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
ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ «МАГІСТР»
ЗІ СПЕЦІАЛЬНОСТІ:
«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Конструкція шпангоуту пасажирського далекомагістрального літака»

Виконавець: __________ **Анастасія ДОВБНЯ**

Керівник: к.т.н., доц. __________ **Тетяна МАСЛАК**

Консультанти з окремих розділів
пояснювальної записки:
охорона праці:
к.біол.н., доц. __________ **Вікторія КОВАЛЕНКО**

охорона навколишнього середовища:
д.т.н., доц. __________ **Тамара ДУДАР**

Нормоконтролер: к.т.н, доц. __________ **Сергій ХИЖНЯК**

Київ 2021

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
DEPARTMENT OF AIRCRAFT DESIGN

PERMISSION TO DEFEND
Head of the department,
Professor, Dr. of Sc.
_________ Sergiy IGNATOVYCH
«___» _______________ 2021

MASTER DEGREE THESIS
ON SPECIALITY
"AVIATION AND AEROSPACE TECHNOLOGIES "

Topic: "Conceptual design of the frame for the passenger long range aircraft"

Fulfilled by:	___________	**Anastasiia DOVBNIA**
Supervisor: **PhD, associate professor**	____________	**Tetiana MASLAK**
Labor protection advisor: **PhD, associate professor**	____________	**Victoria KOVALENKO**
Environmental protection adviser: **Dr. Sc., professor**	____________	**Tamara DUDAR**
Standards inspector **PhD, associate professor**	____________	**Sergiy KHIZNYAK**

Kyiv 2021

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Аерокосмічний факультет
Кафедра конструкції літальних апаратів
Освітній ступінь «Магістр»
Спеціальність 134 «Авіаційна та ракетно-космічна техніка»
Освітньо-професійна програма «Обладнання повітряних суден»

ЗАТВЕРДЖУЮ
Завідувач кафедри, д.т.н, проф.
__________ Сергій ІГНАТОВИЧ
«_____» _____________ 2021 р.

ЗАВДАННЯ

на виконання дипломної роботи студента

ДОВБНІ АНАСТАСІЇ ВІКТОРІВНИ

1. Тема роботи: «Конструкція шпангоуту пасажирського далекомагістрального літака», 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: максимальна кількість пасажирів 460, дальність польоту з максимальним комерційним навантаженням 11000 км, крейсерська швидкість польоту 905 км/год, висота польоту 11 км.

4. Зміст пояснювальної записки: аналіз навантажень та ролі шпангоутів у конструкції літака, аванпроект далекомагістрального літака високої пасажиромісткості, проектування типового шпангоуту для задньої секції фюзеляжу літака.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: креслення загального виду пасажирського літака, складальне креслення шпангоута.

6. Календарний план-графік:

№	Завдання	Термін виконання	Відмітка про виконання
1	Огляд літератури за проблематикою роботи. Аналіз варіантів конструкції шпангоутів для пасажирських літаків.	11.10.2021–13.10.2021	
2	Проведення досліджень та розрахунок параметрів літака.	14.10.2021–20.10.2021	
3	Дослідження та підбір оптимальних параметрів конструкції шпангоутів.	21.10.2021–24.10.2021	
4	Проєктування шпангоута в CAD-системі Catia.	25.10.2021–15.11.2021	
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.	30.11.2021–31.12.2021	

7. Консультанти з окремих розділів:

Розділ	Консультант	Дата, підпис	
		Завдання видав	Завдання прийняв
Охорона праці	к.біол.н., доцент Вікторія КОВАЛЕНКО		
Охорона навколишнього середовища	д.т.н, доцент Тамара ДУДАР		

8. Дата видачі завдання: 8 жовтня 2021 року

Керівник дипломної роботи ____________ Тетяна МАСЛАК

Завдання прийняв до виконання ____________ Анастасія ДОВБНЯ

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty
Department of Aircraft Design
Educational Degree «Master»
Specialty 134 «Aviation and Aerospace Technologies»
Educational Professional Program «Aircraft Equipment»

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

TASK

for the master degree thesis

Anastasiia DOVBNIA

1. Topic: «Conceptual design of the frame for the passenger long range aircraft», approved by the Rector’s order № 2173/ст from 8 October 2021.
2. Period of work: since 11 October 2021 till 31 December 2021.
3. Initial data: 460 passenger capacity, maximum flight range 11000 km, cruise speed 905 km/h, flight altitude 11 km.
4. Content: analysis of loads and the role of frames in the design of the aircraft, preliminary design of long range aircraft with high passenger capacity, design of a typical frame for the rear section of the aircraft fuselage.
5. Required material: drawings of the general view of the passenger aircraft, assembly drawing of the frame.

6. Thesis schedule:

№	Task	Time limits	Done
1	Analysis of the frame tasks, loads on the frame, frame construction	11.10.2021–13.10.2021	
2	Preliminary design of a long range passenger aircraft.	14.10.2021–20.10.2021	
3	Design of the fuselage construction.	21.10.2021–24.10.2021	
4	Construction of a frame in the Catia CAD system.	25.10.2021–15.11.2021	
5	Performing of the special parts, devoted to the environmental and labor protection.	16.11.2021–21.11.2021	
6	Preparation of illustrative materials, drawings and report.	22.11.2021–29.11.2021	
7	Explanatory notes checking, editing and correction.	30.11.2021–31.12.2021	

7. Special chapter advisers:

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

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

Supervisor: ____________ Tetiana MASLAK

Student: ____________ Anastasiia DOVBNIA

РЕФЕРАТ

Пояснювальна записка дипломної роботи магістра «Конструкція шпангоуту пасажирського далекомагістрального літака»:

с., рис., табл., джерел

Дана дипломна робота присвячена розробці аванпроекту пасажирського літака для далекомагістральних авіаліній, що відповідає міжнародним стандартам польотів, нормам безпеки, економічності та надійності, а також проектування типового шпангоуту для задньої секції пасажирського далекомагістрального літака.

В роботі було використано методи аналітичного розрахунку, комп'ютерного проектування за допомогою CAD/CAM/CAE систем, ескізного проєктування шпангоута з використанням технічних даних подібних пристроїв.

Практичне значення результату дипломної роботи магістра полягає у підборі найдоцільнішої конструкції та способу виготовлення типового шпангоута літака. Матеріали дипломної роботи магістра можуть бути використані в навчальному процесі та в практичній діяльності конструкторів спеціалізованих проектних установ.

Дипломна робота, аванпроект літака, компонування, центрування, типовий шпангоут, розрахунок навантажень для шпангоута

ABSTRACT

Master degree thesis "Conceptual design of the frame for the passenger long range aircraft"

pages, figures, tables, references

This master thesis is dedicated to preliminary design of long range passenger airplane and the design of a typical frame for the rear section of a long range passenger aircraft.

The design methodology is based on prototype analysis to select the most advanced technical decisions, engineering calculations to get the technical data of designed aircraft and computer based design using CAD/CAM/CAE systems. In special part sketch design of the frame is constructed using the technical data of such devices.

Practical value of the result of the master's thesis is the selection of the most appropriate design and method of manufacturing a typical aircraft frame. The materials of the master's diploma can be used in the aviation industry and in the educational process of aviation specialties.

Master thesis, preliminary design, cabin layout, center of gravity calculation, frame design, stress-strain calculation

CONTENTS

INTRODUCTION

The topic of the diploma thesis is the “Conceptual design of the frame for the passenger long range aircraft”.

Nowadays, the long range flights have their own specific area at the aviation market. The long-haul flights are demanded for transatlantic flights, for the flights from USA to Canada, to the South America and East market, especially China market. Long-haul aircraft allows transporting a great number of passengers and cargo at long distance without refueling. It helps transport company to save money and time.

The subject of my investigation is the preliminary design of long-haul aircraft with the 460 passenger capacity for 11 000 km of flight range. For the long range aircraft, the number of structure elements increases with the dimension of the fuselage cabin. So, the detail design of the fuselage structure element will make a huge impact on the total mass of the structure, but from other side the strength and stiffness of the airframe is the key requirement to any aircraft element.

The object of the diploma work will be the frame design for wide-body aircraft with sizing and stress-strain analysis of it. The design of main elements is based on the analysis of the fuselage frame types and design, their loads in operation. The design of the fuselage formers with optimal strength and mass parameters for a long-haul passenger aircraft, will give the possibility to simplify manufacturing of fuselage structure with the cheapest and fastest methods.

PART 1. THE FUSELAGE STRUCTURAL LAYOUT AS A COMPLEX TASK OF AIRCRAFT DESIGN PROCESS

1.1. Design criteria in the fuselage structure

Aircraft design process generally comprises three main stages after the requirements stage: conceptual, preliminary and detailed design phase. At my diploma paper I will consider a preliminary phase of a long range passenger aircraft with the detail design of the fuselage structure.

