium surface forces.

If the equilibrium of surface forces or the equilibrium of mass forces is greater than the weight of the aircraft, the aircraft perceives overload. The load can occur once per flight, both for example, lifting force, and many times per flight, for example, the load from air gusts. In any case, during long-term operation, these loads are repeated and therefore cause accumulation of fatigue damage. The problem of fatigue resistance is one of the main ones, which is solved when choosing structural materials.

In accordance with the state standard [Розрахунки і випробовування на міцність: ДСТУ 2825 – 94. [Чинний від 1996 – 01 - 01]. – К., 1996. 13 с.], fatigue – the process of gradual accumulation of damage, the formation and development of cracks in the material under the influence of cyclic loading. Fatigue is a problem of a very wide range of structures, but it remains the most relevant for aircraft designs.

The problem is to be indicated by the nature of the aviation construction loads and manufacture features. The aim of the main infrastructure of the construction is called to significant in the constructive elements.The using of alluminium alloys are burdened with their specific strenght, in other words, relation between strenght and density. At the same time, there is a problem is their sensitivity to the concentrated loads. Such load concentrators are open rivet, bolts, screws, technological holes, welding joints, and other. In the design of the middle range aircraft number of rivets can reach 10^6. The result of cyclic loads is damage accumulation of the structure and the formation in the form of appropriate changes in structure, formation and development of fatigue cracks.

Fatigue damage analysis is performed primarily for the so-called "principal structural elements" (International Civil Aviation Organization (ICAO) in the Technical Guidance on Airworthiness",(Doc.9051-AN/896, ICAO, 1987), which include those elements, the destruction of which can lead to the crash of the aircraft, such as structural elements of the wing and tail unit, slats and flaps , butt elements, casing, wing and fuselage, elements of the frame of the wing and fuselage, and others. Based on the above, when considering the strategy of import substitution, it is necessary to determine first of all the materials of the main structural elements that determine the strength and durability of structures in general.

1.2 . Requirements for structural aviation materials

Requirements for aviation structural materials differ from the requirements that exist in general engineering.

Consider some of them, which are generally accepted in domestic and global aircraft construction.

Strength is the ability of a metal not to collapse under external stress.

Indicators of strength that are taken into account when choosing structural materials are:

- tensile strength, ie stress corresponding to the fracture load;
- conditional yield strength is the stress at which the residual deformation is 0.2% of the initial length of the sample;
- yield strength is the stress at which the deformation of the sample does not require an increase in external load;

An important characteristic that should be considered when choosing materials for aircraft design is the specific strength.

Specific strength is the ratio of metal strength to specific gravity. For aviation materials, it is one of the key parameters due to the requirement to minimize the weight of aircraft structures.

Fracture toughness is a characteristic of the fracture of metals, numerically equal to the value of the stress intensity factor, at which the rate of crack propagation increases catastrophically and the sample (structural component) rapidly collapses. Fatigue strength is the ability of a metal to withstand cyclic loads.

Corrosion resistance is the ability of a metal to resist the action of a corrosive environment.

The cost of materials is definitely important. The main mechanical characteristics of alloys used in modern aircraft construction are given in Table 1.1.

Aluminium alloys	Density, d, кг/м^3	Ultimate strenght, $\sigma_в$, MPa	Yield limit E, GPa	Specific strength $\sigma_в/d$	Specific stiffness E/d
Aluminium alloys	2700	400-650	72	14,8-24,0	26500
Magnesium alloys	1800	200-340	45	11,0-18,9	25000
Titanium alloys	4500	500-1300	120	11,0-29,0	26600
Steels of medium strength	7800	800-130	210	10,3-16,7	27000
Steels of high strength	7800	1300-2300	210	16,7-29,5	27000
Composite materials	1400-2600	500-1300	35-250	40-60	25000-100000

Table 1.1 - Comparative data on materials used in aircraft structures

In the global economy, the ability to purchase the necessary materials abroad is important. The ability to diversify supplies is an additional requirement for construction materials. In this regard, the following are the physical and mechanical properties of structural materials that can be used in the construction of aircraft, instead of the previously widely used materials.

Given that aluminum alloys are the main material for the manufacture of the aircraft frame (fuselage, wing, keel, stabilizer) and parts of the systems (hydraulic, fuel, control) of the aircraft, the following will consider the properties of aluminum alloys, which determine their choice and diversification .

Conclusion to part 1

As shown in the first section, the choice of structural materials to solve the problem of diversification of sources of supply of metals required for the production of modern regional passenger aircraft, must be justified by analyzing a set of functional properties. To accomplish this goal, the following tasks are set in the work:

- Identify typical structural elements of the glider, on the example of which the problem of import substitution of structural materials is solved;
- to develop a preliminary design of a mid-range transport aircraft in order to specify the technological tasks of import substitution;
- determine the list of materials that need to find analogues and criteria for their compliance;
- to analyze the data concerning the conformity of functional properties.

2. PRELIMINARY DESIGN OF MID RANGE CARGO AIRCRAFT WITH PAYLOAD 45 TONS

According to the task on diploma work the preliminary design of cargo plane has been performed. The plane has following technical parameters: takeoff mass – max 135000kg; cruising altitude – 11000m ; cruising speed – 700-750km/h; range of flight – 1200-8000km; engines – 4.

The advanced system of high-lift devices gives the aircraft possibility to 600-1200 m for takeoff; 400 m for roll after the touch dawn.

For engines of turboprop type supply plane with 10300kWt of takeoff power.

The prototypes of the plane are: A400, AN-70, C-130-J30.

Calculations of aircraft parameters were conducted according to the guides of the Aircraft Design Department. For the drawing the software AutoCad was used.

Main part of the project contains initial data of prototype of mid range aircrafts on the design of an aircraft, descriptions of the selected airframe scheme advantages, principles of optimal wing, fuselage, tail unit and engine parameters selection. It includes calculations of main masses and geometrical parameters of an aircraft, layout and alignment, main aircraft performance characteristics. The design was made by the means of training appliances made by the Aircraft Design Department handbooks, on aircraft design and strength, technical data from internet sites of aircraft design companies and according to Airworthiness Requirements FAR-25 and CS-25.

Analysis and calculation is applied to the following characteristics and airplane parameters: crew members number, equipment; choice and motivation of the aircraft layout, mass of payload, fuel mass for the flight with full payload, main wing parameters (aerodynamic profile, and Cl of the profile, mean thickness ratio, wing sweep angle, aspect ratio of the wing on the full area, taper ratio on the full area, relative area of the wing root extensions, type of wing high-lift devices); main fuselage parameters (equivalent diameter, fuselage fineness ratio at the fuselage equivalent diameter, fineness ratios at the nose and rear parts of the fuselage); main parameters of the tail unit (sweptback angle of the horizontal tail, sweptback angle of the vertical tail); number, type and basic parameters of the engines (bypass ratio, engine pressure ratio, thrust/weight ratio or power/weight ratio) and other parameters, which are necessary for comparison the project aircraft with existing ones, which author used in this diploma paper.

2.1 Choice and substantiation of aircraft data

The choice of the project data of the airplane is based on the operational requirements. I have chosen An-70, Airbus A400M, C-130J-30 as the prototype aircrafts.

	Antonov 70	Airbus A400M	C-130J-30	Shaanxi Y-9
Wing Span m	44,06	42,40	39,7	38,015
Length m	40,73	45,10	34,69	33,109
Wing area m2	204,0	221,50	162,1	121,7
Cruise Speed km/h	700-750	780	640	550-600
Engine power, h.p	4 x 13880	4 x 11000	4 x 4700	4 x 4250
Empty Weight,tonns	73,0	76,5	34,3	39,0
Maximum payload,tonns	47,0	37,0	21,8	25,0
Maximum take-off weight,tonns	135,0	141,0	74,4	77,0
Cost (on 2012 year)	67,0 million $	145,0 million €	65 million $	------

Table 2.1- Prototypes comparison

They are the aircrafts that have the similar type of the engine, payload, and speed and flight range. I have collected and analyzed the data of operational characteristics correspondingly to the obtained prototypes. I make the statistics accordingly to the given data in technical literature and by the most modern aircrafts.

The structure of the plane is determined by a mutual arrangement of units, their quantity and form. The structure of the aircraft is designed taking into account safety of the structure and economical efficiency. The structure is made in accordance with prototypes analysis. Aircraft scheme is determined by mutual placing of aggregates, their shape and quantity. Aerodynamic and operational qualities basically depend from the scheme and aerodynamic composition of the plane. Good chosen scheme gives the possibility to raise the safety, flight regularity and economies efficiency of the airplane. Also I have analyzed the schemes of the prototype aircrafts before choosing the scheme for the designed aircraft.

I. An arrangement of a wing and control surface relative to the fuselage, and also choice of their shape;

II. An arrangement of engines, their quantity and type, if it is not specified in the design assignment;

III. Type and arrangement of LG support.

2.1.1 Choice of the wing general geometrical parameters.

Within the main geometrical parameters of the wing we consider type of profile, relative thickness or , sweptback χ by 0.25 of the chord, aspect ratio λ, η, dihedral angle V, specific wing loading, wing shape in the plane.

Geometrical characteristics of the wing are determined from the take of weight m0 and specific wing load P0. These are:

- Full wing area with extensions is: 180(m2);
- Wing area is: 63.8(m);
- Wing span is: 40(m);
- Root chord is: 6.42(m);
- Tip chord is: 2.568(m);

At a choice of power scheme of the wing we determine quantity of spars and their positions, and the places of wing portioning.

On the modern aircraft we use double or triple spars wing. The designed has three spars.

The mean aerodynamic chord geometrical method were used.

Mean aerodynamic chord is equal: 4.3 (m).

After determination of the geometrical characteristics of the wing we come to the estimation of the ailerons geometrics and high-lift devices.

Ailerons geometrical parameters are determined in next consequence:

- Ailerons span: 8(m);
- Aileron area: 5.85(m).

- Relative spars position is equal:

$$\bar{x}_i = \frac{x_i}{b_i}$$

x_i –distance i-th spar from wing tip; b_i – wing chord i-th cross-section.

- Front spar:

$$x_1 = \bar{x}_1 \cdot b_o = 0{,}2 \cdot 8{,}551 = 1{,}71 \text{ (m)}$$

$$x_1 = \bar{x}_1 \cdot b_к = 0{,}2 \cdot 2{,}634 = 0{,}527 \text{ (m)}$$

- Aft spar:

$$x_2 = \bar{x}_2 \cdot b_o = 0{,}6 \cdot 8{,}551 = 5{,}130 \text{ (m)}$$

$$x_2 = \bar{x}_2 \cdot b_к = 0{,}6 \cdot 2{,}634 = 1{,}580 \text{ (m)}$$

- Mean relative profile thickness:

$$\overline{c_{cp}} = 0{,}125$$

- MAC tip coordinates:

$$b_A = \frac{4}{3} \cdot \frac{\eta_{кр}^2 + \eta_{кр} + 1}{(\eta_{кр} + 1)^2} \cdot \frac{S_{кр}}{l_{кр}} = \frac{4}{3} \cdot \frac{3^2 + 3 + 1}{(3+1)^2} \cdot \frac{325}{52{,}56} = 6{,}7 \text{ (m)}$$

$$X_A = \frac{X_к}{3} \cdot \frac{\eta_{кр} + 2}{\eta_{кр} + 1} = \frac{8{,}16}{3} \cdot \frac{3+2}{3+1} = 4{,}011 \text{ (m)}$$

$$Y_A = \frac{Y_к}{3} \cdot \frac{\eta_{кр} + 2}{\eta_{кр} + 1} = \frac{2{,}049}{3} \cdot \frac{3+2}{3+1} = 1{,}007 \text{ (m)}$$

$$\chi_{пк} = 17^\circ \qquad \lambda_{пк} = 4^\circ$$

$$Z_A = \frac{l}{b_{cax}} \cdot \frac{\eta_{кр} + 2}{\eta_{кр} + 1} = \frac{52{,}56}{6{,}7} \cdot \frac{3+2}{3+1} = 13{,}054 \text{ (m)}$$

Ailerons geometrical parameters:

- Aileron span:

$$l_{ail} = 0{,}22 \cdot \frac{l}{2} = 5{,}8 \text{ (m)}$$

- Aileron area:

$$S_{ail} = 0{,}031 \cdot \frac{S_{кр}}{2} = 5{,}04 \text{ (m}^2\text{)}$$

Layout and determination of geometric parameters of high lift devices.

- Total slats span:

$$l_{slats} = l_1 + l_2 = 5{,}290 + 7{,}742 = 13{,}032 \text{ (m)}$$

- Total slats area:

$$S_{slats} = S_1 + S_2 = 3{,}317 + 3{,}862 = 7{,}179 \text{ (m}^2\text{)}$$

Increasing of l_{ail} and b_{ail} more than recommended values is not necessary and convenient. With the increase of l_{ail} more than given value the increase of the ailerons coefficient falls, and the high-lift devices span decreases. With b_{ail} increase, the width of the xenon decreases.

In the airplanes of the third generation there is a tendency to decrease relative wing span and ailerons area. So, l_{ail} = 0.122. We can increase the area of the wing by using of high-lift devices such as spoilers and ailerons.

The aim of determination of wing high-lift devices geometrical parameters is the providing of take off and landing coefficients of wing lifting force, assumed in the previous calculations with the chosen rate of high-lift devices and the type of the airfoil profile.

The airfoil should be choosed before calculation, specify the value of lift coefficient $C_{y\max bw}$ and determine necessary increase for this coefficient $C_{y\max}$ for the high-lift devices outlet by the formula: $\Delta C_{y\max} = (\frac{C_{y\max l}}{C_{y\max bw}})$.

Where $C_{y\max l}$ is necessary coefficient of the lifting force in the landing configuration of the wing by the aircraft landing insuring (it is determined during the choice is the aircraft parameters).

In the modern design the rate of the relative chords of wing high-lift devices is:

b_{sf} = 0.25..0.3 – for the split edge flaps;

b_f = 0.28..0.3 – one slotted and two slotted flaps;

b_f = 0.3..0.4 – for three slotted flaps and Faylers flaps;

b_s = 0.1..0.15 – slats.

2.1.2 Choice and substantiation of the fuselage scheme

The fuselage is a thin-walled cylindrical shell framed in the middle and tapered with a double curvature nose and tail sections.

The fuselage conventionally divided into three parts - the nose part, middle part and tail unit. The important factor is corrosion prevention, that's why the drain system should be used in order to decrease the risk of corrosion appearance.

Placed in the fuselage and cabin crew cabin transport, bay mounting tail and APU compartment. Fuselage cabin is pressurized.

Airframe cover, made of aluminium alloy, stressed skin includes a longitudinal force set in the form of stringers and beams, the transverse force in the form of a set of frames and walls, and floors in the cabins. The cross-section of the fuselage is oval.

To the main frame are the transverse and longitudinal force sets, strengthening openings of doors and hatches.

Fuselage skin consists of sheet steel casing, seating and overhead sheets.

Airframe has the row of slots according to which it is divided on separate technological parts. In order to decrease the mass of the structure, special programming method of manufacturing were used. Also structures made by the means of stamping and pressing and cell constructions with the composite materials are widely used in the airframe design.

The basic advantages of the normal scheme are:

- an opportunity of an effective utilization of mechanization of a wing;
- easy balancing of the plane with extended flaps;
- accommodation of the control surfaces behind a wing allowing to produce the nose part of the fuselage shorter, that not only improves the review to the pilot, but also reduces the area of vertical tail, as shortened nose part of the fuselage causes occurrence of smaller destabilizing moment;

It is natural, that in the considered scheme there are disadvantages also:

Horizontal tail creates negative lift force on all modes of flight, that results in reduction of lift force of all plane;

Horizontal tail functions in the indignant air flow behind a wing that negatively has an effect for its job.

2.1.3 Choice and substantiation of the wing location

Wing - swept, high attached, high aspect ratio, free-carrier. The wing consists of center section and two console parts.

Due to analysis of prototypes, the scheme of the wing location was choosed – high-wing location.Such scheme gives a possibility to install the engines on the pylons under the wing The advantages of the high-wing scheme are the following:

- In comparison with others small aerodynamic resistance from interference, especially for round fuselage. Lift-to-drag ratio of the high-wing aircraft with round fuselage is on 4-5% greater than in low-wing aircraft (with other the same conditions). The higher values of C_{ymax} are got thanks to the conserving under the fuselage aerodynamically completely or partially clean wing, better work of wing mechanization due to decreasing of tip effect on the flaps.
- There is the possibility of maneuvering of special vehicles appears;

The distance from the fuselage to the ground decreases that provides convenient loading and unloading of the passengers without using of high ladders, and loading and unloading of the cargoes and baggage are made without usage of complex mechanisms. All these decrease cost of operation, especially of cargo aircraft;

- Longer service life of the engines as they are located far from the ground and getting different parts, such as sand and stones from the aerodrome surface during take-off and landing to the inlet ducts, is lower. Resource life of the engines on the high-wing aircraft is on 10-15% greater than on the low-wing aircraft. That’s why cost price of the transportations on the high-wing aircraft decreases;

- It is increased the weight of force elements (formers) of the fuselage, which perceive loadings from landing gear, if main landing gear is attached to the fuselage;
- It is difficult to provide necessary track of the landing gear for stability and controllability of the aircraft on the ground;
- In total weight of the structure of the high-wing aircraft increases on 2.5-3% from take-off weight if landing gears are attached to the fuselage and on 0.6-1.0% if landing gears are attached to the wing;

2.1.4 Choice and substantiation of engine location on the aircraft

The power plant consists of:

- four sustainer propulsion system consisting of a Turboprop Engine D-27
- electronic automatic control system propulsion systems - fuel system, located in the wing tanks, three tanks (one in the wings and one in the center section)
- Engines unload wing structure in the flight, decreasing bending and torque moment from external loadings that allows to decrease wing weight on 10- 15%;
- Centre of masses of the aircraft with loading and without it is placed approximately on the same distance on mean aerodynamic chord of the wing (MAC), because engines on the wing and payload in such scheme are located near from centre of masses;
- Engines damp wing vibrations during flight in turbulent atmosphere, and because of offset of their centre of masses forwardly there are improved flatter characteristics of the wing;
- Convenience of engine removal and change for another one in aircraft modification;
– Aircraft centre of masses due to the fuselage is moved forwardly in comparison with engine location in aft part of the fuselage, nose part of the fuselage is shorter, the shoulders of horizontal and vertical tail units are increased, and weight of the tail units is less.