The main tasks of the presented fuselage design are accommodation of the crew, passengers, baggage, equipment and systems.

When designing any aircraft, basic requirements must be met in order to ensure the integrity of the structure and the safety of the flight. The following requirements are presented to the aircraft fuselage, as to the main body [1]:

- to reduce the drag of the aircraft in flight, all the units of the aircraft should be smoothly connected, there should be no sharp corners, irregular bends, there should be no open slots, and the surface should also be smooth. Such requirements are called aerodynamic (Fig. 1.1).

- with the maximum weight and correctly positioned structural elements, the maximum strength and integrity of the structure must be ensured. Such requirements are called structural integrity requirements.

- the scale of production and general construction materials, which include the limiting dimensions and materials of the workpieces, the general production requirements, the processes required for production, the degree of standardization and technological characteristics of the fuselage are determined by the manufacturing requirements.

- all requirements which are related to equipment, emergency and main exits, cockpit visibility, passengers comfort airplane life-span are called operational requirements.

- all efficiency parameters of airplane manufacturing and operating related to technical and operational requirements. It includes traffic handling cost, fuel efficiency ratio, the cost of a flight hour and etc.

More detailed explanation of the main requirements are presented below [2]:

- low aerodynamic drag,
- to minimize aerodynamic instability,
- to provide the most comfortable design of passenger seats and places for storage
- to provide safety for passengers, crew and flight attendant during emergency situations
- to provide safe cargo doors and hatches and to ease process of handling in loading and unloading for personal
- to provide the structural stability under the action of wing and tail forces during take off, flight and landing
- to provide weight normalization of the sytructure after anti-icing and anti-corrosion procedures
- to prevent the crew fatigue and passenger intrusion by the way of flight deck optimization
- comfortable placing of common areas, such as lavatories, galleys and coat racks
- to provide the safe environment by the way of control the level of noise and all sounds
- to provide comfortable climate conditions for passengers and crew

to foresee the posibility of placing main and additional equipment and systems such as air condition system, electrical system, ram air turbine, etc.

When the requirement stage finish, the conceptual phase will start. At this stage (sometimes it is called external design), on the basis of parametric studies of promising aircraft as elements of the transport system, analysis of their interaction with the components of the complex in which they will operate, the required general characteristics of the future aircraft are predicted. At the same time, multivariate calculations are carried out to determine and optimize the technical and economic indicators of the operation of the proposed aircraft on the planned network of air routes.

As a result of this work, the necessary technical, economic and tactical and technical characteristics of the aircraft are determined, which make it possible to formulate the technical task (TT). It should be emphasized that the reasonable assignment of requirements largely determines the success of the program for the creation of a new aircraft [3].

After the requirement and conceptual stage it is possible to start the preliminary design stage [4].

The purpose of this design stage, called the development of TT (preliminary design), is to select a scheme and determine the most advantageous combination of the main parameters of the aircraft and its systems that ensure the fulfillment of the specified requirements, or justify the need to adjust them. At this stage, on the basis of the analysis of the technical task, the ideas of the chief designer, the experience of the design bureau, the concept of the aircraft is formed, and its preliminary design is developed. At the same time, in the first approximation, the main geometric, weight and energy characteristics of the projected aircraft are determined, as well as the laws of its control in various parts of the trajectory for various flight profiles provided for by the requirements are formed. This is the stage of synthesis of the appearance and determination of the basic dimensions of the aircraft, in the process of which various aspects of aircraft design are linked together, concerning the study of its geometric, weight, aerodynamic characteristics, altitude, speed and throttle characteristics of engines, structure of equipment and equipment, flight technical data and flight trajectories.

The output information of this stage are drawings of general views of a rational version of the aircraft, as well as documentation on its flight technical, economic and operational characteristics. Based on these materials, the competent authorities decide on the feasibility of further development of the project.

During the assembly process, the aircraft alignment is specified, the calculation of which is preceded by the compilation of a weight report based on the strength and weight calculations of the airframe and power plant units, lists of equipment, equipment, cargo, etc. aircraft. Models of an aircraft and its individual units are made and blown in wind tunnels. Based on the results of these studies, aerodynamic calculations, stability and controllability calculations, as well as aeroelasticity characteristics are defined. Based on these calculations, appropriate corrections are made to the layout of the aircraft, and the weight calculations are specified. A mock-up of the aircraft is being built, which makes it possible to make mutual spatial coordination of the aircraft's units and systems, the placement of equipment, and to evaluate the convenience of the accommodation of the crew and passengers.

The detailed design is the final stage of the design process [4]; it is aimed at the practical implementation of the declared characteristics and parameters of the aircraft. Necessary for manufacturing, assembling and installing technical documentation is issued at this stage. Drawings of general types of aircraft units, assembly and detailing drawings of its individual parts are being developed. Before this stage starts, all necessary researching works, dynamic and static experiments, materials characteristics and equipment bench experiments are conducted.

Fig. 1.1 - Airplane model streamlining test

The data of external loads, first iteration of geometry calculations and structure of the aircraft give possibility to build the master-geometry of aircraft model and perform the stress-strain analysis. CAD/CAM/CAE programs could perform the simulation of the loading of the structure, to simulate the static and fatigue test, aerodynamic tests in the airflow. One of such models is shown at Fig 1.1 [5].

The basic layout of the structure starts from the evaluation of loads, which act on the structure during the operation of the aircraft according to its category and permissible regimes of flight. The aircraft design process begins from the day when the idea of introducing a new design appeared and continues until the moment when the aircraft receives all the documentation approved by the civil aviation authority (FAA, ICAO, etc.)

1.2. Fuselage load cases

It is necessary to consider the options for loading the fuselage and the typical loads to which the aircraft lends itself to the development of the fuselage. loads can be both concentrated and distributed. They are also divided into static and dynamic loads (Fig. 1.2).

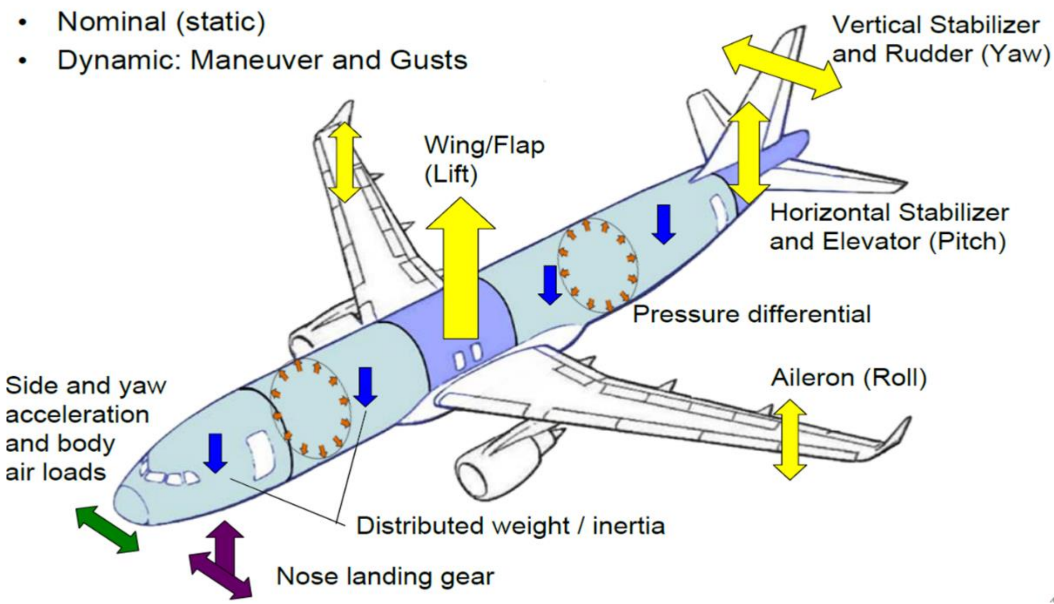


Fig. 1.2 - Fuselage primary loads

During flight and landing next forces acting on the fuselage [6]:

- aerodynamic forces of the air flow that acts directly on the;
- aerodynamic and mass loads from the wing, tail, landing gear and other units attached to the fuselage (forces thrust of engines, launch boosters, brake parachutes, etc.);
- distributed over the surface aerodynamic forces;

- forces of overpressure in pressurized cabins, air channels of engines and fuselage compartments included in its power circuit.