Disadvantages of the location of engines on the wing:

- In the case of engine failure it is created great moment, which rotates, in horizontal plane, that is especially dangerous during take-off when efficiency of vertical tail is not enough.

Main engine parameters	Units of measurements	Value
Type and subtype of engine (design)	Д-27	4
Maximum thrust (power)	hp (kWt)	1400 (10294)
Specific fuel consumption	lb/lbf*hr	0.170
By pass ratio		5.6
Engine mass	Kg	1650
Diameter	Mm	1370
Length	Mm	4198

Table 2. 2 - Selected engine parameters

2.1.5. Choice of wing main parameters

To number of the basic parameters of a wing concern a structure and relative thickness C, sweep angle by ¼ of the chord (MAC), aspect ratio, angle of incidence, dihedral angle of a wing and specific loading on a wing. Aerodynamic characteristics of a wing are greatly defined by the form of a wing in the plan. The parameters of a profile (and relative thickness of a wing (C), as the practice of aircraft construction shows, depend on the cruise flight Mach number (see tab. 2.3).

M_{cr}	$\chi°$	λ	H	C, %	X_c, %	f, %
0.85-0.9	35-40	6.5-8.5	3.5 – 4.5	9 -12	35 - 45	0 – 2.5
0.6-0.8	0-25	7-12	2.5 – 3.5	12 - 18	30 - 40	1.0 – 3.5

Table 2.3 - Dependence of wing parameters on Mach number

To the modern subsonic airplane wings are applied close to symmetric and asymmetric structures by sharper forward edge and with a rather back position of the maximal thickness X_c = 35... 45 %. Smoother distribution of pressure along the chord of a wing is characteristic for them that lowers meanings of local air speed above the top surface of a wing and promotes increase of critical number of flight

Sweepback of the wing is mean to increase critical Mach number of the flight. Increase of the wing sweepback not only displace on greater speeds of the flight beginning of wave crisis and also smoothes its proceeding, decreases increment of resistances, improves stability and controllability characteristics of the aircraft on transonic speeds.

Because of lateral flowing of a boundary layer by the ends of the swept wing it has a tendency to trailer failure of a flow at the large corners of attack, which consequence can be loss of cross controllability and longitudinal instability of the plane at landing. Sweep angle construction complicates manufacture and increases of weight of a wing.

The specified circumstances cause “economical” application of sweep angle, i.e. the sweep angle of a wing of the subsonic plane gets out usually on the minimum determined by size of given speed (of number M) of cruise flight.

The aspect ratio of a wing is parameter essentially influencing size of inductive resistance and the maximal quality of a wing and the plane. Besides that it influences on weight and rigidity characteristic of a design of a wing.

Large (with maximum payload greater then 100 tons) subsonic transport airplanes with $M < 0.8$ have the wings with medium sweep angle. The aspect ratio of wings with sweepback angle lays in a rather wide range 7...12, and the large

meanings of aspect ratio concern, as a rule, to large planes with the large settlement range of flight. Due to all said above and statistical data of prototypes the aspect ratio is chosen as $\lambda = 9.5$ and sweepback angle $\chi = 22^{o}$.

The taper ratio of a wing renders inconsistent influence on aerodynamic, weight and rigidity characteristics of a wing.

Increase of taper ratio η favorably has an effect for distribution of external loadings, rigidity and weight characteristics of a wing. It results also in increase of building height and volumes of the central part of a wing, that facilitates accommodation of fuel and various units, and the increase of the area of a wing served mechanization, appreciably raises its efficiency.

However increase of taper ratio has also negative sides. Main of them is tendency of a wing with the large taper ratio to trailer failure of a flow at simultaneous decrease of ailerons efficiency. In connection about specified by circumstances the taper ratio of direct wings of subsonic planes which $M_{cr} < 0.8$ is filled usually small and makes size $\eta = 2.5...3.5$ that provides inductive resistance, close to a minimum, of a wing and high meanings of C_{Ymax}.

The dihedral angle of a wing V, as it is known, serves as mean of maintenance of a degree of cross stability of the plane. Its size and mark depend on the plane structure, and for planes with swept wings – also from the sweep angle. For direct wings subsonic planes the meaning of dihedral angle V lay in a range from -1...-5 – for high-wing. Sweep angle increases cross of a wing and consequently to swept wings should be given negative angle V. It will entail installation in a control system automatic damper yawing and will require some increase of the area of vertical tail.

We choose the following basic parameters of a wing η = 2.5; C = 0.125.

The mean aerodynamic chord has been determined by the graphic method (Fig.2.1).

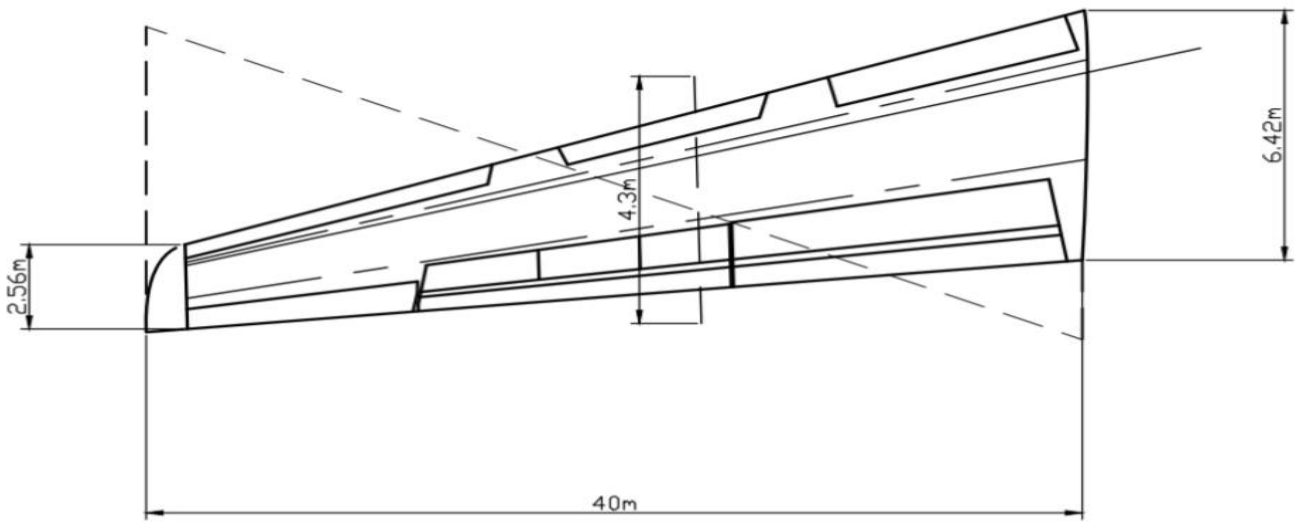

Fig. 2.1 - Wing MAC positioning calculation scheme

2.2. Brief description of the airplane structure

Fuselage. The projected plane has fuselage with semi-monocoque structure. This construction consist of beams, stringers and frames.

Fuselage has high critical value of Mach number.

In the cockpit there are seats for the first and second pilots. There is also a space for a flight engineer crew member.

The first pilot is on the left on the flight, the second pilot on the right, the flight engineer in behind of the second pilot. In front of the pilots, instrument panels are installed, and between them an average pilot console.

Ahead of the first and second pilot's seats there are steering wheels for driving the elevator and ailerons and pedals for steering the rudder. There are emergency exits on the left and right side.

Wing. Most of the modern aircrafts use the wing with caisson structure, our projected aircraft is not exception. It consists of a centroplane and two detachable parts of the wing, attached along the ribs.

The forward part of the wing is equipped with anti-icing system.

The caisson structure takes almost all loads wich act on the wing.

The take off and landing characteristics are improved due to relatively small distance of the wing to the ground.

The wing is made swept, as a result of which it has a larger M_{cr} and a weaker wave crisis, but there are a number of drawbacks:

- Large tearing speeds and landing and, as a consequence, a long run and run length.
- It has smaller aerodynamic qualities than direct, greater drag of the aircraft and a shorter range, and the duration of the flight.
- Have a tendency to end the flow from the wing.
- Lowest coefficient of maximum lift.
- External lateral stability, leading to aircraft swinging.
- The lateral controllability is reduced at large angles of attack due to a stall from the wing ends, has a reverse roll response.

The lateral stability decreases with M> Mmax

Tail unit. The empennage is swept, consists of vertical and horizontal stabilizers and control surfaces.

Vertical tail includes fin and rudder, horizontal tail - stabilizer and elevator.

The sweep of the vertical and horizontal tail is greater than the sweep of the wing, so that the aerodynamic characteristics of the tail unit with an increase in the number M do not deteriorate faster than the characteristics of the wing. The vertical and horizontal tails profile is symmetrical. Symmetric profile allows to maintain the same character of aerodynamic loads during deflection of rudders in different directions and, in addition, has a smaller resistance.

Vertical tail in comparison with horizontal tail has an increased relative thickness of the profile in order to reduce the mass of fin loaded with forces, both from vertical and horizontal plumages.

Control system. The aircraft control system includes: elevator control system, stabilizers, rudder, ailerons and aileron-spoilers, air brakes, flaps and slats.

To help pilots controlling the aircraft during any period of flight, the flight control system is installed. Such system is used on every modern aircraft and significantly decrease the stresses and .increase cheerfulness. There exist different modes for the aircraft control system operating.

The aircraft control system works accordingly in the following modes:

- Steering control mode - the mode in which aircraft control is made by the first or second pilot by the usual movement of command levers(columns, steering wheels, pedals) when the automatic system is operating;

- semi-automatic control mode - the mode in which the pilot drives by plane (using the same command levers) by the position of the commander pilot-command instrument or other navigation-flying instruments;

- automatic control mode - the mode in which the aircraft is controlled by the automatic system in conjunction with the flight-navigation complex.

The control of the main controls is double: each pilot has command levers of these systems installed on the consoles of the first and second pilots in front of the seat of each of them, and control can be performed simultaneously by two pilots and separately - the first or second.

Aircraft control. System of aircraft control includes roll control system and control system of high-lift devices.

Roll control system. Roll control system serves for control on pitch, roll and yaw in manual and automatic modes with provision of necessary stability and controllability characteristics.

For aircraft control there are used mini control wheel and pedals without offset of neutral positions during trimming.

Operating controls of roll control system are elevator, ailerons, multifunctional spoilers (three sections on each semi-wing) and rudder. Flatter of external sections of rudder and elevator, which don’t have weight balances, is prevented by holding them from vibrations with the help of steering gears of system of column control.

Roll control system provides the following functions:

- control of rudder and elevator sections, ailerons and spoilers;

- loading and trimming of efforts on control levers;
- tactile indication of exceeding of allowable angle of attack, bank angle and side overloading.

The base of roll control system is multi-channel digital-analog electrical-remote system (ERCS).

Digital part of ERCS consists of three parallel working digital computers, each of which gives control signals for all three control channels.

Level of ERCS redundancy and interacting systems provides practical availability of ERCS and invariance of stability and controllability characteristics in change of any single failure, except mechanical one. For the case of disconnection or seizure of any part of mechanical wiring in ERCS there are foreseen means, which allow finishing of the flight with such failure.

After failure of ERCS digital part control is made from analog subsystems in small decrease of level of stability and controllability characteristics.

As the mean of diverse backup of ERCS it is used hydraulic-remote control system (HRCS). Transfer on control from HRCS is performed by turning off of servo drives of ERCS from mechanical control wiring.

Normal and emergency exits, emergency means. Dimensions of side door cutouts on the left and right sides of the cargo cabin: Width 0,8 m; height 1,8 m.

Dimensions of emergency hatch cutouts on the left and right sides of the cargo cabin: Width – 0,61 m; Height – 1,22 m.

- The dimensions of the cutout of the upper emergency hatch in the cockpit:

0,5×0,6 m.

- Dimensions of the cutout of the lower emergency hatch in the cockpit:

0,7×0,95 m.

Wing high-lift devices control system. Wing high-lift devices control system includes:

- flaps control system;
- slats control system;

- control system of stabilizer deflected nose;
- spoilers control system.

Flaps control system consists of two same double-channel electrical-remote control systems.

Besides, each control system has double-channel system of electrical-mechanical brakes control.

System of electrical-mechanical brakes control provides automatic braking of transmission of correspondent flaps by turning on two electrical-mechanical brakes and gives signals on turning off of flaps swinging mechanism in manual and backup modes.

When alternating current is absent in the electrical circuit, both flaps control systems are transferred on emergency supply of direct current in the mode of limited power, which provides flaps extension in the backup mode on the angle not more than 25° with the velocity much less than nominal one.

Besides, slats control system provides:

- during asymmetry of left and right sections of the slats more than allowable value, deflection and locking of hydraulic drive in main and backup modes, and also turning on of down-lock mechanism.

Deflector's extension and retraction is made in two modes – main and backup. Spoilers control system with the help of ERCS provides spoilers operation into three modes:

- spoiler-aileron mode;
- glide-path mode;
- brake mode.

In the spoiler-aileron mode it is provided automatic deflection of the spoilers on all flight modes.

In glide-path mode it is provided synchronic deflection of all spoilers.

In brake mode on the landing run or during aborted take-off it is provided synchronic deflection of all spoilers on full angle.

Besides, in brake and glide-path modes spoilers control system provides:

- retraction of earlier extended spoilers;
- cut-off and retraction of any pair of the spoilers during asymmetry between spoilers of this pair more than allowable;
- it is foreseen forced cut-off of any pair of spoilers by correspondent switches.

Cargo cabin and transport equipment

In the cargo cabin of the aircraft there is performed transportation of the cargoes. Aircraft can provide transportation of every wide range of the cargoes:

- nominal combat material;
- bulky cargoes;
- self-propelled and non-propelled machines;
- cargoes in aviation containers;
- cargoes on the pallets;
- heavy agricultural machines etc.

Pressurized cargo cabin provides transportation of cargoes which general weight is near 35 tons, cargo paradropping on the platforms, and also prepared cargoes and technique without usage of the platforms. Titanium alloyed floor of the cargo cabin can carry any type of cargoes without potential damage to the floor.

Special barriers are installed in order to prevent unpredictable situations.

Dead roller equipment provides cargo movement in the containers and on the pallets in aircraft cargo cabin and their fixation.

Loading, unloading and fixation of cargoes is performed by transport equipment of cargo cabin.

Transport equipment consists of:

- upper loading equipment;
- lower loading equipment;
- mooring equipment;
- roller equipment.

Upper loading equipment consists of four monorail motor hoists, each of which has load-carrying capacity 5000 kg.

Lower loading equipment consists of:

- two winches;
- tackle system;
- protective floorings on the floor and ramp.

This equipment is not used in flight and that's why it is considered as cargo fixed in the cabin.. The fixation of this equipment can withstand any possible loads including emergency situation.

Mooring equipment provides cargoes fixation in the cargo cabin.

Mooring equipment consists of:

- tie-down fittings;
- mooring chain devices;
- tie-down belts;
- straps and clamps.

Dead roller equipment includes:

- roll tracks;
- latch beams;
- side directrices;
- end locks.

Power plant.

The power plant consists of the following components:

- four bypass engines;
- auxiliary power unit;
- engines control system;
- fuel system;
- fire-extinguishing system.

The engines of the designed aircraft provide enough power for short take-off and rapid climb with any payload, including maximum.

Engine is attached to the wing with the help of braces in forward and backward planes of the mounts. Engine nacelle provides minimal aerodynamic resistance of the power plant in the flight, organized engine cooling and its aggregates, and creates limited compartment, localizing fire spreading in the case of its appearance.

Air inlet-heat exchanger forms input channel into the engine and serves as primary air-to-air heat exchanger for preparation of the air in the air conditioning system in the aircraft cabin.

Caps of the cowling are made of fire-resistant material and are attached to the beam with the help of hinge units. The caps are connected between each other by tabled scarves. When opening the cap it is provided access to the engine aggregates during ground operation.

Cargo compartment. For transport aircraft one of the most important parameters are sizes of the cargo cabin, especially height of the cabin. Very important is possibility to transport non-standard cargoes.

For better accommodation of the cargoes, the oval cross section was choosed. Such form requires strenghthened bulkheads due to additional loads on the structure.

Determination of the diameter fuselage is made on prototypes, so $D_f = 4.5$ m.

As we have cargo aircraft all place will be occupied by the cargoes. One of the most important features of the cargo aircraft is to make the cargo compartment as long as it's possible. This feature is the key advantage comparing with the analogues.

As it was mentioned, in order to transport different types of cargoes, the cargo cabin should be pressurized.

By norms of airworthiness is stipulated, that at flights with H = 3500 m the cabin should be pressurized, superfluous pressure in a cabin not less than 567 mm of a hg (2400 m), speed of change of pressure in a cabin no more than 0.18 mm hg/s, temperature in a cabin 18... 22ºC and humidity 30... 60%. As in the cabin there will be placed two load masters, and then all these requirements should be satisfied.

Crew cabin. The crew cabin should be balanced between the good visual observation and small dimensiones to decrease total mass of the aircraft and increase aerodynamic characteristics. The strictest requirements are given to workplaces of the pilots. Except of convenience they should provide good review. The size of a service cabin depends on structure of crew. On intercontinental and long-range aircraft the crew consists of 3... 5 men, on midrange and short-range aircraft it has 3...4, on local lines – 2...3 men.

In modern aircraft is tendency to decrease the aircraft staff, but of course in the limits of flight safety.

Crew of the aircraft consists of the three members:

- pilot-in-command;
- co-pilot;
- flight engineer.

Crew seats are depeloped to be comfortable and safety for the crew.

They are equipped by electrical mechanisms of the height regulation.

The inside view of the cabin should be strict without any ultracolored objects.

On the cargo aircraft besides the flight crew there are also two load masters.

Their seats will be placed in the cargo cabin. The number of crew members is changed according to the distance of flight. The pilots are placed in armchairs directly opposite to window, flight engineer more often is located behind armchair of the co-pilot, to provide between him and commander of the plane the visual communicationThe cabin of crew is separated from other compartments by a rigid frame with a locked door.

Galley. It is necessary to make galleys because of long flights, in order to keep the crew in good conditions.

For transport aircraft it is enough single galley. This galley should be placed between the crew and cargo cabin. Such layout is most comfortable and provides easy access. As the flights can continue more than 9 hours, there should be provided enough food and water for the crew.

Lavatory. The duration of flight is long, that’s why it is necessary to set lavatory on the board. But as we have only five members on the board of the aircraft it is enough to have only one lavatory. Even in the case of additional crew members for some flights, it will satisfy free access to it.

The area of the lavatory is 1.5…1.6 (m^2).

Lavatory is designed similarly to the prototype.

It is foreseen by the norms to have store of the water and chemical liquid.

Normal and emergency exits and emergency means. In the forward part of the fuselage there are placed two doors on the port side and starboard. The normal door for an entrance and exit of the crew and load masters carries out on the left board of the plane with board ladder, which is retracted manually and is set on the board inside the fuselage. The door is open outside in the direction of the flight as manually so remotely. Height of a door depends on a diameter of the fuselage and is equal to 1400... 1830 mm. Width of a door should be not less than 860 mm.

The door on the starboard of the aircraft is used as the emergency exit in the case of emergency situations for leaving the airplane by the load masters.

It is provided the emergency exit door in the upper part of the crew cabin. The crew also can leave the plane through the first main door together with the load masters.

Sometimes exit doors are made in the ceiling of the aircraft. But in our case there are no any doors on the upper plane of the aircraft because it is the high-wing airplane.

In the tail part of the aircraft there is cargo door, which is closed by the ramp and pressurized doors. Ramp performs the function of ladder for loading of different cargoes.

Near the exit doors there are placed inflatable escape chute and liferaft in the region of forward left wing fillet.

The windows (illuminators) are of round form with the diameter 400 mm. they provide good lighting by daylight and view from the cargo cabin.

On the aircraft there are installed electronic indication system, which monitors the position of side doors and cargo door, and signalization, which warn pilots about non-closed position of each door of the aircraft.

The exits are protected from the accidental opening.

2.5 Calculation of the main parameters of the landing gear

The landing gear parameters are next: base,track, number of wheels, type of pneumatics and etc.

On the modern planes the tricycle scheme is applied with the nose landing gear. The number of the struts can be different 2, 3, 4 and greater.

The base of the landing gear is defined by the next formula:

$$B = (0.3\ldots0.4)\cdot L_f = 14.6\ (m).$$

Main LG wheels axel offset:

$$e = (0.15\ldots0.2)\cdot b_{MAC} = 1.005\ (m),$$

Nose LG wheels axel offset:

$$d = B - e = 13.595\ (m).$$

The track of the landing gear is determined as:

$$K = (0.7\ldots1.2)\cdot B = 9.8\ (m).$$

The wheels of the landing gear are chosen due to parking load from take-off weight on them; during choosing of the wheels to the nose landing gear we should take into account dynamic loadings. The type of the pneumatics (balloon, semi-balloon, arch) and pressure in them are determined due to the type of the runways, on which the plane will be operated. The main landing gear must be equiped with ceramic brakes which can withstand extremely high temperature during landing. The loading on the wheels is equal to:

$$P_{MLG} = \frac{(B-e)\cdot m_o \cdot g}{B\cdot n\cdot z} = 101{,}761\ (kN)$$

$$P_{NLG} = \frac{e\cdot m_o \cdot g \cdot k_Д}{B\cdot z} = 67{,}703\ (kN)$$

k_d – is the dynamic coefficient.

Wheel size	$P_{st.toff}$, N	$P_{st.land}$, N	P_o, 10^5Pa	δ_{st}, mm	$P_{fract.}$, N	V_{land}, Km/h	V_{toff}, Km/h

For Main Landing Gear							
1100×330B	110000	86000	10	81	540000	260	330
For Nose Landing Gear							
1000×280B	66000	5750	10	65	345000	240	330

Table 2.3. - Landing gear wheels parameters

Object name	**Mass, kg**	**Relative mass, %**
Frame	37497,73	0,26
Wing	13977,37	0,098
Fuselage	14650,15	0,10
Horizontal tail unit	1412,56	0,009
Vertical tail unit	1416,83	0,009
Nose L.G.	604,08	0,0042
Main L.G.	5436,72	0,038
Equipment and control	18021,2	0,126
High-lift devices	2579,95	0,0181
Cabin equipment	28,50	0,0002
Decorative covering	826,72	0,0058
Loading equipment	4247,66	0,0298
Control system	712,69	0,005
Hydraulic system	2095,32	0,0147
Electrical equipment	4062,36	0,0285
Locational equipment	527,39	0,0037
Navigational equipment	798,21	0,0056
Radio communication equipment	399,10	0,0028
Instrumental equipment	926,50	0,0065
Other equipment	816,74	0,00573

Additional equipment	260,84	0,00183
Power plant	23802,58	0,16699
Fuel system	798,21	0,0056
Fire protection system	2850,78	0,02
Anti-ice system	712,69	0,005
APU	1268,59	0,0089
Engine equipment	11403,12	0,08
Engine nacelle power units and engine mounts	6769,17	0,047
Dry weight	79582,37	0,558
Equipment	1063,34	0,00746
Crew	170	0,00119
Documentation and tools	120	0,00084
Water, chem.liquid	100	0,00070
Oils and working fluid	420	0,0029
Emergency-rescue equipment	168,34	0,0011
Empty equipped aircraft	80645,71	0,565
Fuel	26892,83	0,188
Commercial load	35000,45	0,245
Payload	61893,28	0,434
Take-off mass	142539	1

Table 2.4. - Values of aircraft masses

2.6. Center of gravity positioning

The center of gravity positioning requires very accurate calculations as it highly influence on the aerodynamic characteristics of the aircraft.

In the process of the plane operation, its center of gravity position may change. The aft center of gravity should be in such place, when the minimal stability of the aircraft is provided.. The forward center of gravity position is defined by the effectiveness of organs of longitudinal control (balancing). The larger is the effectiveness of organs of longitudinal control, the wider will be the range of operational center of gravity positioning.

Determination of wing center of gravity positioning.

Results of the mass calculations required for the center of gravity positions are shown in Table 2.5.

№	**Object name**	**Mass, kg**	**Coordinate x, m**
C.G. positioning of equipped wing			
1	**Wing (structure)**	13977,37	2,48
2	Fuel system (part)	558,75	0
3	Power plant (part)	14751,36	-1,41
4	Aircraft control (part)	213,80	3,42
5	Electrical equipment (part)	1218,70	0,57
6	Anti-ice system	199,55	0,57
7	Hydraulic system (part)	1047,66	3,42
8	Nose strut - "Extended"	604,08	-12,77
9	Nose strut - "Retracted"	604,08	-13,63
10	Main strut - "Extended"	5436,72	2,34
11	Main strut - "Retracted"	5436,72	3,84
12	**Fuel used**	23156,88	1,072
13	**Fuel of navigational reserve**	3735,94	3,49
2.6. Equipped fuselage masses			
1	Fuselage	14650,15	19.22
2	Horizontal tail unit	1412,56	37,64
3	Vertical tail unit	1416,83	37,015
4	Aircraft control (part)	498,88	19,22
5	Electrical equipment (part)	2843,65	19,22
6	Anti-ice system	513,14	0,43

7	Hydraulic system	1047,66	19,82
8	High-lift devices	2579,95	19,22
9	Locator	100	1,14
10	Decorative covering	826,72	4,25
11	Main crew seats	70	-11,3
12	Crew rest apartment equipment	50	9,8
13	Crew	170	11,3

Table 2.5- Trim sheet of equipped wing masses

№	Loading options	Mass,kg	Mass moment, kg*m	Center of mass,m	Centering
1	Main takeoff, l.g. extended	133681	342897,1	12,74	0,281
2	Main takeoff, l.g. retracted	133681	342627,95	12,73	0,279
3	Landing l.g. extended	117566,15	428917,6	12,67	0,26
4	Transit, l.g. retracted	98681	408879,9	12,63	0,255
5	Parking empty	82566	276959,4	12,49	0,217

Table 2.6. - Calculation of centering options

Conclusion to part 2

During this designing work I’ve got the next results:

- preliminary design of the middle range cargo aircraft;

- the cabin layout of the middle range cargo aircraft;

-the center of gravity of the airplane calculations;

-the calculation of the main geometrical parameters of the landing gear;

-the chose of the wheels, which satisfy the requirements;

- the design of nose landing gear.

The chosen design of low-wing aircraft with four engines, which are located on the wings, makes it possible to increase aerodynamic characteristics of the wing, to reduce the aerodynamic effects from engines jet stream and to decrease the noise level .

Installation of turboprop engines type, Д-27 provides high cruise speed and good thrust-to weight ratio.

PART 3. MODERN CONSTRUCTION MATERIALS, WHICH ALLOW TO IMPLEMENT THE REQUIREMENT OF IMPORT OF SUBSTITUTION ON THE PRINCIPLE OF CONFORMITY OF FUNCTIONAL PROPERTIES

3.1. Aluminum structural alloys and related structural elements

Aluminum alloys are the most common material in the aviation industry.

Traditional and improved aluminum alloys are used in world aircraft construction: Д16АТ, Д16чТ, В96, 1163АТВ, 1163РДТВ, 1441РТ1, 1163Т, 1163Т7, 1161Т, В95очТ2, В96-3пчТ12, 1973Т2 (BIAM development); and developed by ALCOA (USA): 2024-T3, 7075-T6, 2524-T3, 6013-T6 HDT, 2324-T39, C433-T351, 7055-T7751 etc.

Materials used in Western aircraft manufacturing and have prospects for use in the Ukrainian aircraft industry are divided into groups according to their composition (Table 3.1).

Group of alloys	The main alloying component
1XXX	Pure aluminium
2XXX	Copper
3XXX	Magnesium
4XXX	Silicon
5XXX	Magnesium
6XXX	Magnesium and Silicon
7XXX	Zink
8XXX	Other elements

Table 3.1 - Designation of aluminum alloys and their main alloying component

For the manufacture of sealed cabins and lower panels (coverings) of the wing, which are quite sensitive to the problem of fatigue damage, the standard material in the production of civil aircraft of the transport category is an alloy 2024-T3.

For the production of upper wing panels, which receive mainly compressive stresses from the action of lifting force, alloy 7075-T6 is the most acceptable.

For corrosion protection alloys 2024T3 and 7075T6 in the process of rolling are covered with an aluminum clad layer (Fig.3.1).

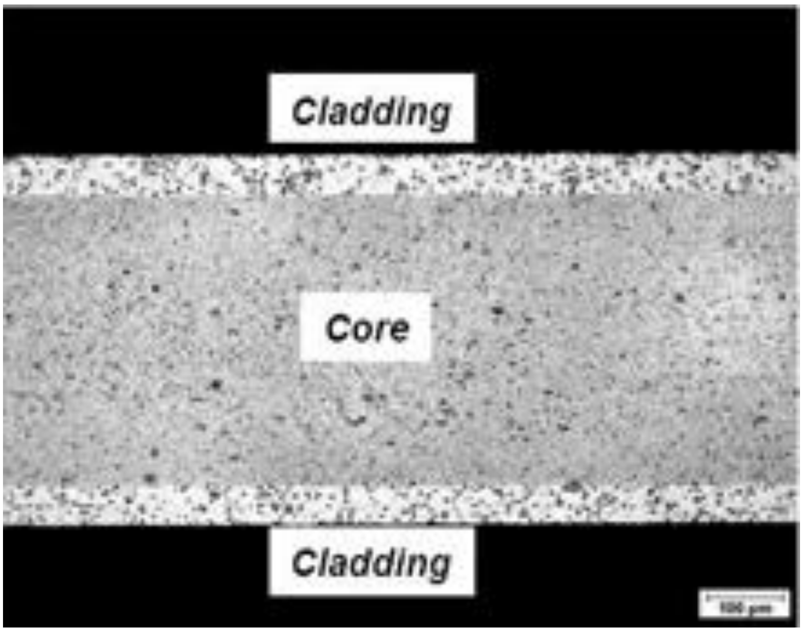

Fig.3.1 - Microstructure of clad aluminum alloys 2024T3 and 7075T6

Chemical composition of aluminum alloys 2024-T3 and 7075-T6 are presented in tables 3.2-3.3.

Si	0,50
Fe	0,50
Cu	3.8-4,9
Mn	0,30-0,90
Mg	1,2-1,8
Cr	0,10
Zn	0,25
Ti	0,15
Other	0,05
Basic component	Aluminium

Table 3.2 - Chemical composition of the alloy 2024-T3

Si	0,40
Fe	0,50
Cu	1,2-2,0
Mn	0,30
Mg	2,1-2,9
Cr	0,18-0,28
Zn	5,1-6,1
Ti	0,20
Other	0,5

Basic component	Aluminium

Table 3.3 - Chemical composition of the alloy 7075T6

The most widespread aviation alloy for many years remains the alloy system Al-Cu-Mg 2024-T3. The characteristics of the alloy without cladding are given in table 3.4.

Form of material	Thickness, mm	Strength limit, MPa	Yield limit, MPa	Elongation, %
0 – sheets and plates	0,25-12,44	220	96	12
T-3- flat sheets	0,203-6,32	434-441	289	10-15
T351-plates*	6,35-101,6	441-393	289-282	12-4
T4 – in the coil	0,254-3,16	427	276	12-15
T81 – flat sheets	0,254-6,32	462	400	5
T851- plates	6,35-38,07	462-465	400-393	5
* The strength decreases with increasing thickness				

Table 3.4 - Characteristics of the alloy 2024-T3 in the absence of the clad layer

The clad aluminum alloy 2024-T3 has a thickness of the clad layer of 0.061 inch, equal to 1.57 mm; 2.5% cladding thickness when the sheet thickness is more than 0.062 inches. The mechanical properties of sheets clad on one side are slightly higher than for sheets clad on both sides. The characteristics of the clad aluminum alloy 2024-T3 are shown in table 3.5.

Form of material	Thickness,mm	Strenght limit,MPa	Yield limit, MPa	Elongation, %
0 – sheets and plates	0,20-44,45	207-220	96	10-12
T-3- flat sheets	0,203-6,32	400-427	269-276	10-15
T351-plates	6,35-101,60	427-393	276—282	12-4
T4 – in the coil	0,254-3,25	400-420	248-262	12-15
T81 – flat sheets	0,254-6,32	427-448	372-386	5
T851- plates	6,35-25,40	448-455	386-400	5

Table 3.5 - Characteristics of clad aluminum alloy 2024-T3

The structural elements of the aircraft operate under cyclic loading. Therefore, when choosing a construction material, it is important to consider the characteristics of fatigue resistance.

Fatigue curves of samples of aluminum alloys 2024-T851 and 2024-T351 with the corresponding scatter of durability are shown in Fig.3.2. The test specimens had a stress concentrator with a radius of 0.33 mm, which determined the stress concentration factor

Kt = 3. The load cycle asymmetry factor was R = 0.

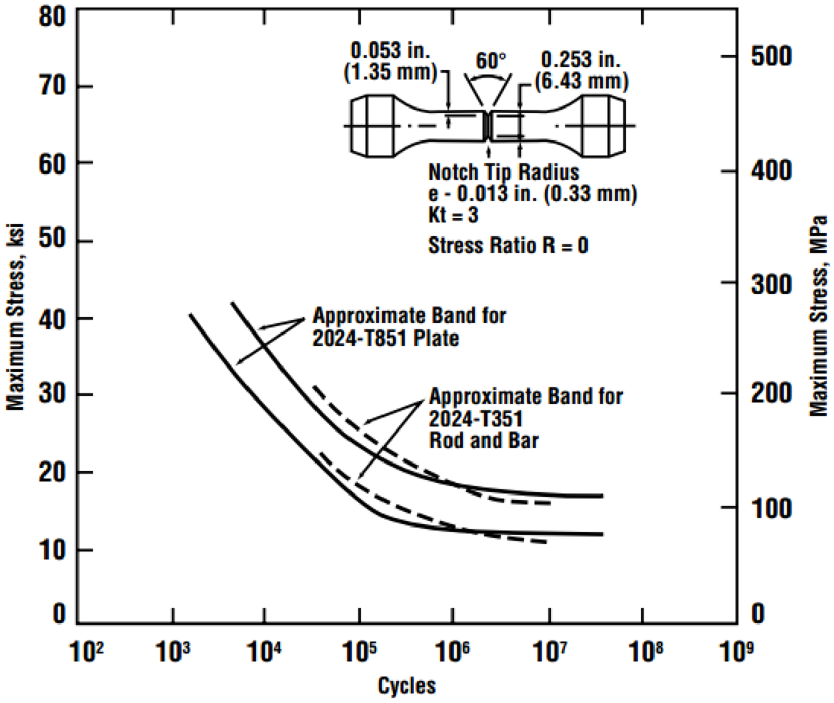

Fig.3.2 - Comparison of fatigue curves of samples of aluminum alloys 2024-T851 and 2024-T351

The mechanical characteristics of the modifications of alloy 7075, which is used for the manufacture of the upper wing panels are given in Table 3.6 (without cladding) and 3.7 (with cladding).