There are basic cases of fuselage loading: [6]

- flight cases (symmetric maneuver and gust loads, lateral gust, horizontal tail elevator deflection, side slipping flight)
- ground cases (three-point landing, two-point landing, abrupt ground breaking)
- cabin pressurization (1.33 times normal pressurization)

In addition to the basic cases there are particular load cases, which are presented in the Table 1.1

Table 1.1. – Unit load cases

	Unit Load Cases (ULC)	Load
ULC1	Cabin Pressurization	Pressurization (no aerodynamic loads, no weights)
ULC2	1G	Weight (no aerodynamic loads, no pressurization)
ULC3	Lateral Gust	Vertical tail side gust (no weight, no pressurization)
ULC4	Symmetrical Horizontal Tail Deflection	100-100% distribution downward (-) and upward (+) (no weight, no pressurization)
ULC5	Side Slipping Flight	Vertical tail reaction (no weight, no pressurization)
ULC6	Three-point Level Landing	Weight, nose landing gear reaction (no aerodynamic loads, no pressurization)
ULC7	Abrupt Ground Breaking	Weight, nose landing gear reaction and horizontal distributed acceleration (no aerodynamic loads, no pressurization)

Considering the types of loads listed above, the following combinations of fuselage loading can be distinguished (Table 1.2):

Table 1.2 Fuselage loading combinations

	Combined Load Cases (CLC)	ULC
CLC8	-1G Maneuver	-ULC2
CLC9	-1G Maneuver + Cabin Pressurization	-ULC2+ULC1
CLC10	2.5G Maneuver	2.5ULC2
CLC11	2.5G Maneuver + Cabin Pressurization	2.5ULC2+ULC1
CLC12	Lateral Gust + Cabin Pressurization	ULC3+ULC1
CLC13	-Lateral Gust + Cabin Pressurization	-ULC3+ULC1
CLC14	Horizontal Deflection Upward + Cabin Pressurization	ULC4+ULC1
CLC15	1G Maneuver + Horizontal Deflection Upward	ULC2+ULC4
CLC16	1G Maneuver + Horizontal Deflection Downward	ULC2-ULC4
CLC17	1G Maneuver + Cabin Pressurization+ Horizontal Deflection Downward	ULC1+ULC2-ULC4
CLC18	1.33 times Cabin Pressurization (1.33×Δp)	1.33ULC1

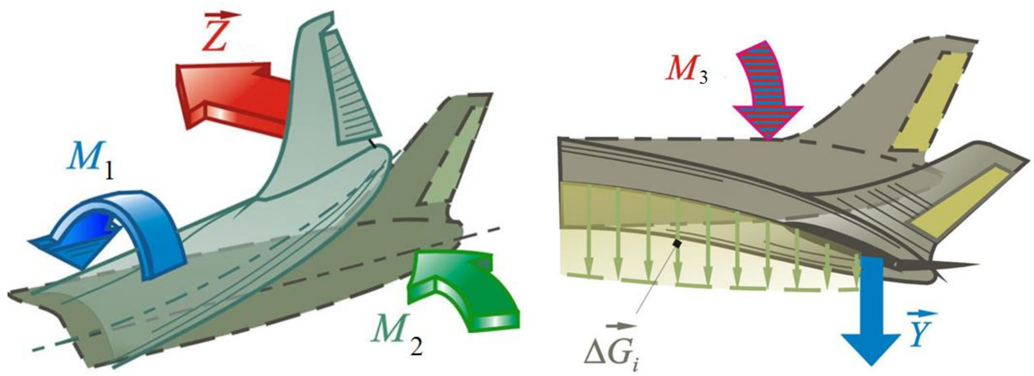
All loads in the fuselage are fully balanced. From the structural mechanic's point of view, the fuselage is presented as a fixed to the wing beam loaded by the loads above. At any section of this beam torque, bending moment and vertical and horizontal shear forces act. Forces from the excessive internal pressure are added to these loads in the sealed compartment.

Fuselage loading from the aerodynamic forces, from the distributed mass forces of structure, the engine thrust are not so excessive and are not the main loads for the full strength analyses of the fuselage. The main types of loads are aerodynamic forces from the wing and from the tail unit:

1. Aerodynamic forces from the wing act on the forward and aft spars of the wing center section, and transmitted to the fuselage frames by the wing-fuselage attachments (by the docking joints)

2. Aerodynamic balance forces and maneuvering forces from the tail unit.

Two special cases of fuselage loading from maneuvering forces from the tail unit are presented in the Fig 1.3: 1) fuselage loading in horizontal plane due to deflection of rudder 2) fuselage loading in vertical plane due to deflection of elevators.



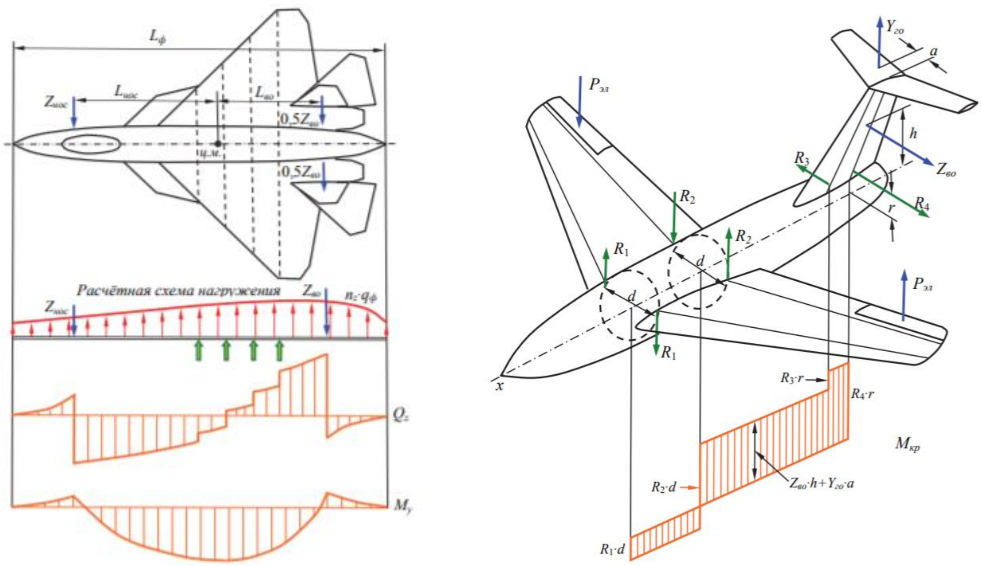
a) b)

Fig.1.3. - Loading of the fuselage rear part by the deflection of control surfaces:
a) fuselage loading in horizontal plane; b) fuselage loading in vertical plane.

Maneuvering side force Z, which is initiated by the deflection of rudder, is applied in the center of pressure of vertical tail and tries to bend the rear part of the fuselage in horizontal plane (M_2 – bending moment) and it also tries to twist rear part of the fuselage by the twisting moment M_1. Fuselage tail part is under the bending and under the torsion around longitudinal axis due to the deflection of rudder.

The fuselage loading in vertical plane is explained by balance force of the stabilizer and maneuvering force Y due to the deflection of elevators. Concentrated balance force of the horizontal tail Y, distributed mass force Gi - mass of the fuselage structure, mass of payload, mass of equipment.

The next step of the fuselage loading analysis is the distribution of shear force, bending moment and torsion moment along the length of the aircraft. As example, at the Fig. 1.4 the diagrams of Q, M_{bend}, M_{tors} are presented for the case of fuselage loading in horizontal plane.



a) b)

Fig. 1.4 - Diagrams of forces and moments for the fuselage loading in horizontal plane: a) Q, M_{bend}, b) M_{tors}

On the vertical tail, when the rudder is deflected, an aerodynamic force Y arises, directed in the opposite direction of the rudder deflection. The aircraft is rotated about the vertical axis Oy with angular acceleration ε_y under the maneuvering loads of vertical tail unit Z. Under the action of side forces, in center of gravity we receive the side load factor n_{zn} and in the other points under the action of angular acceleration we receive increment of side load factor. Y force also induces a bending moment and shear force, acting in the horizontal plane.

Since the aerodynamic force of the vertical tail is applied above the axis of symmetry of the fuselage, in addition to the bending moment and the shear force, the fuselage is also affected by the torsion moment tending to twist the fuselage.

As it seen from the diagrams, the most loaded part of the plane is the cross section of the fuselage where wing is attached to the fuselage.

According to the analyzed information about loads can be pointed basic loads types acting on certain elements of fuselage structure. It is presented on Fig. 1.5

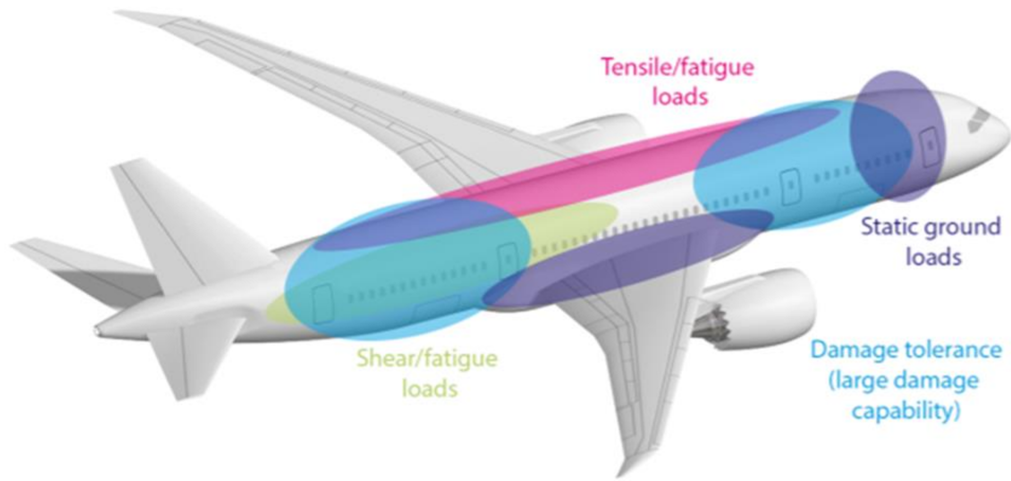


Fig. 1.5 - The dominant load cases and design criteria in the fuselage structure

As a result, it is important to understand that loading variations of the fuselage, both concentrated and distributed loads, help to form an overall picture of loading and scenarios of structural damage. Based on (Fig. 1.5), we can conclude:

- the fuselage area near the landing gear is most susceptible to static ground loads, which are insignificant for other areas.

- the upper part of the fuselage is subject to longitudinal tension, since the wing bends the fuselage downward under its own weight. With increasing pressure and circumferential stress, tensile and fatigue loads will be concentrated mainly on the top of the fuselage.

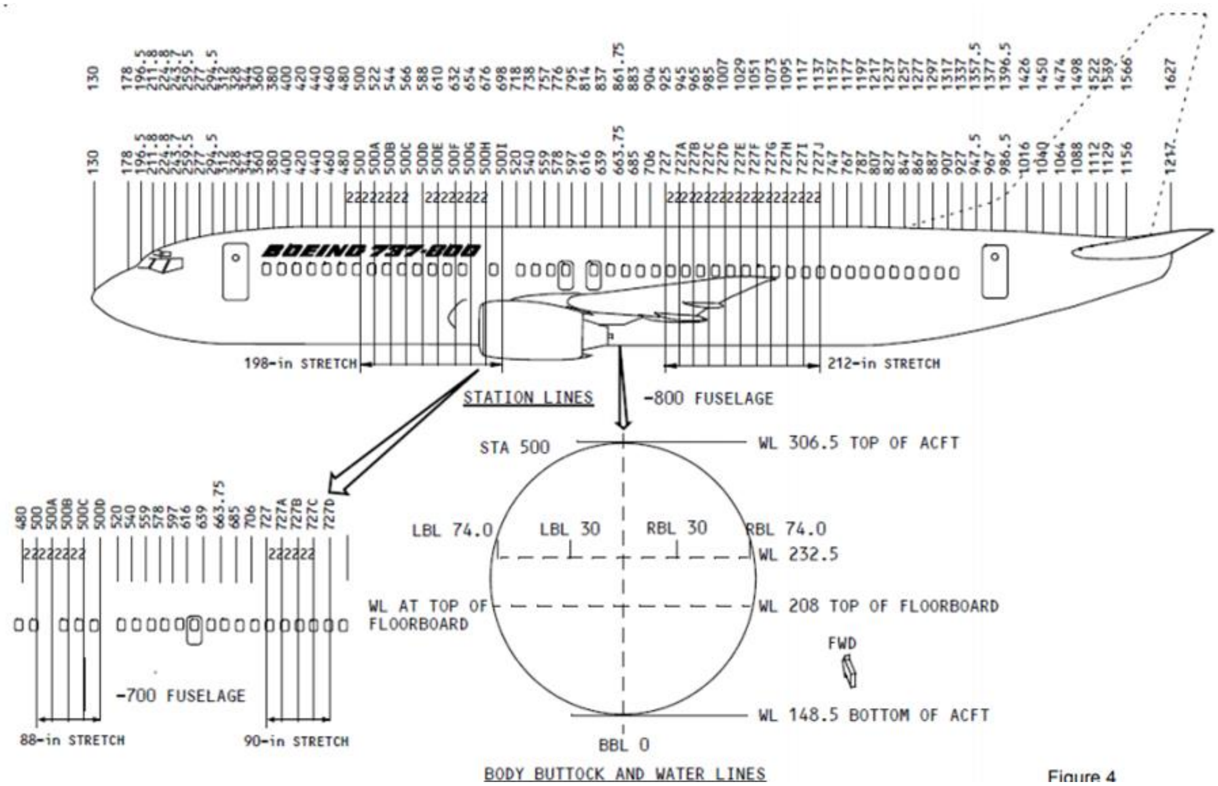
- as a result, the lower part of the fuselage is subjected to compression, which is the main criterion for the stability of the aircraft.

- since the aft fuselage is connected to the tail, it will be most susceptible to lateral and fatigue loads that arise as a result of loads created by the deflection of the control surfaces on the tail [7].

1.3. Frame as a main beam of the fuselage

The fuselage of the aircraft being designed, which is a semi-monocoque structure, can be conditionally divided into 6 sections. This is done for convenience in navigating the aircraft.

The sections are divided by frames (Fig. 1.6), this is one of their functions during the design and maintenance phase.



Figure

Fig. 1.6 - Schematic presentation of frames and section dividing

From a design point of view, the importance of using frames is that, firstly, it defines and supports the shape of the fuselage (Fig. 1.7). For these purposes, typical frames (formers) are used. They take on aerodynamic loads and internal pressure, so, it strengthens the skin. Depending on the geometric and strength parameters of the fuselage, the pitch of installing the frames is selected. The pitch of the frames is varied from 150 to 600 mm [8].


Fig. 1.7 - Real frame’s view

The second type of the frames is reinforced frames (bulkheads). It is intended for concentrated forces perception. Zones of connection of heavy equipment (Fig. 1.8) or zone of connection wing with the fuselage are zones of the aircraft with high level of concentrated loads, so there bulkheads are installed.


Fig. 1.8 - Installed bulkhead

Bulkheads can be as prefabricated as monolithic. Such type of the frames help to distribute the external loads along the skin, but itself works for bending and its cross section works under a shear too. Therefore, bulkheads are installed at the areas of large cutouts and in the role of the partitions at the pressurized compartments for excess pressure absorbing.

Conclusions to the part and the task for the research

This part contains general information about requirements to the aircraft design, possible ways of optimal fuselage shape achieving and design procedure suggestions.

The purpose of the diploma is the selection of the frame parameters, the selection of the most suitable manufacturing method for the frame, as well as the construction of the frame in Catia, taking into account the obtained results.

PART 2. PRELIMINARY DESIGN OF A HIGH SEATING CAPACITY LONG RANGE AIRCRAFT

2.1. Prototypes the designing airplane analysis and its description

Optimal design parameters choosing is the first step in idea of the airplane design creation. It is equally important to take into account the geometric, aerodynamic, economic and other technical characteristics. General view formation consists of two stages:

- at the first stage, information about the listed parameters is collected and analyzed. This step is called the statistical method;

- at the second stage, a complete aerodynamic calculation is performed for the main units.

In my work, I will consider a long-haul passenger aircraft, and in my opinion, the most successful options for prototypes are: Airbus A350-1000, Boeing 777-300 and Boeing 777-300ER. The Table 2.1 shows the main technical characteristics of the prototypes.

Table 2.1 Statistic Data of prototypes

Name and dimensions	Boeing 777-300	Boeing 777-300ER	Airbus A350-1000
Number of passenger	450	479	412
Crew, numbers	2	2	2
Range of flight with $m_{k\ max}$, km	11000	14600	15600
Cruising speed, Vkm/h	905	905	903
Wing span	60.9	64.8	64.8
Number and type of engines	2×R-R Trent 892	2×General Electric GE90-115B	2 ×R-R Trent XWB
Maximum flight altitude km	13.1	13.1	13.15
Cruising thrust, kN	440	513	411
Maximum take off weight t	299.4	351.8	308

The characteristics of the prototypes have minor differences, so it is necessary to select the optimal parameters for the designed aircraft.

So, the designed aircraft will have semi monocoque construction of the fuselage. The cross section has the circular form. The aerodynamic scheme was chosen cantilever low-wing. Since aerodynamics and weight balancing are important to the aircraft, I have chosen a double-hinged rudder design, in which the upper part is controlled by the surfaces of the control system, and the lower part is controlled by the pedal. Also, the rudder is equipped with trim and servo tabs. If the landing gear hydraulic system fails, the landing gear will extend mechanically.

The fuselage of the designing airplane is wide body, and its length is equal 73.9 m. It consists three parts, such as nose, main and tail part. The main task of the fuselage is to place equipment, baggage, cargo, passengers etc. As fuselage is main body of all aircraft, wing is attached to it.