Form of material	Thickness,mm	Strenght limit,MPa	Yield limit, MPa	Elongation, %
0 – Sheets and plates	0,38-50,80	276	145	9-10
T6 - Sheets	0,203-6,32	510-538	434-476	5-8
T651 - Plates	6,35-101,60	538-462	462-372	9-3
T76 - Plates	3,18-6,32	503	427	8
T7651 - Plates	6,35-25,40	496-490	421-414	8-6
T73 - Sheets	1,02-6,32	462	386	8
T7351 - Plates	6,35-101,60	476-421	393-331	7-6

Table 3.6 - Mechanical properties of alloy 7075 in the direction of the texture, which corresponds to their smallest values

Form of material	Thickness, mm	Strength limit,MPa	Yield limit, MPa	Elongation, %
0 – Sheets and plates	0,203-6,32	248-276	138-145	9-10
T6 – Sheets	0,203-6,32	469-524	400-448	5-9
T651 – Plates	6,35-101,60	517-462	448-372	9-3
T76 – Sheets	3,18-6,32	469-482	393-407	8
T7651 - Plates	6,35-25,40	476-490	400-414	8-6
T73 – Sheets	1,02-6,32	434-455	352-372	8
T7351 – Plates	6,35-25,40	455-476	372-393	8-7

Table 3.7 - Mechanical properties of clad alloy 7075 in the direction of the texture, which corresponds to their smallest values

In table 3.7, the cladding thickness is 4% for metal with a thickness of 1.57 mm; 2.5% on the material of 1.57 mm.

Comparison of fatigue characteristics of samples of alloys 7075-T73XXX 2024-T351 and 7475-T7351 is shown in Fig.3.3.

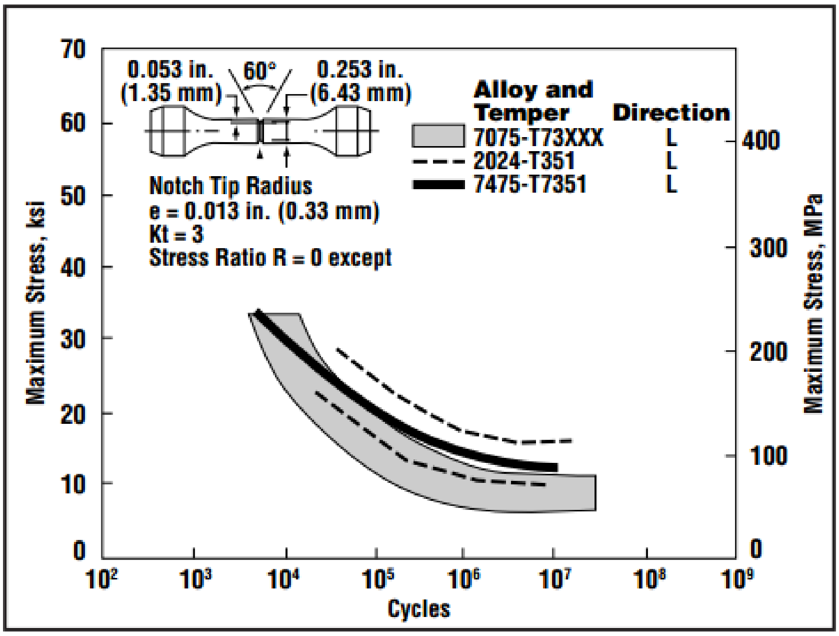

Fig.3.3 - Comparison of fatigue curves at axial tension of samples of alloys 7075-T73XXX, 2024-T351 and 7475-T7351

3.2 Comparison of aluminum alloys according to the criteria of resistance to the propagation of fatigue cracks

When choosing a material for structural elements in which fatigue cracks are likely to occur, the speed of propagation of which must be minimized, an important aspect is the analysis of crack kinetics based on fracture mechanics.

According to the basic principles of fracture mechanics, the rate of crack propagation can be predicted using the Paris equation:

$$\frac{da}{dn} = C(\Delta K)^m ,$$

in which K is the stress intensity factor;

C, m - coefficients that are determined experimentally (Table 3.8).

Table 3.8 - Comparison of the coefficients of the Peris equation of aluminum alloys 2024-T3 and 7075-T6

Material	Coefficient ***C***	Coefficient ***n***
7075-T6	$2{,}13 \times 10^{-13}$	3,21
2024-T3	$3{,}21 \times 10^{-14}$	3,38

The results of the study of fatigue crack growth rates in alloys 2024T351 and 2024-T851 with the corresponding range of data are shown in the graph (Fig. 3.4).

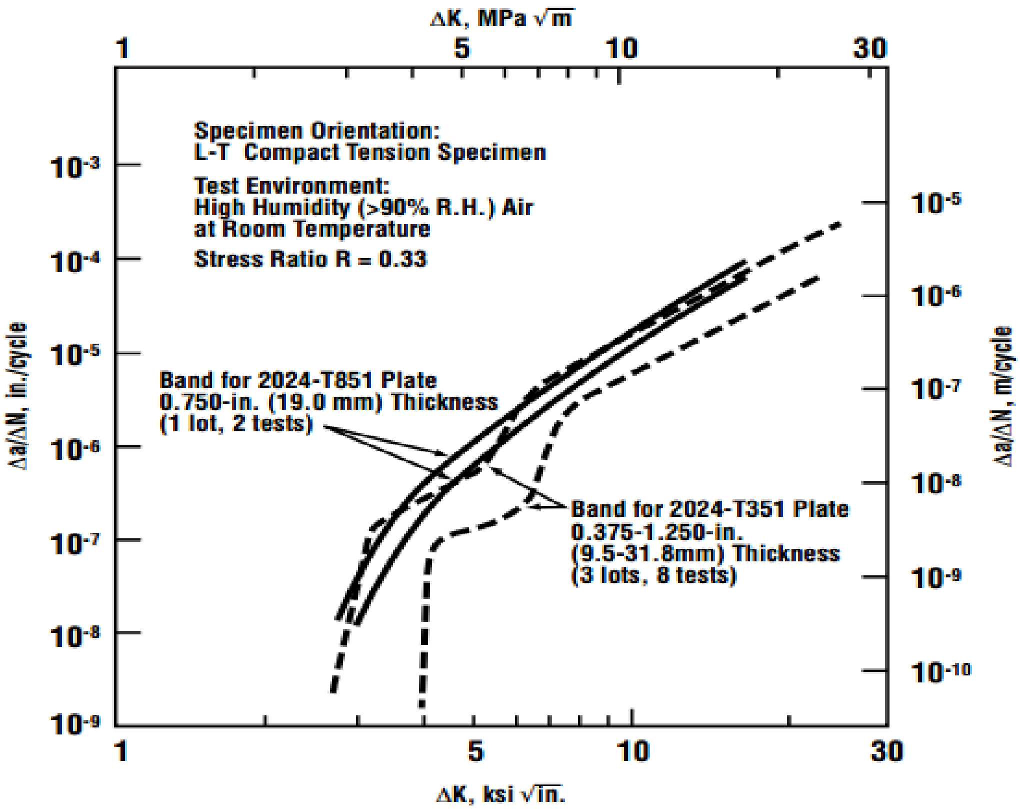

Fig.3.4 - Comparison of fatigue crack growth rates in alloys 2024-T351 and 2024-T851

Comparison of the propagation velocities of fatigue cracks in alloys 7075-T651, 2024-T351 and 7475-T651 in tests with a constant stress amplitude is shown in Fig.3.5.

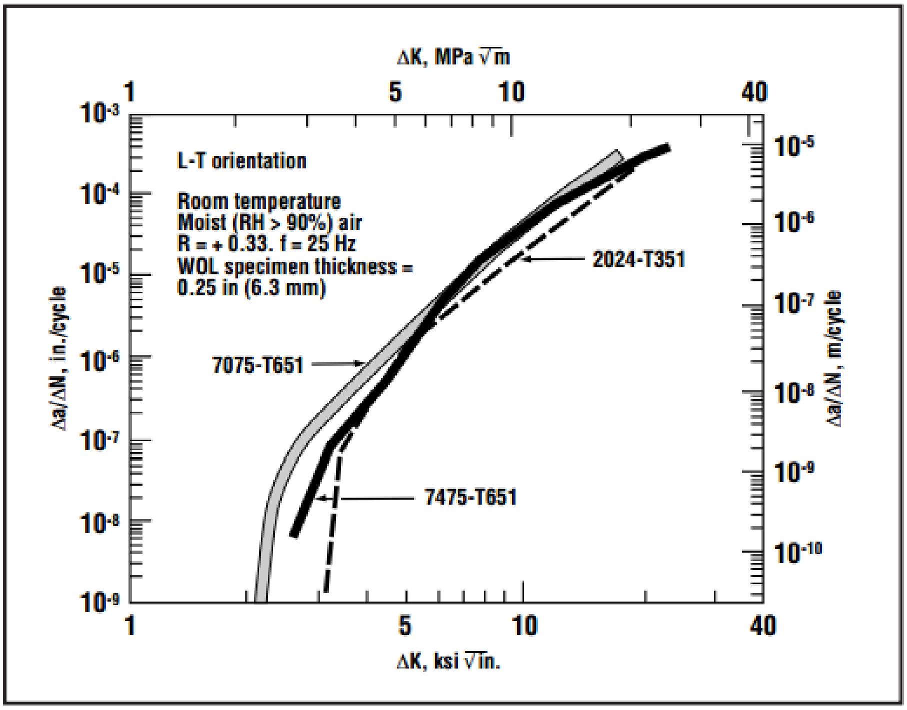

Fig.3.5 - Comparison of the rates of propagation of fatigue cracks in alloys 7075-T651, 2024-T351 and 7475-T651

The correct choice of materials to meet the import substitution requirement requires an analysis of the behavior of selected and potential materials under different loading conditions in order to provide the necessary functional properties of structural materials in the entire range of potential operating conditions. In this regard, we consider the data presented in the paper [Б.Г. Нестеренко трещиностойкость материалов обшивки конструкции гражданских самолетов, научный вестник мгту га 2010, №153 серия аэромеханика, прочность, поддержание летной годности , cc.7-14]. Important results are also given in the works [Schijve J. Fatigue of Structures and Materials. Second Edition with CD–ROM. Springer, 2008, 621 p. ; Воробьев А.З., Олькин Б.И., Стебенев В.Н., Родченко Т.С. Сопротивление усталости элементов конструкций. – М.: Машиностроение, 1990. - 199 с.]

Data on the properties of semi-finished products of various aluminum alloys are given in the works: [Кишкина С.И. Сопротивление разрушению алюминиевых сплавов. – М.: Металлургия, 1981. - 279 с.; Фридляндер И.Н. Алюминиевые сплавы в летательных аппаратах в периоды 1970–2000гг. и

2001–2015 гг. // Технология легких сплавов. – М.: ВИЛС, 2002. - № 4. - С. 12–17; Фридляндер И.Н., Садков В.В., Сандлер В.С., Федоренко Т.П. Свойства полуфабрикатов из высокотехнологичного Al–Li–Сплава 1441 // Технология легких сплавов. – М.: ВИЛС, 2002. - № 4. - С. 24–26; United States Patent, 4,294,625. Oct. 13, 1981; Airliner, April–June 1996, Boeing. Boeing Structural Design and Technology Improvements. 3–7].

For all alloys, the kinetic fracture diagrams were determined, ie, the dependences of the crack velocity da / dN on the amplitude of the stress intensity factor ΔK. Figures 3.4 - 3.5 show the average values of crack growth rate V31 = da / dN at ΔK = 31 MPa√m and the cycle asymmetry coefficient R = 0. In the given a - is the half-length of the central crack.

Material	$\sigma_{0,2}$	V_{31}, mm/1000 cylces	K_c, MPa√m
Д16АТВ sh.4-6	343	4,0	100
2024-T3 sh.3-6	372	2,0	110
Д16чТ pres.panel	400	2,5	140
1163T p.20	340	2,5	175
1163T7 p.30	392	3,0	163
1161T pres.panel	324	1,4	155
2024-T351 p.20	380	2,0	136
2024-T351 p.20	390	2,0	135
2324-T39 p.20	458	2,5	148

Table 3.9 - Characteristics of crack resistance of aluminum alloys used for cladding the lower surface of the wing of transport aircraft

Material	$\sigma_{0,2}$	V_{31}, *mm/1000 cylces*	K_c, MPa√m
В95АТ1 sh.3,5	514	15	52
7178-T6 sh,.3,5	569	15	55
7075-T6 sh, 1,7-3,5	520	7,5	77
В95пч T2 pres.panel	480	3,0	135
В95очТ2 р.30	455	3,25	175
7475-T651 p.25	505	2,75	135
В96ц-3пчТ12 р.25	595	5,0	70
7055-T7751 p.25	594	3,5	90

Table 3.10 - Characteristics of crack resistance of high-strength deformable aluminum alloys used for the manufacture of the upper surface of the wing of transport aircraft

Material	$\sigma_{0,2}$	V_{31}, *mm/1000 cylces*	K_c, MPa√m
Д16АТВ sh.1,2-2	321	3,0	100
2024-T3 sh.2	345	3,0	110
1163АТВ sh.1,5-2	315	2,0	120
1163РДТВ sh.1,5-2	340	2,0	129
2524-T3 sh.1,6	326	2,0	132
2524-T3 sh.3-6*	346	1,7	-
1441РТ1 sh.2,0**	337	2,7	100

Table 3.11 - Characteristics of crack resistance of aluminum alloys used for casing the fuselage of transport aircraft

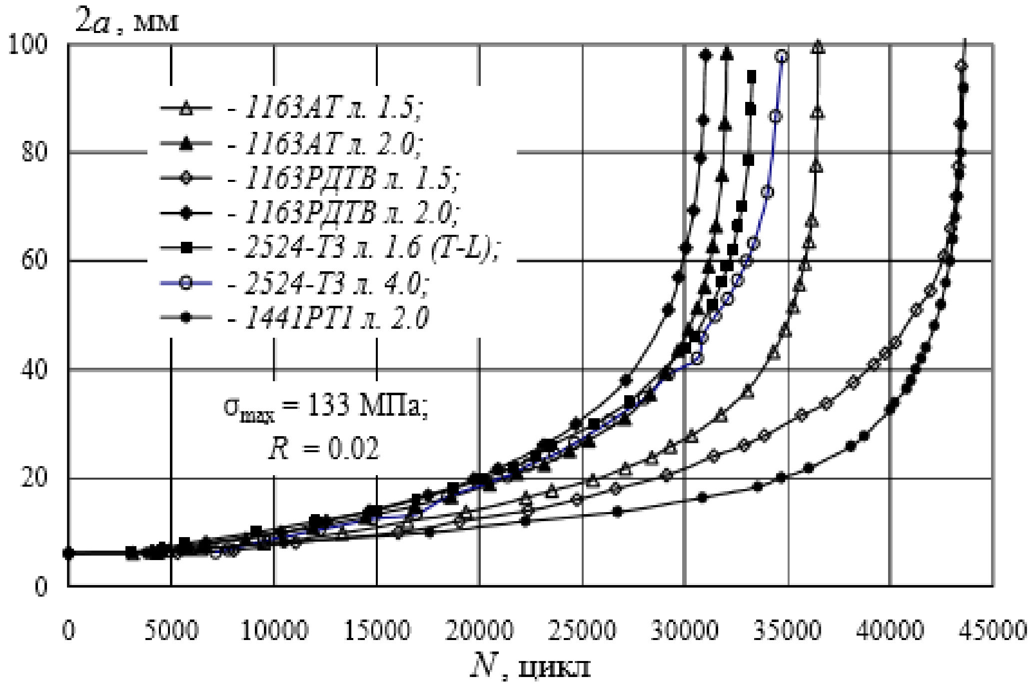

Fig.3.7 - Comparison of the duration of growth of fatigue cracks in the sheets of aluminum alloys used for the manufacture of fuselage cladding

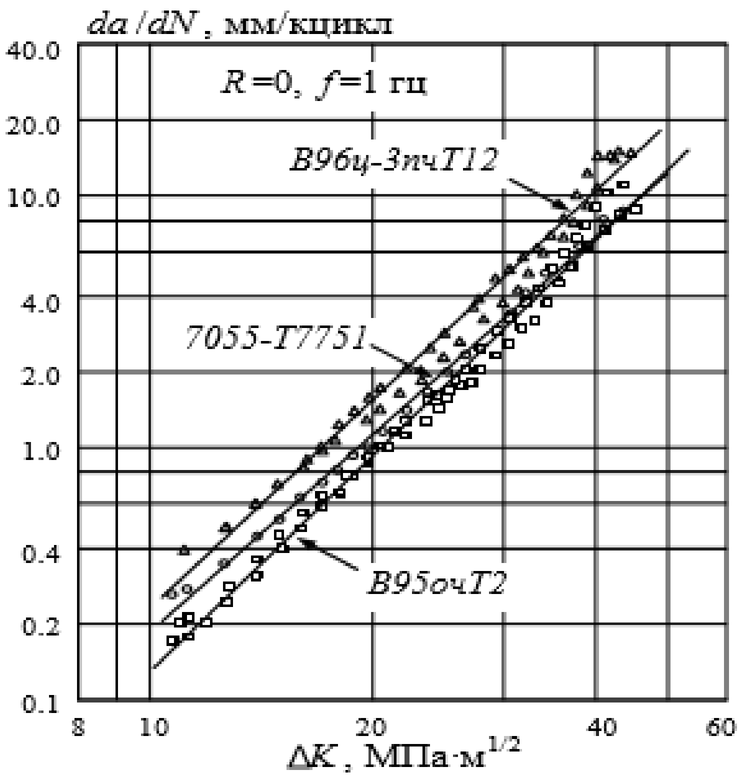

Fig.3.8 - Comparison of growth rates of fatigue cracks in the samples of the upper wing casing, made of advanced high-strength aluminum alloys

The ratio of the duration of crack growth in different alloys depends on the cycle asymmetry coefficient (Fig. 3.9, 3.10). Compression loads determine the different effects on crack growth in different alloys.