The role of the wing in aircraft construction is so high. First of all it provides lift and airplane stability. Fuel tanks are located in wing. Type of wing, which are typpicaly for Boeing family, I have chosen for designed aircraft. It is sweepback wing with high aspect ratio. This type of wing was chosen by me because it is easy to maintain and good for extending and retracting the type of landing gear I have chosen.

For stabilization an airplane during flight the tail unit is used. It consists of vertical (rudder) and horizontal (elevator) stabilizers.

2.2. Aircraft geometry calculations and fuselage layout

The goal of aircraft layout is selectin the best satisfying parameters and scheme of an airplane. It is necessary to choose the relative disposition of all principal units of the aircraft.

2.2.1. Wing geometry calculation

For the preliminary design stage, we need the initial data. It is presented in Appendix A and were obtained on the basis of statistical data of prototypes and calculated in a special computer program of the department. Of course, the statistical factor for most of the aircraft will be taken into account.

The ratio of the take off weight to the area of the wing determines wing loading. I take necessary data from the Appendix A, so the wing area is [10]:

$$S_w = \frac{m_0 \cdot g}{P_0} = \frac{335686 \cdot 9{,}8}{5298} = 520.937\ (m^2)$$

Where

m_0 - take off weight;

P_0 – specific wing load.

Comparing the obtained values of the wing area and the wing area of the prototypes, it can be understood that the resulting theoretical value is significantly exceeded in practice value, so for my work I will use the wing area of 427.8 m2, based on the experience of the design bureau.

Since now there is a value for the wing area, I can find the length of the wing, given that the aspect ratio of the wing is 8.7 [10]:

$$l = \sqrt{S \cdot \lambda} = \sqrt{427.8 \cdot 8.7} = 61(m)$$

Where

S – area of the wing;

λ – aspect ratio.

According to equation [4], we can find the root chord of the wing:

$$b_o = \frac{2S_w \cdot \eta_w}{(1+\eta_w) \cdot l} = \frac{2 \cdot 427.8 \cdot 3{,}3}{(1+3{,}3) \cdot 61} = 10.76(m)$$

The value of the root chord is known, then tip chord is:

And then according to equation presented at method guide [4] the board chord is:

Wing consists of the skin, spars and ribs, so its type is called semi monocoque with two

$$b_t = \frac{b_o}{\eta_w} = \frac{10.76}{3{,}3} = 3.26(m)$$

$$b_{ob} = b_0 \cdot (1 - \frac{(\eta_w - 1) \cdot D_f}{\eta_w \cdot l_w}) = 9.996(m)$$

spars. Therefore, spars position nearer to the leading edge are located [10]:

$$\bar{x}_i = \frac{x_i}{b},$$

Where

x_i – distance of i-spars to the leading edge of the wing in current cross- section;

b – chord of the wing in the current cross section.

Wing with two spars: $\bar{X}_1 = 0{,}2$; $\bar{X}_2 = 0{,}6$ [10].

It is necessary to know, because the capacity of the fuel tanks and width of the torsion box, correspondently, determines by distance between spars.

So, other important parameter for the wing is mean aerodynamic chord (MAC). It can be determined in two ways, such as geometrical or with the help of formulas [30]. In our case more appropriate to use geometrical method. It is presented on Fig. 2.1

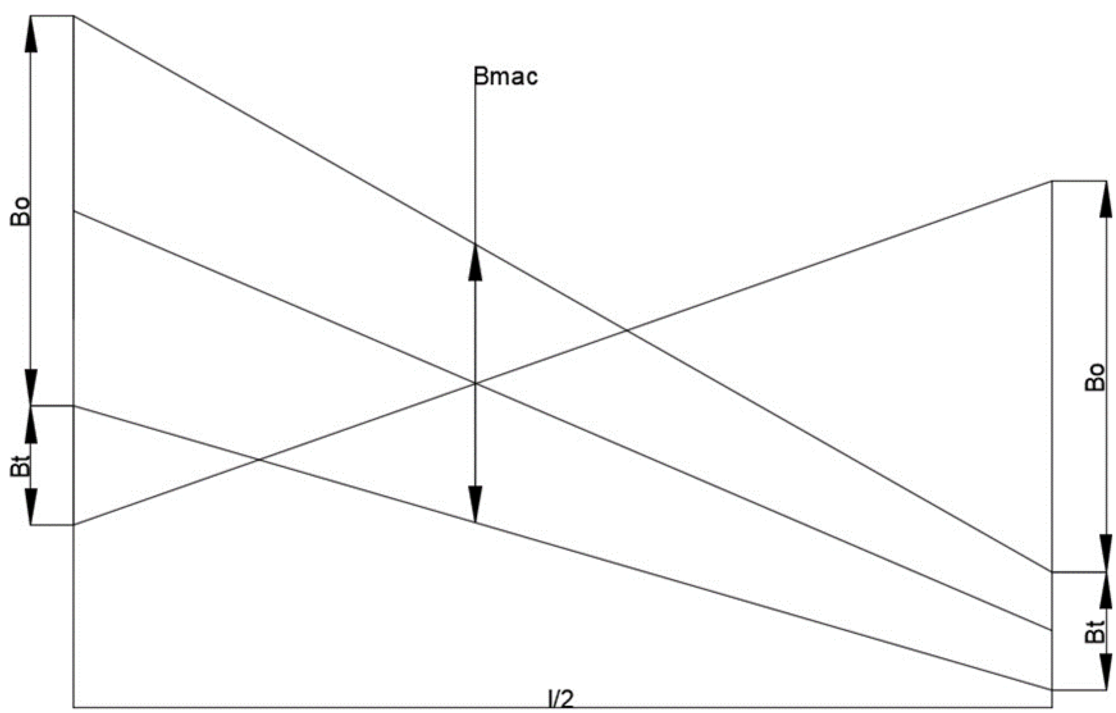


Fig. 2.1 - Geometrical method of a mean aerodynamic chord determination

The length of the mean aerodynamic chord, which is equal b_{MAC} = 7.692 m.

As the full wing area has already determined, it is possible to go to determining the geometry of lifting devices and ailerons. according to the appendix, on the wing, there are double-slotted flaps with a rigid deflector.

So, the length of the ailerons is equal to [10]:

$$l_{ail} = (0,3\ldots0,4)\cdot l/2 = 10.675\ m;$$

To calculate the aileron chord, I use recommendation [31], which is based on statistical data:

$$b_{ail} = (0,22\ldots0,26)\cdot b_i;$$

Where

b_i - the current chord of a wing in a cross-section where we have ailerons

And after that we can find aileron's area:

$$S_{ail} = (0,05\ldots0,08)\cdot S_w/2 = 12.834 m^2.$$

In modern aircraft of the same type as my prototype B777-300, designers tend to reduce the relative area and span of the ailerons. The wingspan of the projected aircraft is 61 m, based on this, we take the aileron span of 10.675 m. And as a result, not only ailerons, but also spoilers will be used for lateral control of the aircraft.

For aerodynamic balance devices, the following expression is recommended [31]:

$$\text{Axial } S_{axinail} \leq (0.25\ldots0.28)\ S_{ail} = 0,26 \cdot 12.834 = 3.34(m^2).$$

Ailerons' deflection range must meet next requirements [31]: upward $\delta'_{ail} \geq 25^{\circ}$; downward $\delta''_{ail} \geq 15^{\circ}$.

2.2.2. Fuselage layout

Requirements for the streamlining of the aircraft, as well as for the aerodynamics of its cross-section, play a key role in choosing the parameters of the fuselage.

Since the projected aircraft is subsonic, the friction resistance and profile resistance can be selected based on statistical data:

$$l_{nfp} = 2{,}1 \cdot D_f = 2{,}1 \cdot 6.2 = 13(m)$$

Where

D_f – diameter of a fuselage.

After analyzing the requirements for aerodynamics, strength and layout, I came to the conclusion that the most advantageous for the projected aircraft would be a circular cross-section. This type of section will allow obtaining the smallest thickness of the fuselage skin, thereby reducing weight, and also meeting the strength requirements. So, the length of the fuselage can be obtained.

Usable geometrical parameters are: fuselage diameter D_f; fuselage length l_f; fuselage aspect ratio λ_f; fuselage nose part aspect ratio $\lambda_{пр}$; tail unit aspect ratio λ_{tu}. Fuselage length is determined considering the aircraft scheme, layout and airplane center-of-gravity position peculiarities, and the conditions of landing angle of attack α_{land} ensuring.

General fuselage length is equal:

$$l_f = \lambda_f \cdot D_f = 11.9 \cdot 6.2 = 73.9(m)$$

Where

D_f – fuselage diameter;

λ_f – fuselage aspect ratio.

Length of the fuselage nose part:

$$l_{fnp} = \lambda_{fnp} \cdot D_f = 1.7 \cdot 6.2 = 10.5(\mathrm{m}$$

Length of the fuselage rear part:

$$l_{frp} = \lambda_{frp} \cdot D_f = 1.77 \cdot 6.2 = 10.974(\mathrm{m}).$$

For passenger aircraft, when determining the parameters of the middle part of the fuselage, it is first of all necessary to take into account the parameters of the passenger cabin.

For long range airplanes correspondingly [10]:

the height as: h1=1.9m;

passage width bp=0.6m;

the distance from the window to the flour h2=1m;

luggage space h3=0.9…1.3m.

For the chosen parameters of cabin, its height is equal:

$$H_{cab} = 1.48 + 0.17B_{cab} = 1.48 + 0.17 \cdot 5.84 = 2.473m$$

Since windows are stress concentrators on the aircraft, their shape and size are essential for strength. The windows are always placed in one row, and in my case, as in all prototypes, they are rectangular with rounded corners. When choosing the pitch of the windows, the pitch of the frames is taken into account and it is equal to 500 - 510 mm[10].

For the economical cabin with a seating arrangement in the same row (3+3+3), the corresponding cabin width is determined:

$$B_{cab}=n_{3block} \cdot b_{3block} + 2b_{aisle}+2\delta$$

$$B= 3 \cdot 1650 +2 \cdot 500+2 \cdot 50=6050\ mm$$

For business class we take the accommodation of the seats in one row like 2+2+2 accomodation.

So, the width of business class cabin is [10]:

$$B_{cab}=n_{2block} \cdot b_{3block} + 2b_{aisle}+2\delta= 3 \cdot 1200 +2 \cdot 600+2 \cdot 250=5300\ mm.$$

The length of passanger cabin is equal:

$$L_{cab}= l_1 + (n_{rows} - 1) \cdot L_{seatpitch} + L_2= 52.2m$$

The length of passenger cabin is equal:

$$L_{cab}= l_1 + (n_{rows} - 1) \cdot L_{seatpitch} + L_2= 52.2m$$

Typically, in passenger airplanes cargo compratment places under the floor of passenger cabin. Placement of the cargo influences on the airplane center of gravity position. So, wrong cargo or passengers placing can lead to emergency situations and in some cases even to injuries. Before every flight special teams calculate methods of cargo placing. And for my work I will use formal method of calculating using data of the prototypes and statistical data. Units of floor loading I will take K=400 ... 600 kg / m2 [4]. Based on the data from the prototype, we assume the maximum possible mail weight is 636 kg and the cargo weight is 7385 kg.

So, then the cargo compartment's area can be defined:

$$S_{cargo} = \frac{m_c}{0{,}4 \cdot K} + \frac{m_l}{0{,}6 \cdot K} = 129.5\ (m^2);$$

Where,

m_c and m_l - the mass of cargo mail and luggage.

And volume of the cargo compartment:

$$V_c = \overline{V}_c \cdot n_{pas} = 0{,}23 \cdot 460 = 105.8(m^3)$$

Luggage compartment design is similar to the prototype design.

2.2.3. Parameters for empennage design

Next step on the preliminary design stage is the tail unit designing. So, the statistic data can be used again for approximately calculations of the empennage area. And the tail unit is divided into two parts - horizontal and vertical. Lets start calculations from the vertical part then the area of vertical tail unit is equal:

$$S_{vtu} = (0{,}12 \ldots 0{,}2) \cdot S_w$$

And area of horizontal tail unit is equal:

$$S_{htu} = (0{,}18 \ldots 0{,}25) \cdot S_w$$

Much better could be calculated like [4]:

$$S_{htu} = \frac{b_{mah} \cdot S}{L_{htu}} \cdot S_{htu} = \frac{10.32 \cdot 427.8}{18.5} \cdot 64.17 = 51.336\ m^2;$$

$$S_{vtu} = \frac{l \cdot S}{L_{vtu}} \cdot S_{vtu} = \frac{73.9 \cdot 427.8}{18.5} \cdot 64.17 = 77.004\ m^2;$$

There are the several principal factors that affect on the length of the empennage (L_{htu} and L_{vtu}). To these factors the length of the nose and rear parts of the fuselage, conditions of airplane stability and wing's location and sweepback are included.

In the first approach we may take $L_{htu} \approx L_{vtu}$ = 18.5m. Determination of the elevator area:

$$S_{ea} = 0{,}345 \cdot S_{htu} = 0.345 \cdot 51.336 = 17.71\ (m^2)$$

Rudder area:

$$\mathrm{S_{rd}} = 0{,}4 \cdot \mathrm{S_{vtu}} = 0{,}4 \cdot 77.004 = 30.8(\mathrm{m}^2)$$

Elevator balance tabs area is equal:

$$S_{eb} = (0{,}22\ldots0{,}25)\times S_{ea} = 0.23 \cdot 17.71 = 3.896(\mathrm{m}^2)$$

Rudder balance tab area is equal:

$$S_{rb} = (0{,}2\ldots0{,}22)\times S_{rd} = 0.2 \cdot 30.8 = 6.78\ (\mathrm{m}^2)$$

The area of elevator trim tab:

$$\mathrm{S_{te}} = 0{,}1 \cdot \mathrm{S_{elv}} = 0{,}1 \cdot 17.1 = 1.71(\mathrm{m}^2)$$

And for rudder of the aircraft with two engines:

$$S_{tr} = 0{,}05 \cdot S_{rud} = 0.05 \cdot 30.8 = 1.54(m^2)$$

The height of the vertical tail unit h_{bo} is determined:

$$l_{\mathrm{vtu}} = 0{,}2 \cdot l_{\mathrm{w}} = 0.2 \cdot 30.47 = 12.2\ (\mathrm{m})$$

Tapper ratio of horizontal and vertical tail unit we need to choose: η_{htu} = 2...3; η_{vtu} = 1…3.3. Tail unit aspect ratio we may recommend: λ_{vtu} = 0.8...1.5; λ_{htu} = 3.5...4.5 [4].

Determination of tail unit chords b_{end}, b_{MAC}, b_{root}:

Horizontal tail unit tip chord:

$$b_{tchtu} = \frac{2 \cdot S_{htu}}{(\eta_{htu}+1) \cdot l_{htu}} = \frac{2 \cdot 51.336}{(2+1) \cdot 18.5}$$

Vertical tail unit tip chord:

$$b_{tcvtu} = \frac{2 \cdot S_{vtu}}{(\eta_{vtu}+1) \cdot l_{vtu}} = \frac{2 \cdot 77.004}{(3+1) \cdot 12.2} = 2.1 (m)$$

Horizontal and vertical tail unit root chord:

$$\mathrm{b_{rchtu}} = \mathrm{b_{tchtu}} \cdot \eta_{\mathrm{htu}} = 1.59 \cdot 2 = 3.975(\mathrm{m})$$

$$\mathrm{b_{rcvtu}} = \mathrm{b_{tcvtu}} \cdot \eta_{\mathrm{vtu}} = 2.1 \cdot 3 = 6.3(\mathrm{m})$$

Horizontal tail unit mean aerodynamic chord:

$$\mathrm{b_{MAChtu}} = 0{,}66 \cdot \frac{\eta_{\mathrm{htu}}^2 + \eta_{\mathrm{htu}} + 1}{\eta_{\mathrm{htu}} + 1} \cdot \mathrm{b_{tchtu}} = 0{,}66 \cdot \frac{2^2+2+1}{2+1} \cdot 1.59 = 1.984(\mathrm{m})$$

Vertical tail unit mean aerodynamic chord:

$$\mathrm{b_{MACvtu}} = 0{,}66 \cdot \frac{\eta_{\mathrm{vtu}}^2 + \eta_{\mathrm{vtu}} + 1}{\eta_{\mathrm{vtu}} + 1} \cdot \mathrm{b_{tcvtu}} = \frac{3^2 + 3 + 1}{3 + 1} \cdot 2.1 = 13.5(m)$$

Empennage sweepback angle can't be higher than wing's. It is important condition for aircraft stability. And in our case the sweepback angle of the horizontal tail is 35, for vertical tail is 40 [10].

2.2.4. Landing gear design

At the stage of preliminary design, it is possible to find only a small fraction of the parameters necessary for the design of the chassis.

The wheelbase of the projected aircraft can be precisely found. It is determined by the distance between the main landing gear and the front landing gear. And if, when landing, the front wheels touch the ground first, then when the aircraft is on the ground, the main landing gear takes on the bulk of the load.

Since the main landing gear is close to the centers of gravity of the aircraft, they affect its position and at the stage of preliminary design it is necessary to calculate the displacement of the axis of the main wheel using the formula:

$$e_g = 0,18 \cdot b_{MAC} = 0,18 \cdot 7.695 = 1.39(m)$$

Landing gear wheel base can be calculated by the equation:

$$\mathrm{B_g} = (0,3\ldots0,4) \cdot l_{\mathrm{f}} = 0.35 \ \cdot 73.9 = 29.56(\mathrm{m})$$

According to the equation, it is necessary to say that the nose landing gear carries only 6...10% of aircraft weight.