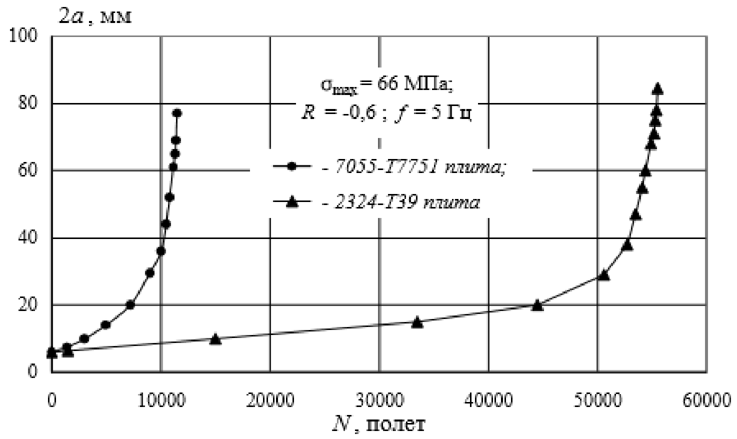

Fig.3.9 - Comparison of the duration of growth of fatigue cracks in the plates of alloys 7055-T7751 and 2324-T39 at regular loading with a negative value of the asymmetry of the cycle

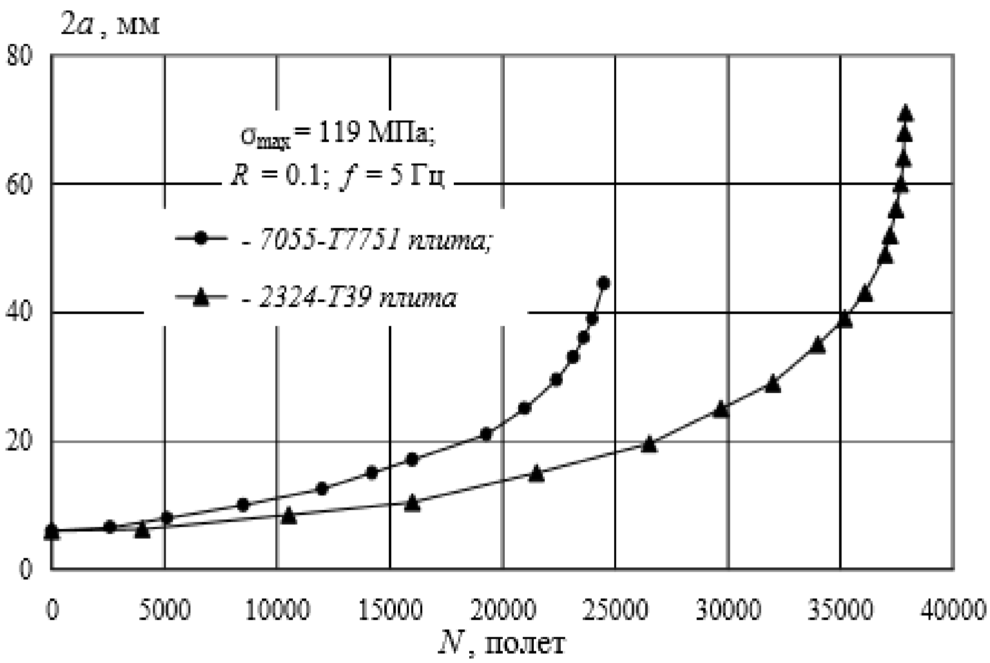

Fig.3.10 - Comparison of the duration of growth of fatigue cracks in alloys 7055-T7751 and 2324-T39 at regular loading with a positive value of the asymmetry coefficient of the cycle

Tests of samples from improved alloys according to the truncated TWIST program showed that the duration of crack growth in extruded panels made of 1161T alloy significantly exceeds the duration of crack growth in plates made of 1163T7 and 2324 – T39 alloys.

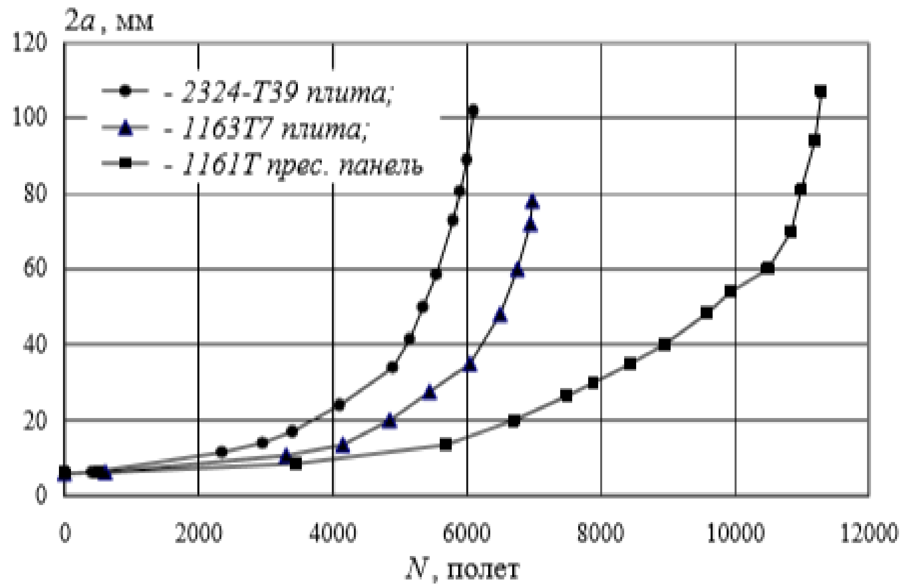

Fig.3.11 - Comparison of the duration of growth of fatigue cracks in different aluminum alloys under load according to the program "cutted TWIST"

The duration of crack growth in samples from extruded 1973T2 alloy panels under loading with the truncated TWIST program is much shorter than the duration of crack growth in samples of the same alloy under loading by Boeing program (Fig. 3.12). The duration of crack growth of samples of alloy 1163 under load according to the TsAGI program is longer than the duration of the process of crack propagation in the same samples under block loading.

The duration of the crack propagation stage at block loading and at regular loading with the maximum stress of the loading cycle σmax = 175 MPa, and the asymmetry coefficient of the cycle R = 0.02 differ slightly (Fig. 8).

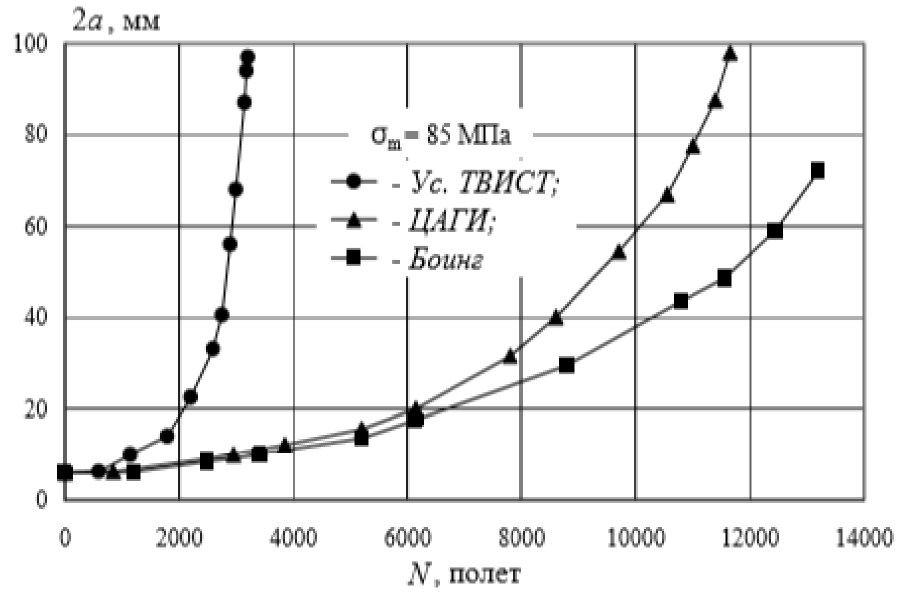

Fig.3.12 - Comparison of loading programs for the duration of growth of fatigue cracks in the extruded panel of aluminum alloy 1973T2 (with the addition of zirconium)

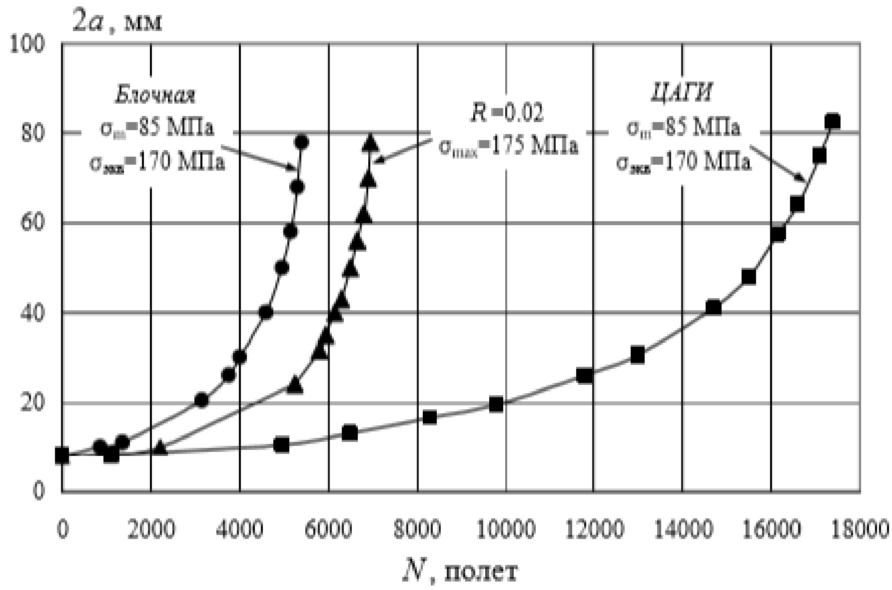

Fig.3.13 - Influence of loading programs on the duration of fatigue crack growth in a plate from an aluminum alloy 1163T

The growth rate of cracks in random programs in alloys 2324 – T39 and 7055 – T7751, which are analogs of 1163T7 and B96ts – 3pchT12, is shown in Fig.3.14, 3.15. These alloys are used for both lower and upper wing panels.

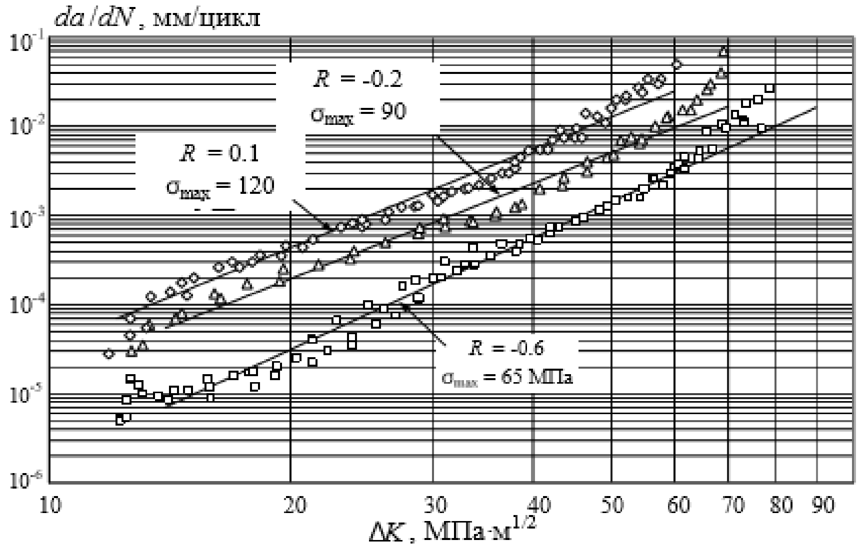

Fig.3.14 - The growth rate of fatigue cracks in the samples of the lower surface of the wing, made of high-resource alloy 2324-T39

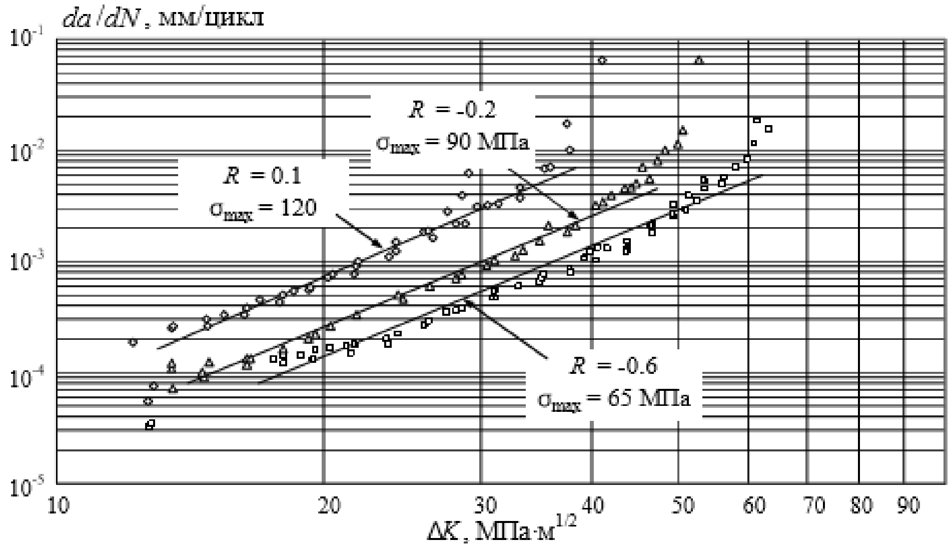

Fig.3.15 - The growth rate of fatigue cracks in the samples of the upper surface of the wing, made of high-strength alloy 7055-T7751

Experimental studies of crack resistance of aluminum alloys used in wing and fuselage structures have shown that the improvement of bearing capacity is achieved by reducing the percentage of silicon and iron impurities, zirconium and lithium additives, improving alloy production technologies.

When conducting research on the functional properties of structural materials, it is necessary to take into account the peculiarities of the operational load of structures. The actual operating load conditions are random in magnitude of the stresses acting in the structural elements and their sequence. Typical test programs that replace the random spectrum of loads are shown in Fig.3.16, 3.17.

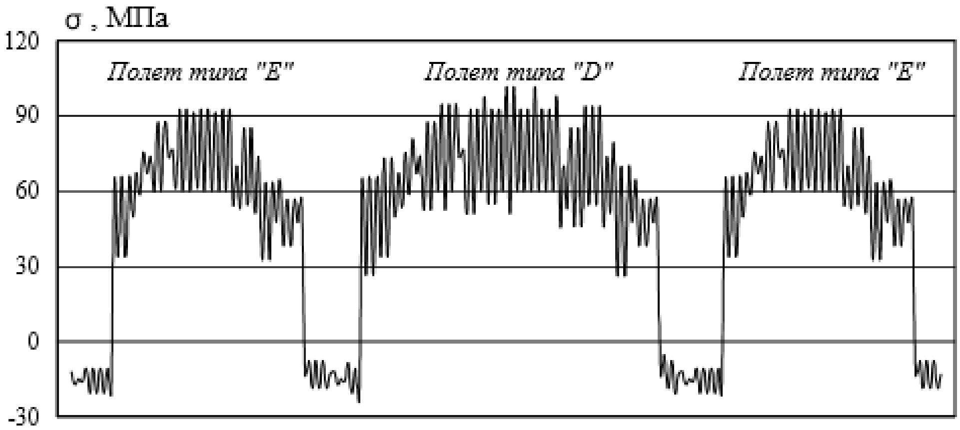

Fig.3.16 - Sequence of extremums of typical flights (E and D) of the Boeing program (B-767) relative to the elements of the lower wing surface

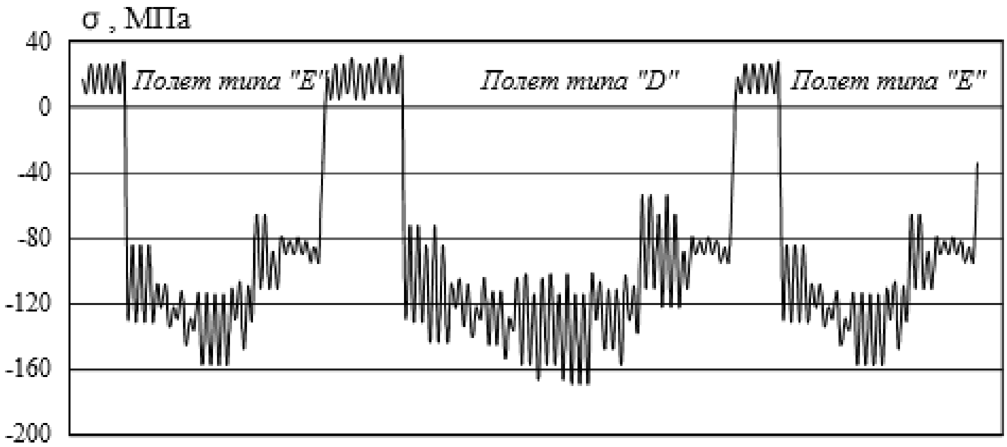

Fig.3.17 - Sequence of extremums of typical flights (E and D) of the Boeing program (B-767) relative to the elements of the upper surface of the wing

Based on the analysis of the properties of modern aluminum alloys, we can offer the following areas of application of materials produced by ALSOA:

- for the manufacture of lower and upper wing panels can be used 2324-T39 and 7055-T7751, which are analogs of 1163T7 and В96ц-3пчТ12;

- for the manufacture of lower wing panels can be used 2024-T851 and 2024-T351, which are analogs of the alloy D16T;

- for the manufacture of the upper panels of the wing can be used 7075-T73XXX, and 7475-T7351, which are analogous to the alloy B95о.ч.T2.