Nose wheel axial offset will be equal:

$$d_{ng} = B_g - e_g = 29.56 - 1.39 = 28.17\ (m)$$

Wheel track is:

$$K_{wt} = 0,42 \cdot B_g = 0,42 \cdot 29.56 = 12.42\ (m)$$

The value of K should be higher than 2H in order to prevent the side stall of the aircraft. Tires are selected based on takeoff loads and landing gear wheel sizes. The dynamic load on the front tires is K_g = 1.5...2.0, that is, it is practically advisable to install the brake discs on the main wheel.

Therefore, load of the nose wheel is equal:

$$\mathrm{P_{nlg}} = \frac{\mathrm{e_g} \cdot \mathrm{m_0} \cdot \mathrm{g} \cdot \mathrm{K_g}}{\mathrm{B_g} \cdot \mathrm{z_{nlg}}} = \frac{1.39 \cdot 335686 \cdot 9.8 \cdot 1.6}{29.56 \cdot 2}$$

Main wheel load is equal:

$$P_{mlg} = \frac{(B_g - e_g) \cdot m_0 \cdot g}{B_g \cdot z_{mlg} \cdot n_{mlg}} = \frac{(29.56 - 1.39) \cdot 335686 \cdot 9.81}{29.56 \cdot 12 \cdot 2} = 130759.6(\mathrm{N})$$

Tires should be selected taking into account the loads acting on the wheels during takeoff and landing. For the designed aircraft, the maximum take-off speed is 305 km / h, and the maximum landing speed is 247 km / h. The prototypes are equipped with high-pressure tires (Fig. 2.2), which is also suitable for our case.

Fig. 2.2 - Main landing gear of prototype Boeing 777-300

Taking into account the maximum loads on the wheels and the speed of the aircraft during take off (305 km/h) and during the landing (247 km/h), we choose the tires: 44 × 16 Type VII (DC-8-55 main gear tires) or 44.5 × 16.5 – 18 Type

VII. Also the next type could be installed on the aircraft: 52×R22.36 PR.

2.2.5. Description of the engines

The power plant of a designed aircraft includes two Rolls-Roys Trent 892 engines and auxiliary power unit (APU). This is an axial flow, high bypass turbofan with three coaxial shafts. Rolls Royce 800 (Figure 1.3) series has the next principle of operation: the fan is driven by a 5-stage low-pressure turbine, and the 8-stage and 6-stage compressors are driven by a single-stage turbine. This type of engine is characterized by an annular combustion chamber with 24 fuel injectors and is controlled by EEP. The compression ratio is 6.4:1 in cruise mode. The take off thrust of the engine depending on the aircraft varies from 340 to 413 kN. Fan has 26 diffusion bonded, wide chord titanium fan blades and its diameter is equal 280 cm [11].

The examples of application of Rolls Royce turbofan engine, bypass engine types you can see in a Table 2.2.

Model	Thrust (kN)	Bypass ratio	Length (m)	Dry weight (kg)	Applications
Series 800	413	6.4:1	4.6	6078	Airbus 350 Boeing 777
Series 700	315	5:1	5.6	6160	Airbus 330
Series 900	374	8.6	5.5	6246	Airbus 380 Boeing 747

Table 2.2 - The examples of application of Rolls Royce Trent turbofan engine

The manufacturer notes that this series of engines is the lightest among engines suitable for such aircraft. The Rolls Royce engine weighs 6.1 tonnes, 3.6 tonnes less than its main competitor, the GE90.

2.3. Airplane center of gravity calculation

2.3.1. Trim sheet of equipped wing

The value of the total mass of the wing is influenced by many factors, such as the position of the center of mass, the mass of the equipment that is located in the wing, the mass of the fuel, the mass of the wing structure itself, and even if the main landing gear strut is not attached to the wing, it is also taken into account when calculating the mass. equipped wing. The trim sheet (Table 2.3) contains the values of the masses and their coefficients for the main factors affecting the weight of the equipped wing.

The coordinates of the centers of gravity of the equipped wing are calculated according to recommendations [10]. The center of gravity is located relative to the front edge of the MAC of the wing with a positive direction to the rear and a positive direction to the nose. And in order to calculate the coordinates of the center of mass, the next formula is used:

$$X_f = \frac{\Sigma m_i^{/} X_i^{/}}{\Sigma m_I^{/}};$$

Table 2.3 - Trim sheet of equipped wing

N	Name	Mass		C.G. coordinates, x_i (m)	Moment $m_i x_i$ (kgm)
		Units	total mass m_i (kg)		
1	Wing (structure)	0,11	37663,97	3,46	130317,33
2	Fuel system, 40%	0,01	1711,99	3,23	5531,47
3	Control system, 30%	0,001	372,61	4,62	1721,47
4	Electrical equip. 10%	0,002	681,44	0,77	524,17
5	Anti-icing system 70%	0,01	3887,24	0,77	2990,07
6	Hydraulic system, 70%	0,01	2762,69	4,62	12763,65
7	Power units	0,07	24367,45	2,92	71152,9
8	Equipped wing without fuel and LG	0,21	71447,41	3,15	225001,1
9	Nose landing gear	0,003	887,55	-8,59	-7624,09
10	Main landing gear	0,03	10206,87	3,93	40143,61
11	Fuel	0,36	121417,63	3,23	392300,35
	Equipped wing	0,61	203959,46	3,19	649820,98

2.3.2. Trim sheet of equipped fuselage

To find the center of mass of the fuselage, it is important to remember that the origin is located on the projection of the aircraft nose onto the horizontal axis of the aircraft. Trim sheet of equipped fuselage masses is presented at Table 2.4. And to find the coordinates of the center of mass of the fuselage, we use the formula:

$$X_f = \frac{\Sigma m_i^{/} X_i^{/}}{\Sigma m_i^{/}};$$

As soon as the coordinates of the centers of gravity for both the wing and the fuselage are determined, we can proceed to the equation of equilibrium of the moments [12] relative to the nose of the aircraft:

$$m_f x_f + m_w (x_{MAC} + x_w^{/}) = m_0 (x_{MAC} + C)$$

Table 2.4 - Trim sheet of equipped fuselage masses

№	Objects	Mass		Coordinates of C.G., m	Moment (kgm)
		Units	Total (kg)		
1	Fuselage	0,08	25807,54	36,95	953588,59
2	Horizontal TU	0,01	3467,64	2,19	7594,12
3	Vertical tail unit	0,01	3434,07	2,73	9375,01
4	Anti-icing system,15%	0,003	926,49	59,2	54848,41
5	Air-conditioning 15%	0,002	520,31	36,95	19225,58
6	Heat and sound isolation	0,004	1409,88	36,95	52095,11
7	Control syst 70%	0,003	869,43	36,95	32125,32
8	Hydraulic sys30%	0,003	1097,69	51,73	56783,67
9	Electrical eq, 90%	0,02	5461,61	36,95	201806,53
10	Radar	0,002	537,1	2,1	1127,90
11	Air-navig. System	0,002	772,08	6,3	4864,09
12	Radio equipment	0,001	436,39	2,2	960,06
13	Instrument panel	0,002	671,37	3,4	2282,67
Passenger aircraft					
14	Seats of pass. economical class	0,01	2641,85	42,2	111486,02
15	Seats of pass. business class	0,003	872,78	19,68	17172,02
16	Seats of crew	0,0003	100,71	12,16	1224,18
17	Seats of flight attendance	0,001	449,82	7,39	3324,16
18	common equipment	0,001	449,82	7,39	3324,16
19	additional equipment	0,001	375,97	17,39	6538,09
20	Mail/Cargo	0,12	38536,75	14,03	540574,3
21	Flight Attendance	0,002	772,08	12,43	9593,84
22	Baggage	0,02	7385,1	36,95	272879,15
23	Meals	0,0008	268,55	61,4	16488,9
24	Passangers	0,1	34239,97	26,21	897532,39
25	Crew	0,0004	134,27	3	402,82
	Total	0,39	335686	9,77	3281090,03

Only after the calculations for the wing and fuselage are completed, and they are combined, can we begin to calculate the position of a fully equipped wing with a starting point at the nose of the fuselage (Table 2.5).