3.3 Structural steels, their properties and application

Steels, widely used in aerospace application in the previous century are now constituting just 7% to 20% of the total weight of the commercial or military aircraft.

The steels used in commercial and military aircraft of the foreing manufactures are primiraly low-alloy steels (4340 and 300M), more highly alloyed secondary hardeding steels (AF1410, HP9-4-20, HY180), precipitation hardened stainless steels (15-5PH and PH13-8) and maraging steels (C250). The nominal compositions of this steels are shown in Table 3.12.

Alloy	**C**	**Ni**	**Co**	**Cr**	**Mo**	**Mn**	**Si**	**Al**	**Ti**
4340	0.40	1.8	—	0.85	0.25	0.7	0.2	—	—
300M	0.40	1.8	—	0.85	0.4	0.7	1.6	—	—
HP9-4-20	0.20	9	4	0.8	1	0.1-0.3	0.2	—	—
HY180	0.10	10	8	2	1	0.15	0.1	—	—
AF1410	0.16	10	14	2	1	—	—	—	—
15-5PH	0.04	4.6	—	15	—	0.25	0.4	—	—
PH13-8	0.04	8	—	13	2.2	—	—	1.1	—
C-250	0.005	18	8	—	4.8	—	—	0.1	0.4

Table 3.12. – The composition ultrahigh-strenght structural steels used in aerospace industry.(All values are given in wt%)

The low-alloy steels are typically used in main landing gear,while the high-alloy secondary hardened steels are used as landing gear and arresting hooks in carrier-based aircraft. The precipitation hardened stainless steels are used for engine attachment fittings and for cargo handling equipment in transport aircraft such as the C5A and C17. Maraging steels are sometimes used as shafts in engines.

The mechanical properties of this alloys are shown in Table 3.13.

Alloy	**YS, MPA**	**UTS, MPA**	**K_{Ic}, MPA$\sqrt{m}$**	**K_{Iscc}, MPA$\sqrt{m}$**
4340	1,482	1,965	71	11-16
300M	1,689	1,965	71	11-16
HP9-4-20	1,276	1,344	192	121
HY180	1,276	1,344	203	45
AF1410	1,551	1,689	187	45,71
15-5PH	1,089	1,124	132	132
PH13-8	1,434	1,551	81	≥69
C-250	1,689	1,724	110	33

Table 3.13. – Mechanical properties of ultrahigh-strenght steels. (The Klscc data are for 1000 hours in 3.5% NaCl in water)

Obviously, if strength were the only criterion, alloys 300M and 4340 would be most widely used in preference to the other materials. Unfortunetly, these materials have very low fracture toughness and are more susceptible to stress corrosion cracking that other steels such as HY180 and AF1410.

The steel selectec for a particular application appears to be the one which has the highest strength consistent with acceptable levels of fracture toughness and resistance to crack growth by stress corrison cracking and fatigue.

The ultrahigh-strength steels are martensitic and are heat treated by austenizing, subsequent cooling to room temperature during which most of the austenite is transformed to martensite and,finally, a tempering or aging treatment during which carbides or other particles are precipitated. There are numerous differences between these steels, including the amoun of plate martensite, the amount of carbon in solid solution, the nature of the particles precipitated on tempering, and inclusion types and volume fractions.

These steels are normally produced for aerospace applications by vacuum arc remelting of electrodes prepared by vacuum induction melting or argon-oxygen decarburization melting.

Alloy 4340 is typical of the low ally steels used in aircrafts. This steel is normally tempered at or close to 200°C. After the tempering treatment about 50% of the carbon has precipitated as carbides. These carbides are not cementite. Alloy 300M is mostly alloy 4340 modified by the addition of 1.6 wt.% silicon. This addition increase the yield strength and allows the steel to be tempered at higher than 200°C temperatutes without decreasing in yield strength and toughness, which is common for 4340 steel in the range of 250-300°C.

The steels HY180, AF1410, HP9-4-20 are very similar. The difference is in the temperature of tempering. This temperature varies from 510 – 565°C. After tempering most of the carbon precipitate as fine-alloy carbides and gives the high strength.

3.4 Ultrahigh-strength steels fracture toughness improvement

The experimental studies of Rice and Johnson suggest that the upper shelf fracture toughness of ultrahigh-strength steels is sensitive to both the inclusion spacing and inclusion volume fraction. In fact, maximizing inclusion spacing appears to be just as important as recuing the inclusion volume fraction. In addition, thework of Cox and Low suggests that increasing the resistance to void nucleation can also be effective in improving fracture toughness.

The effects of particle spacing on toughness are illustrated by considering three heats of AF1410 steel whose compositions are given in Table 3.14.

Sample	C	Co	Ni	Cr	S	Si	Al	O	La
Heat 1	0.16	14	9.97	2.04	0.001	0.01	0.003	0.001	≤0.002
Heat 2	0.16	14	10.1	2.1	0.001	0.03	0.003	0.0009	0.012
Heat 3	0.16	13.8	10.1	1.95	0.001	0.02	—	—	0.008

Table 3.14. Compositions of Three Heats of AF1410 Steel (wt.%)

The predominant inclusion type in heat 1 is chromium sulfide, as the alloy contains virtually no manganese. Heats 2 and 3 have been modified by lanthanum additions and the inclusions are primarily La_2O_2S.

Sample	Primary Type	Volume Fraction	Avg. Radius, µm	Avg. Spacing, µm
Heat 1	CrS	0.00034	0.18	2.3
Heat 2	La_2O_2S	0.00042	0.64	7.6
Heat 3	La_2O_2S	0.00036	1.24	15.4

Table 3.15. – Inclusions in three heats of AF1410 steel

As shown in Table 3.15, the inclusion volume fractions are similar for three huts but the inclusion spacings for heats 1,2 and 3 are 2.3, 7.6 and 15.4 µm, and as shown in Table 3.16, heats 2 and 3 have much higher toughnesses that heat 1.

Sample	Aging Temp, °C	YS, MPa	UTS, MPa	Strain to Fracture	K_{Ic}, MPa $\sqrt{m}$	δ_{Ic} , µm
Heat 1	510	1,524	1,696	1.16	130	28
	425	1,400	1,758	0.94	87	12
Heat 2	510	1,503	1,662	1.16	197	67
	425	1,351	1,751	0.96	120	23
Heat 3	510	1,531	1,675	1.31	185	59
	425	1,455	1,724	0.98	118	23

Table 3.16. – Mechanical properties of three heats of AF1410 steels aget at 510°C and 425°C

The higher toughnesses of these two heats is attributed to the increase in inclusion spacing.

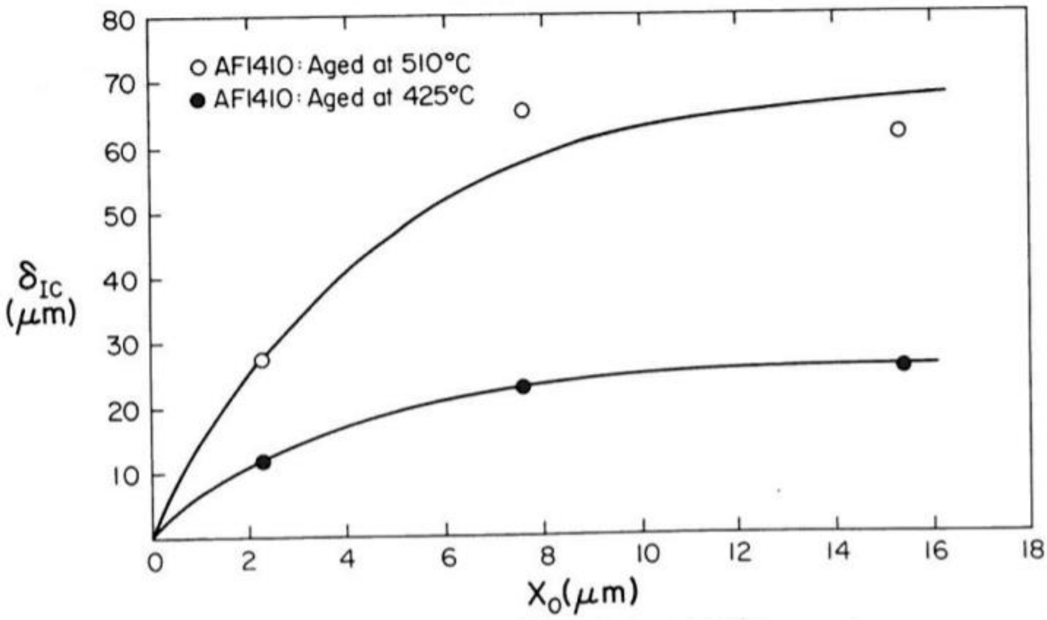

Fig.3.18 – Critical crack tip opening displacement (δ_{Ic})

However, when δlc, the crack tip opening displacement at fracture, is plotted as a function of inclusion spacing as in Figure 2, it is seen that increasing inclusion spacing from 2,3 µm to 7.6 µm is associated with a significant improvement in toughess while increasing spacing from 7.6 ụm to 15.4µm does not leat to a further increase in toughness. Thus, it would appear that, at constant inclusion volume fraction, once the inclusion spasing exceeds some critical value, it has little influens on toughness.

However, data suggest that appropriate lanthanum additions can be used to increase inclusion spacing and to obtain higher levels of toughness than would be obtained by smaller, more closely spaced chromium or manganese sulfides.

Conclusions to part 3

The choice of structural aluminum alloys in the world aircraft industry is based on common criteria. As a result of realization of criteria of conformity of functional properties of metals in different countries of the world alloys with similar characteristics are developed.

The presence of materials similar in physical and mechanical characteristics will allow to implement the requirement of import substitution and diversification of the market for the supply of semi-finished products in the manufacture of domestic aircraft.

The following factors should be considered when selecting structural materials: static strength, endurance limit, modulus of elasticity, fracture toughness, corrosion resistance, and others.

An important factor influencing the resource characteristics of structural materials is the mode of their loading.

Improving the strength and durability characteristics can be achieved by reducing the percentage of silicon and iron, as well as by adding zirconium and lithium.

Lanthanum additions must be made with some care. If the lanthanum additions are insufficient to getter all of the sulfur, then other sulfides will be formed. If the steel is low in manganese, as is AF1410, then small, closely spaced chromium sulfides will be formed and the toughness will be less that one would obtaion with an optimum lanthanum addition.

Unlikely, if too much lanthanum is added, it is possible the inclusion volume fraction will be excessive.

PART 4.
ENVIRONMENTAL PROTECTION

Introduction

Today, a commercial aircraft has an average retirement age of around 25 years, after which hard technical dismantling and recycling process.

Different sources says that exact number of aircraft thought to need scrapping before 2030 varies significantly: the Aircraft Fleet Recycling Association (AFRA) estimates that 12,000 aircraft could be retired in the next 20 years; Avolon's World Fleet Forecast puts that figure at 13,000; and Flightglobal's calculations go up as high as 17,000.

More than 16,000 commercial aircraft have been retired worldwide in the past 35 years, and more recently, some 700 aircraft per year are reaching the end of their operational lives.

Airplanes are extremely expensive, airlines spend millions and millions to get the latest models, and millions more to operate them. But what happens when the old airplanes get too old to fly, and the lifespan of airplanes is much shorter.

The average airplane can fly for around 25 years; some can fly for 30 years but never more than that. So what happens to old airplanes when they reach that age.

An airplane's age is usually measured by pressurization cycles. An airplane is pressurized every time it takes flight, inflicting stress on fuselage and wings.

That is why, contrary to popular belief, short-haul airplanes age faster than long haul airplanes.

There are maintenance programs designed by airplane manufacturers that determine if some of the airplane's components have become weary by pressurization. These parts should then be replaced. If the whole airplane has become over-fatigued it should be retired.

4.1 Aircraft utilization

Many airplanes do not even reach old age. Even though the lifespan of an airplane is around 25 years as stated earlier, most airplanes are dismantled when they reach 18 years old.

The decision to disassemble an aircraft and sell the parts usually depends on whether the value of its parts and components is higher than that of the airplane as an aircraft.

In the middle of its expected lifespan, most airlines reevaluate the plane. How much does it cost to run the airplane? Are there newer more fuel-efficient models that can fly at a cheaper cost? How much is this plane worth now? Is the sum of its parts larger than the value of it as a plane?

If the cost of running the plane is high but it is still valuable as an aircraft it is usually sold to other smaller airlines.

If the value of the parts and components is higher than the whole the plane is replaced, When an airplane is no longer operational it often takes the last flight to a storage airport. These facilities are huge open-air parking lots which are available in several places around the world.

But most of them are located in the southwestern United States, to take advantage of the land availability, and also because the dry climate in these states slows down rusting.

Once an airplane arrives at a storage airport, it is meticulously washed to wash off any salt that may cause corrosion to the exterior. After that, fuel tanks are drained and flushed with lubricant.

Tires are then covered in Mylar to prevent the sun from deteriorating the rubber. And the topcoat is painted in white to deflect the scorching sun rays. retired, and dismantled.

On average, every plane includes more than 350,000 individual components, such as engines, fuselage parts, and electronics.

And even though the plane itself is out of service, many of these parts can be used as spare parts for other aircraft. It is often better to replace a malfunctioning part in an airplane than to fix it.

This process takes a while and when there is nothing of value left, the remains of the airplane are melted for scrap metal.

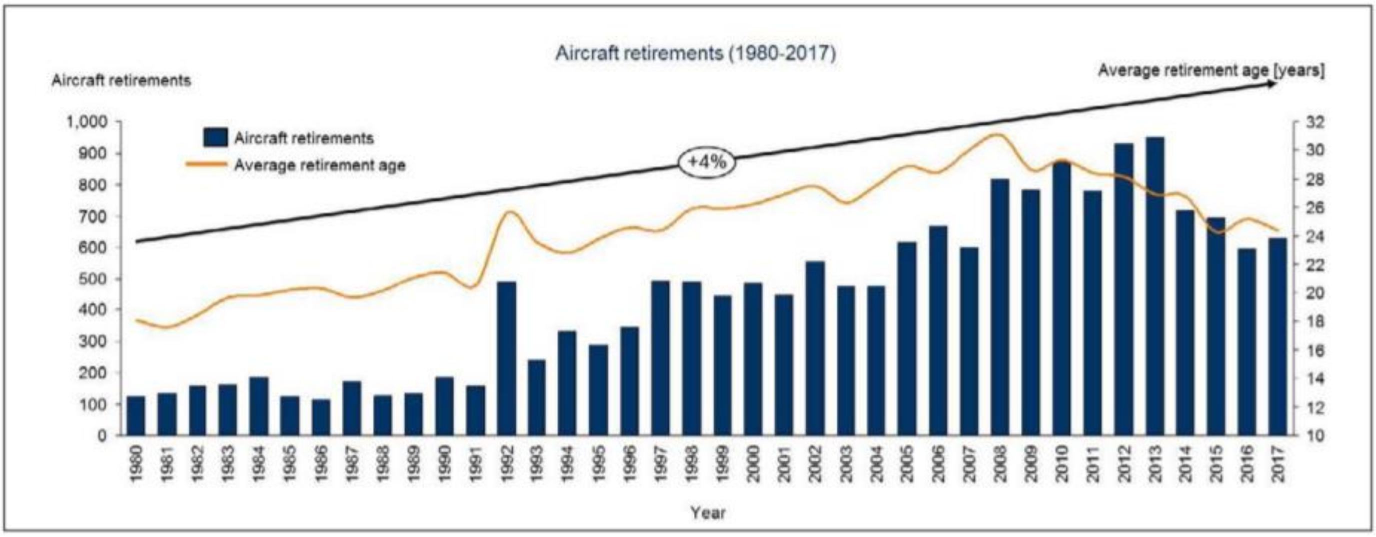

Fig.4.1 - Historical aircraft retirements (1980-2017)

The retired aircrafts value increase every year (see Fig. 4.1). During the global economic recession starting in 2008, up to about 900 aircraft were retired per year. The current rate is about 600 aircraft per year, and the rate can fluctuate up and down depending on business conditions. The average retirement rate is expected to continue to grow as an increasing fleet is coming of age. Of the more than 27,000 commercial aircraft in service globally, over 20 per cent are older than 20 years and likely to be decommissioned in the coming decade. It is estimated that more than 20,000 commercial aircraft will be retired over the next 20 years.

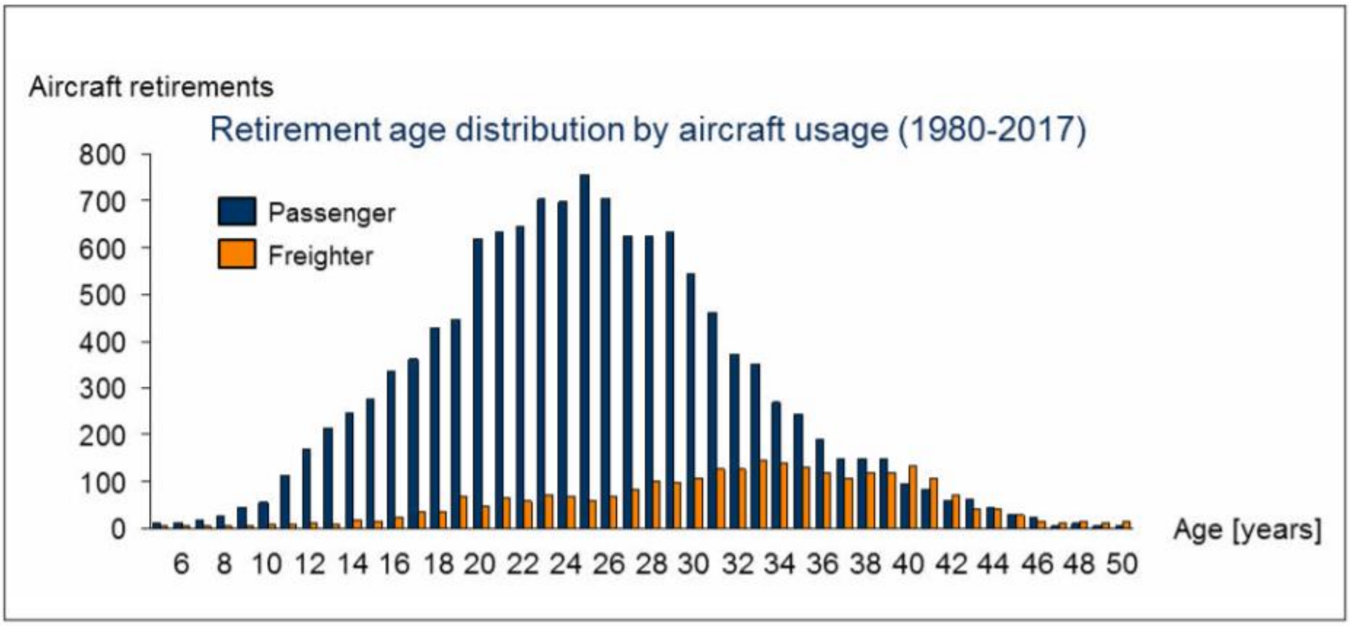

Fig.4.2 - Retirement age distribution by aircraft usage

As indicated in Fig.4.2, the average age of aircraft at retirement is about 26.5 years. While aircraft retirements for technical lifetime reasons at around 15 years were quite common in the 1980s, this is quite rare today and mostly affects small regional carriers and business aircraft. On the other hand, early retirement for economic reasons is not uncommon today. This occurs when an aircraft is still in satisfactory technical condition, but disassembling it and selling the individual parts is more profitable than continuing to operate it.

Air freighters tend to be retired later than passenger aircraft. Their average retirement age is 32 years, compared with 25 years for passenger aircraft. Many of today's freighters are converted former passenger aircraft. Through freighter conversion, the aircraft in-service time can be extended by typically 10 to 20 years, mostly because the utilization of freighters is normally much lower than that of passenger aircraft.

The overall aircraft end-of-life process is divided into two clearly separate phases: • The first phase, which includes the processes up to the removal of parts for re-use in other aircraft, is part of the aviation domain and subject to the related regulations. During this phase, the retired aircraft is still certified. • In the second phase, which comprises final dismantling and recycling, the retired aircraft has lost its certification and aviation regulations are no longer applicable. A well-organized aircraft end-of-life process is carried out as follows: After the owner's decision to disassemble and dismantle an aircraft, it will enter the disassembly process, the purpose of which is to remove the valuable components from the aircraft. The removed components, depending on their technical condition, will either return to the aviation market directly or need to be inspected and repaired or overhauled by an approved repair shop before returning to service. These activities are performed by competent and authorized/certified actors in the aerospace sector.

Once the aircraft has permanently lost its airworthiness, it will not be considered as an aircraft under the State of registry's responsibility anymore and may be considered as waste instead. Usually this occurs once the last aircraft owner has sold the aircraft to a dismantling company and all parts intended for re-use have been disassembled. Thereafter, it becomes business waste. Through the process of dismantling, some parts of the aircraft can be re-used for non-aerospace applications, while the rest of the aircraft will be considered as waste and will be extracted and transferred for further treatment. Recyclable wastes will be processed, and batches will be prepared for recycling, and the non-recyclable wastes will be prepared for disposal.

From an environmental point of view, the aircraft endof-life process presents both risks and opportunities. On one hand, aircraft contain a variety of hazardous materials that must be handled carefully during disassembly and dismantling. On the other hand, the vast majority of aircraft parts can be re-used or recycled without taking special precautions. Handling hazardous materials requires compliance with national occupational health and safety laws and standards, in order to prevent unanticipated releases of these materials into the environment. Fuel remaining in the tanks, as well as hydraulic oil, waste water, and other fluids must be properly drained before the aircraft can be disassembled and dismantled. Examples of other components requiring special treatment include: emergency oxygen bottles, generators, and halon cylinders. Some aircraft manufactured before the 1980s may contain blocks of depleted uranium, which was used as ballast weight due to its high density. These must be disposed of following nuclear waste regulations, which prescribe special procedures regarding: segregation from other wastes, packaging, transportation, tracking, and final disposal.

End-of-life aircraft that have been abandoned on the edges of airfields present a particular risk of leakage of hazardous material and the contamination of surrounding soils and water. This can be especially problematic if the manufacturer’s documentation is no longer available. Because these aircraft are no longer able to fly to dedicated aircraft dismantling facilities, mobile dismantling equipment may need to be used, and particular care is necessary to identify and prevent any contamination risk. It clearly makes both economic and environmental sense to re-use or recycle parts and components of an aircraft. However, expert knowledge is required to identify which parts of an aircraft can be re-used or recycled, and how much residual value can normally be recovered.

Overall, the current state of retired aircraft treatment is a positive example of responsible environmental practices. Today, 85% to 90% of the weight content of retired aircraft is re-used or recycled, reflecting the fact that both re-usable parts and recycled materials represent significant residual value. It is estimated that between 40% and 50% of the weight of all dismantled aircraft is returned to the parts distribution pipeline. Most of the remaining unserviceable material is recycled and returned to the supply chain as raw materials, although the separation of different structural materials such as various aluminum alloys, titanium, and stainless steel, all require substantial manual work. In some cases, aircraft parts, or even entire aircraft have been repurposed for unconventional uses, ranging from furniture and art work, to hotels inside of an aircraft fuselage.Usually, less than 10 % of material is treated as waste.

Today, the largest part of it is carbon-fiber material, which is more and more widely used for its low weight and related fuel burn reduction. However, there was no method to recycle it in the past, and recycling technologies have been developed only recently. Another type of unrecyclable material consists of cabin interior components such as: insulation blankets, carpets, seat cushions, sidewalls, and ceiling panels. These all contain embedded flame retardants, and safety regulations preclude them from recycling.

4.2 How to delimenate the impact from aircraft wastes

Aircraft dismantling activities have to comply with existing rules and regulations issued by ICAO relating to aircraft airworthiness, general and hazardous waste management, and recycling activities. CAEP has gathered existing ICAO Standards and Recommended Practices (SARPs), as well as other material of a regulatory nature from various international bodies, including from non-aviation organizations. These bodies include the International Maritime Organization (IMO) and the Basel Convention and the International Telecommunications Union (ITU), which cover aspects of waste management and recycling activities in non-aviation sectors such as shipping and electronics. It is a very important safety requirement that parts that have been disassembled from a retired aircraft maintain their airworthiness status before being reinstalled in another one. Parts that have been deemed nonairworthy must be recertified by an approved maintenance organization before re-entering service. These companies must ensure that the life history (i.e., operations, modifications and repairs) of the refurbished part is properly recorded.

As the utilization of composite materials using lightweight and high-strength carbon fiber has been increasing mainly for aircraft parts, **thousands tons of waste composite materials are produced annually and are disposed of as industrial waste.**

The production of carbon fiber includes a large energy load and generates more than twice the amount of CO2 in comparison with the production of aluminum. In addition, **disposing of composite materials as industrial waste also has an impact on the environment.**

Due to this, many companies are focused on composite material recycling technology and evaluate the performance of recycled carbon fiber and study its strength characteristics.

Carbon fiber is difficult to burn, light, scatters easily and is conductive, so there are many problems in its disposal. For example, in the case of thermal recycling accompanied by combustion, the scattering of unburned fibers can cause electrical short circuits. For this reason, currently many waste composite materials are disposed of in landfills. In addition, carbon fiber is expensive, and its production includes a large energy load generating more than twice the amount of CO2 in comparison with the production of aluminum, so there is a great need to use carbon fiber for material recycling in terms of its overall life cycle.

However, since recycled carbon fiber is considered to have lower physical properties than new carbon fiber, **full-scale material recycling has not progressed**.

Considering practical application, **the pyrolysis method and the solvolysis method** are considered promising at the present stage. This composite materials recycling technologies are widely applied abroad.

XPS (X-ray photoelectron spectroscopy analysis) of the surface of recycled carbon fiber was carried out to calculate the amount of oxygen atoms present on the surfaces of recycled carbon fiber and virgin carbon fiber (Fig. 3).

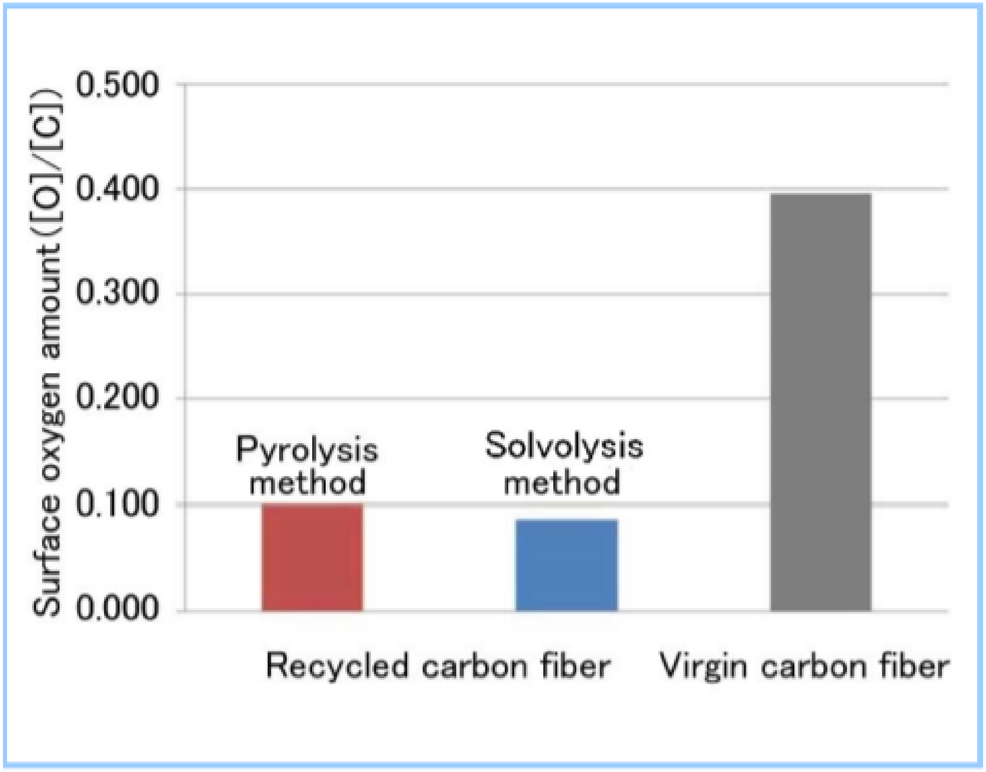

Fig.4.3 - Surface oxygen atomic weight of recycled carbon fiber

The surface oxygen atomic weight of recycled carbon fiber was lower than that of virgin carbon fiber. This is considered to be because not only was matrix resin removed during the recycling process, so were functional groups on the surface of the carbon fiber. However, since remaining functional groups containing oxygen atoms were also observed on the recycled carbon fiber surface, adhesion and wettability with matrix resin can be expected.

Since the waste composite material is cut to a predetermined size during the recycling process, it is difficult to extract the recycled carbon fiber as a continuous fiber. The form of recycled carbon fiber includes milled fiber of 1 mm or less, short fiber of 10 mm or less, and long fiber of 10 mm or more. It is desirable to use the fiber forms for highly-value-added methods such as pelletizing and nonwoven fabric manufacturing accordingly.

For the strength comparative calculation of recycled carbon fiber the commercially available high-strenght type T700 carbon fiber was used.

The results of tensile strength and bending strength tests are shown in Fig.4.

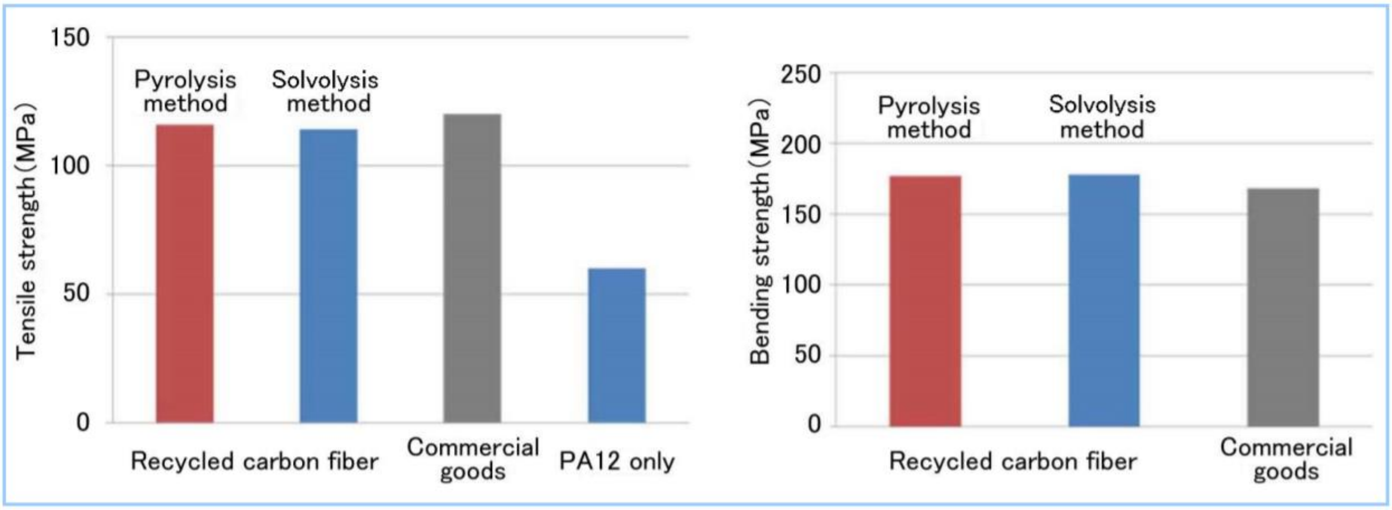

Fig.4.4 - Strength characteristics of composite material of recycled carbon fiber and thermoplastic resin

The test pieces using recycled carbon fiber showed comparable results to the commercially available product and **the effectiveness of recycled carbon fiber was verified.**

Conclusion to part 4

It is generally reported that amount of energy required for the production of virgin carbon fiber is 286 MJ/kg and the CO2 emissions are 22.4 kg-CO2/kg(4). However, as a result of this effort, the energy consumption for the production of carbon fiber can be reduced to about 1/6, and the CO2 emissions can be reduced by nearly 10,000 tons annually by reusing waste composite material (Fig. 5).

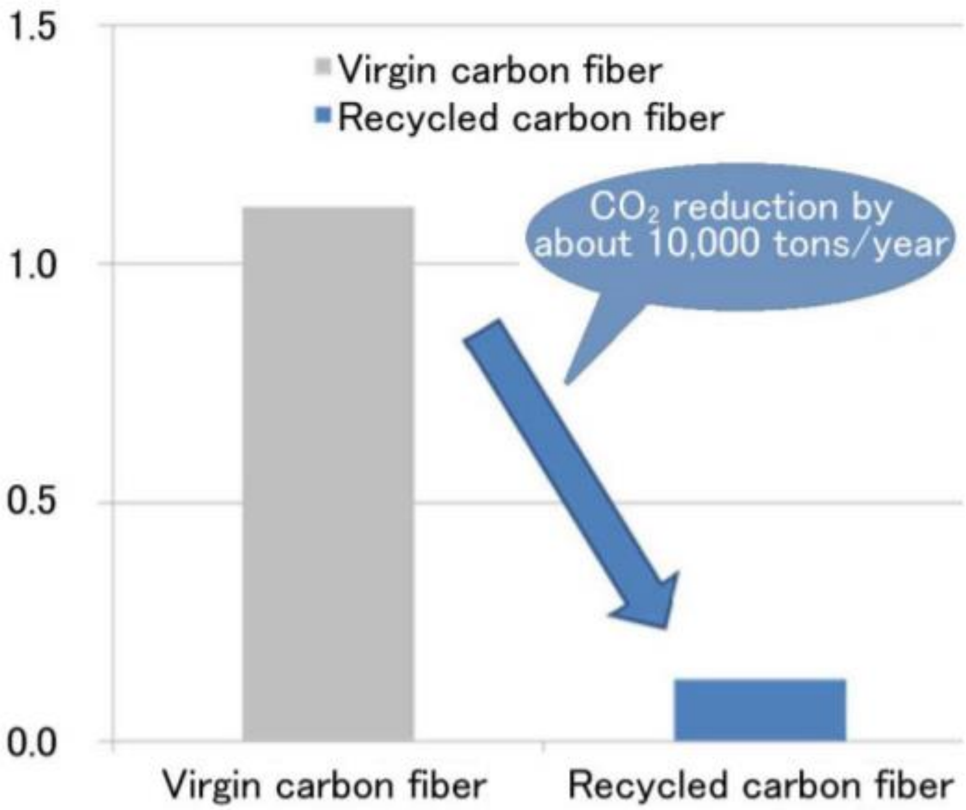

Fig. 4.5 - CO2 emissions reduction effect of recycling our CFRP waste materials

PART 5.
LABOR PROTECTION

Introduction

This diploma work is based on several experimental and practical investigations. They should be performed by well-educated and experienced specialists in order to prevent any impact on human health and life. The subject of this work is technician working in approved Part-145 aviation maintenance organization performing base and linear maintenance of the aircrafts. In this chapter will be considered working conditions and safety precautions for it's workers.

5.1 Analysis of working conditions

Working conditions on workplace, safety of engineering procedures, machines, mechanisms, the equipment and other means of production, condition of the means of collective and individual protection used by the worker and also sanitary living conditions shall meet the requirements of the legislation. The absence of one or more of this factors can be dangerous and lead to human injuries or even death.

Depending on the nature and intensity of this factors the influence on human health will be different. Some of them can lead to serious physical injuries and other's have not less important influence on psychological aspects of human health. Workers in the industries with the lowest levels of compliance with the labor protection and precaution are the most potentially subjected to the undesirable consequences. It is important for every employer to provide proper system of labor precaution instruments and make sure that every worker is acquainted with them.

5.1.1 Workplace organization

The maintenance hangar is designed for 40-50 persons. It's total area is equal to:

$$A = a \cdot b [m^2]$$

$$A = 90 \cdot 80 = 7200 [m^2]$$

Where a – length and b – width (Fig.5.1)

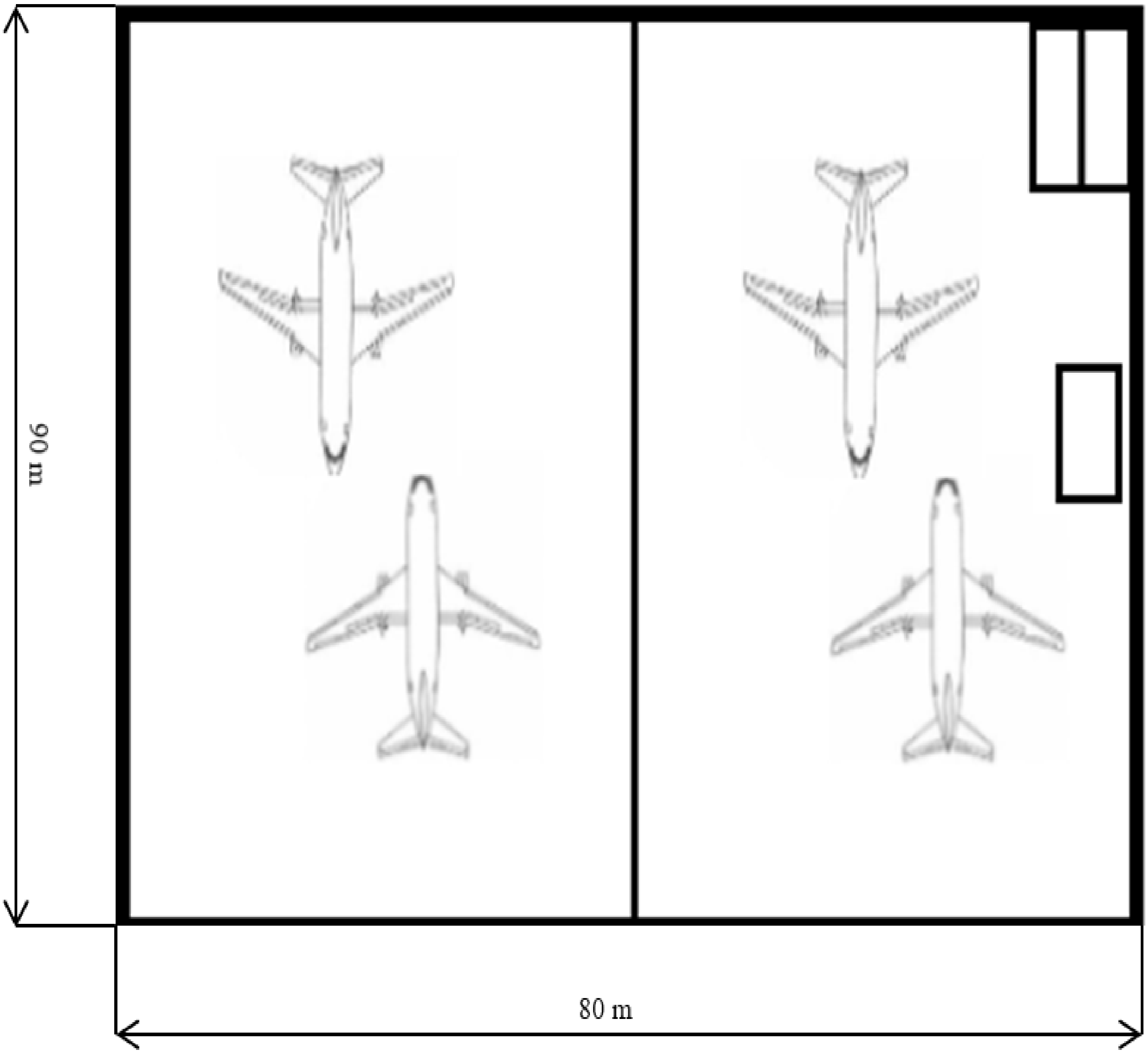

Fig.5.1- Hangar layout

The working area of one worker is equal to:

$$A_{worker} = \frac{A}{n}[m^2]$$

$$A_{worker} = \frac{7200[m^2]}{40} = 180m^2$$

Where n – number of workers.

Perimeter of the hangar is equal to:

$$P = 2a + 2b[m]$$

$$P = 2 \cdot 90 + 2 \cdot 80 = 340[m]$$

All dimensions are approved by building codes of Ukraine ДБН В.2.6-198:2014 “Metal constructions”.

The hangar is equipped with 150 ceiling lights, gates for taxiing the aircraft inside or outside the hangar, floor heating system, module for tools and equipment storage, different types of sockets with different voltage, system of overhead cranes.

The most preferable microclimate is:

- Air temperature 18°C;
- Air velocity - 0,1 m/s;
- Relative humidity – 30-50%.

In order to maintain such values the air ventilation and heating systems are used.

There are different sources of noise including noise from the hydraulic system, tools and machines, aircraft engines (during check procedures), special vehicles, aircrafts landing/take-off on the nearby runway, air conditioning systems and electronic equipment.

The hangar is equipped with first aid kits. Also the hangar is equipped with fire detecting, fire fighting systems and different types of fire extinguishers.

5.1.2 The list of harmful and hazardous factors

From the state regulation ДНАОП 0.00-5.28-03 “Інструкція з охорони праці під час виконання робіт на висоті з використанням спеціальних страхувальних засобів” and hygienic standarts ГН від 08.04.2014 №248 “Гігієнічна класифікація праці за показниками шкідливості та небезпечності факторів виробничого середовища, важкості та напруженості трудового процесу” we can underline next harmful and hazardous factors:

- Working with mechanisms, ramps, ladders;
- Noise, ultrasonic vibrations, radiation from airborne and airfield radar systems, high frequency radio transmitters;
- Working at height;
- High or low temperature;
- High or low humidity;

- Overvoltage in the electrical network;
- Poor lighting of the working area;
- Chemical liquids;
- Physical tiredness due to overloading;
- High static voltage;
- Psychological stresses;
- Ultrasound, production noise.

5.1.3 Analysis of hazardous and harmful factors

According to the above listed factors we can subdivide them on groups and provide adequate and necessary means in order to prevent any possible dangerous situation.

The analysis of this factors is shown below.

5.1.3.1 Microclimate of the hangar

The microclimate parameters of the hangar are subjected to change during the working day. This changes is the result of opening/closing the hangar gates. Considering this fact, we should analyze two cases separately.

<u>1-st case</u>:

	Optimal	Actual
Air temperature °C	18°C	15°C
Air humidity %	30-50%	37%
Air velocity m/s	0.1 m/s	0.1 m/s

Table 5.1(a). Comparison of microclimate parameters (Gates closed)

2-nd case:

	Optimal	Actual
Air temperature °C	18°C	5°C
Air humidity %	30-50%	32%
Air velocity m/s	0.1 m/s	0.5 m/s

Table 5.1.(b) Comparison of microclimate parameters (Gates opened)

Table 5.1.(a) shows that all microclimate parameters are within the limits. This conditions are optimal for human activity and provide a better quality of any type of work.

Table 5.1.(b) shows that air humidity is within the optimal limits. The attention is attracted to the air velocity and especially air temperature inside the hangar. This parameters are not allowable and require some means in order to prevent undesirable effect.

In order to minimize the risks, all staff should be announced about the gates opening and be ready for rapid temperature and air velocity change. The features of the aircraft maintenance hangar exclude additional air heaters installation due to their ineffectiveness.

The only way to decrease impact of the cold temperature is to ensure that every worker is dressed in warm workwear provided by the employer. Additionally, the qualification of the staff and rate of taxiing the aircraft inside/outside the hangar directly affects on the normalization of microclimate inside the hangar.

It is although important to emphasize that this analysis was accomplished in winter period. The actual microclimate parameters for summer period can differ.

5.1.3.2 Working on height

According to ДНАОП 0.00-5.28-03 “Інструкція з охорони праці під час виконання робіт на висоті з використанням спеціальних страхувальних засобів “ the safety measures should be provided.

Almost 70% of aircraft maintenance requires different type of ramps, ladders due to working on height. Correspondently, this factor is one of the most important and the additional safety means should be provided to minimize the risk of physical damage to the worker or even death.

The term designated as “working on height” is type of work when the altitude from the ground is greater than 1.3m.

The main precaution measures are given and described below.

- Only special ramps and ladders are to be used in all cases for maintenance of high elevated parts of the aircraft;
- When working at heights above 1.3 m, use safety harnesses, snap hooks and special ropes that are attached to the safety nodes;
- Safety belts must have a length regulation, label with the date of the next test. The snap hook must be provided with a safety device to prevent self-opening;
- When it is necessary to carry out short-term work at height without a barrier or when it is impossible to install a barrier, it is mandatory to use safety harnesses. An employee who is not engaged in other work and is ready to help the person working at height must be present at the place where such work is to be performed.

5.1.3.3 Chemical liquids

It is known that chemical liquids may cause serious damage to the human health. This damage can be external (skin damage, eyes damage, etc.) and internal (lungs damage, immune system and nervous system damage).

Chemicals can enter and irritate the nose, air passages and lungs. They can become deposited in the airways or be absorbed by the lungs into the bloodstream. The blood can then carry these substances to the rest of the body. Ingestion (swallowing) of food, drink or other substances is another route of exposure.

Studies have proved that ED, such as bisphenols, phthalates, triclosan, propanil, tetrachlorodibenzo-p-dioxin, diethylstilbestrol, tributyltin, and parabens can affect the development, functions, and lifespan of immune cells

Depending on the chemical, these longer-term health effects might include:

- organ damage.
- weakening of the immune system.
- development of allergies or asthma.
- reproductive problems and birth defects.
- cancer.

The workers in the aircraft maintenance hangar should be protected due to wide application of different types of aircraft greases, lubricants, hydraulic liquids and other dangerous mixtures.

The means of safety precaution are described below.

According to state regulations НПАОП 0.00-4.12-05 “Правила безпеки праці під час роботи з пально-мастильними матеріалами та спецрідинами” the following measures should be provided:

- Use personal protective equipment (rubber gloves, aprons, sleeves) if necessary use protective goggles and respirators;
- Use protective ointments to protect exposed parts of the skin;
- Avoid contact of hot lubricants with the skin;
- In case the grease gets on your skin, wash it off with soap and water;
- In case of contact of grease with eyes, rinse them immediately with plenty of water;
- Do not spill lubricants, fuels, slurries, synthetic oils on the ground
- Work with special liquids must be carried out in personal protective equipment. If the fluid gets on your skin, you should wash these places with warm water and soap or saline solution. If the fluid gets into the eyes you need to rinse them immediately with a special saline solution or rinse the affected eye for 20 minutes with warm running water.

5.2 Fire safety of the hangar

According to the state regulations: ДСТУ 2272:2006 “Пожежна безпека. Терміни та визначення основних понять”, ДСТУ 2273:2006 “Протипожежна техніка. Терміни та визначення основних понять” ДСТУ ISO 6309:2007 “Протипожежний захист. Знаки безпеки. Форма та колір” (ІБО 6309:1987, ЮТ) the maintenance hangar should be secured by several fire prevention, protection means in order to minimize risks and possible human health damage or human death.

Referring to ДСТУ Б В.1.1-36:2016 «Визначення категорій приміщень, будинків та зовнішніх установок за вибухопожежною та пожежною небезпекою» the maintenance hangar is assigned to the “A” explosion-fire hazardous category.

As it was mentioned above, the hangar is equipped with fire detecting, fire fighting systems and different types of fire extinguishers. The emergency evacuation can be performed through several emergency exits located in many places of the building.

The evacuation scheme is shown below.

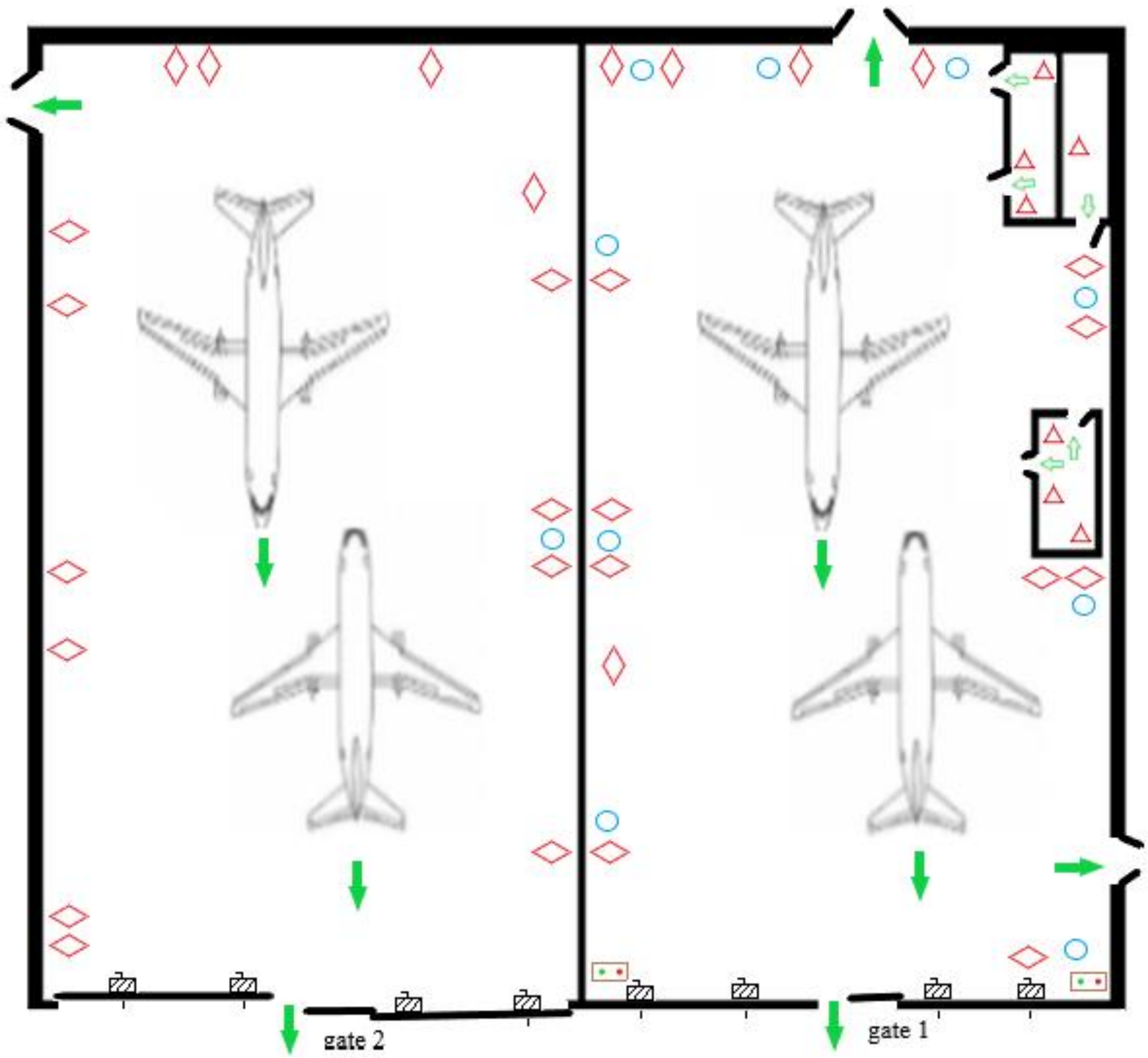

Fig.5.2. Evacuation scheme

Legend

- portable fire extinguisher
- mobile fire extinguisher
- fire hydrant
- gate opener
- electromechanical drive with a lever for a manual gate opening

The approximate distance to evacuation exit is 5-15 meters. This allows to leave the hangar in case of any emergency situation for less than 30 seconds. Such values gives a good chance for safety evacuation and avoiding any potential suffered. All of the emergency exits are in visual contact and labeled well. In the middle part of the gates there exist emergency evacuation door for fast evacuation and additionally electromechanical levers for gates opening in order to save the aircrafts from the fire when the main electrical system of gates opening is cut-off.

Conclusion to part 5

In this chapter the aircraft maintenance hangar was examined for satisfying the requirements of state labor protection rules and laws.

The workers of the hangar should be examined for the instructions of fire safety, working on height, working with chemical liquids and fluids understanding.

Fire detecting, preventing and fighting systems should be examined for their workability and suitability.

GENERAL CONCLUSION

Improving the strength and durability characteristics can be achieved by reducing the percentage of silicon and iron, as well as by adding zirconium and lithium.

Lanthanum additions must be made with some care. If the lanthanum additions are insufficient to getter all of the sulfur, then other sulfides will be formed. If the steel is low in manganese, as is AF1410, then small, closely spaced chromium sulfides will be formed and the toughness will be less that one would obtaion with an optimum lanthanum addition.

Unlikely, if too much lanthanum is added, it is possible the inclusion volume fraction will be excessive.

Among the functional properties of materials when choosing them for the production of the aircraft, first of all, it is necessary to highlight: static strength, fatigue durability, viability of destruction, specific strength, corrosion drainage. It is these indicators that are sold out when searching for analogues of traditional materials, which for decades have been used in domestic aircraft construction.

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