Table 2.5 - Center of gravity position of the aircraft

Name	Mass, kg	Coordinates	Moment
Object	m_i	C.G. M	Kgm
Equiped wing withoutfuel and L.G.	71447,41	12,44	225001,09
Nose landing gear (retracted)	887,56	36,95	-7624,09
Main landing gear (retracted)	10206,87	26,21	40143,61
Fuel	121417,63	61,4	392300,35
Equiped fuselage	50389,83	7,39	1543618,64
Seats of economical class	2641,85	19,68	111486,02
Seats of bussines class	872,78	42,2	17172,02
Meals	268,55	61.42	16488,89
Baggage	7385,09	36.95	272879,15
Cargo	38536,75	14.03	540574,29
Crew	134,27	3	402,82
Attendants	772,08	12.43	9593,84
Nose landing gear (opened)	887,55	-8.59	-7624,09
Main landing gear (opened)	10206,87	3.93	40143,61

The position of the center of gravity of the aircraft relative to the leading edge of the MAC is called the centering. It is expressed as a percentage.

$$x_T = \frac{x_T - x_A}{b_A} 100\%$$

Optimization of the calculations involves entering the corresponding values for the centers of mass from Table 2.5, and the final results of the calculations are the positions of the centers of gravity of the aircraft under different operating conditions. The results are presented in Table 2.

Table 2.6 - Airplane's center of gravity position variants

№	Variants of the loading	Mass, kg	Moment of the mass, кg*m	Centre of the mass, m	Centering
1	Take-off mass (L.G. opened)	335686	2654336	7,91	0.23
2	Take-off mass (L.G. retracted)	335686	2734417	8,15	0.22
3	Landing variant (L.G. opened)	227514	2342181	10,29	0.2
4	Transportation variant (without payload)	145996	1810751	12,4	0.17
5	Parking variant (without fuel and payload)	136446	1801209	13,2	0.16

So, the most forward center of gravity is located on the 16% from the leading edge of the mean aerodynamic chord, and the most aft center of gravity on the 23%.

Conclusions to the part

The goal of this part of my diploma project was developing a preliminary design for a long-range passenger aircraft. According to this part calculations, the designed aircraft can accommodate 460 passengers in a single-class layout, as well as baggage and mail. Optimal parameters were selected for the airplane, geometrical characteristics were calculated for the main units. Rolls-Roys Trent 892 engines were selected for the power plant. 52 × R22.36 PR tires were selected for the chassis wheels.

Also the most forward and backward centers of gravity positions were calculated correctly and their values are within the acceptable range for the selected type of aircraft and are equal 16% and 23% correspondently.

PART 3. FUSELAGE FRAME SIZING AND DESIGN

3.1. The main aspects in the aircraft frame design

We have noted that structure elements of the fuselage take a wide range of external and internal loads. The main structure elements of the fuselage are frames: 1) normal (typical) frame or former and 2) reinforced frame or bulkhead and pressure bulkheads.

The transverse structure elements of the fuselage are normal frames or just formers, installed along the length of the fuselage with special pitch, which depends on the fuselage dimension and positions of windows and concentrated loads from masses. The fuselage frames transfer all loads to the fuselage body and provide circumferential support for the longitudinal elements, stringers and longerons. The normal frames are manufactured in the form of open rings. They are connected with the fuselage shell and usually are symmetrical about a vertical axis [28].

The main tasks of normal frames are: to support skin and stringers, to prevent loos of stability (buckling) of the stringers and skin, to withstand tension-compression loads from differential pressure in a cabin, to take loads (bending and torsion) from the deflection of control surfaces at the tail unit. Fuselage frames are in equilibrium under the action of any external loads and shear force flows generated in their structure have to withstand all loads. They are closed of an annular or similar shape.

At the preliminary design stage of the fuselage structure, the reduced forms of frames to the round or oval type make it possible to simplify their design and calculation.

In the general case, the external forces loading the frames are balanced on the skin by the flow of distributed shear forces. In the sections of the frames, in this case, internal bending moment, transverse and axial forces (Figure 3.1) arise, the value of which is found according to the classical method for circular frames. The known moment and forces can be used to determine the normal stresses in the chords and tangential stresses in the walls of the frame [13].

$$\sigma = \frac{M_{изб} \cdot y}{J} + \frac{N}{F_{сеч}}$$

$$\tau = \frac{Q}{h_{шп}\delta}$$

δ - frame's thickness;

h – cross-section high

The strength of frames and their parameters, as a rule, are determined from the condition of loading them with a bending moment.

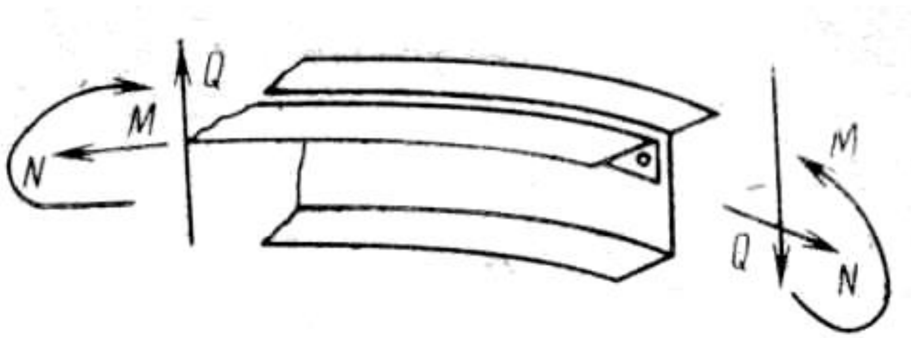


Fig. 3.1 - Internal forces arising in the frame

Skin always works in the tandem with frames and its bending stiffness in comparison with frame is almost equal zero. The lower the stiffness of the frames, the more carefully their parameters should be chosen, the less mass can be obtained for the structure of the connection with the skin.

3.2. Fuselage frame sizing

The parameters of normal frames of the most common sections - z-shaped, channel and I-beams - can be selected based on the following recommendations established in design practice:

- the height of the frame wall for small fuselages (D_f =1.5 m) is taken h_{st} = 0.02 D_f, and for fuselages D_f > 2 m h_{st} = (0.025 ... 0.03) D_f;

- the width of the shelves of the frames $b_п \leq 0.5h_{st}$. In composite frames with a rim and a compensator, the width of the shelves is reduced to $0.3h_{st}$;

- the thickness of the shelf $\delta_п$ is chosen taking into account the type of panel and the type of its connection with the frame. So, if the sheathing is made of sheet δ_{sk} <2.5 mm, then it is advisable, without excessively increasing the rigidity of the belts, to maintain the ratio δ_p / δ_{sk} = 1.0… .1.3.

If it is necessary to determine the parameters by calculation, then first of all it is necessary to know the loads acting in the considered sections. During bending, external loads are determined by well-known methods [14] by the formula:

$$M_{\max} = 0{,}23 q_{\max} R^2$$

where

$$q_{\max} = \frac{\delta_{обш} a R M^2}{EJ}$$

R - is the radius of the fuselage;

q_{max} - is the maximum distributed load;

δ_{sk}- sheathing thickness;

a - the step of the frames;

M_{max} - maximum bending moment;

E is the modulus of elasticity of the material;

J - moment of inertia of the frame with attached skin.

The type of loading, a typical diagram of the bending moment, and design sections are shown in Fig. 3.2.

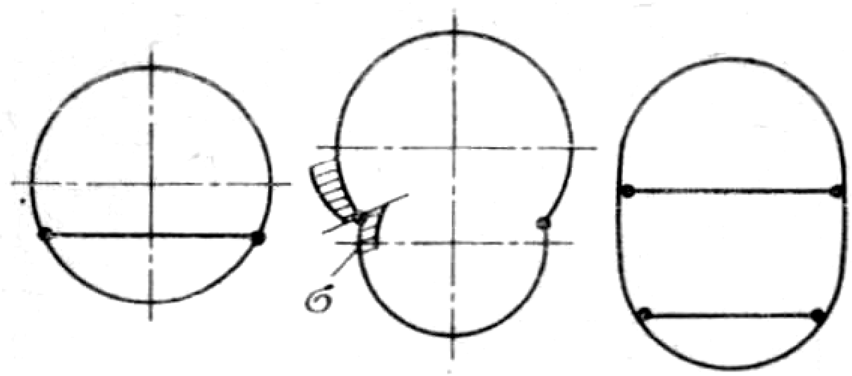


Fig. 3.2 - Loading and bending moment diagram of a normal frame.

In the general case, from the available values of M_{sr}, Q and N for the frame, using formulas, it is possible to determine the normal stresses in the chords and shear stresses in the wall.

Additionally, by the value of M_{max}, it is possible to approximately determine the radial stresses σ_r in the wall of the frame, which arise in it as a result of the work on the bending of the frame as a curved beam

$$\sigma_r = N_ц/(R\delta),$$

where

$$N_п = M/h_{fr};$$

$N_п$ – axial force in the chord.

The value of the permissible stresses in the wall should be clarified from the condition of preventing its loss of stability

$$\tau_{кр} = 8{,}6\tau_0,$$

Where

$$\tau_0 = 0{,}95E/(b/\delta)^2;$$

b is the distance along the wall between the axis of the stringers (if ribs or reinforcing posts are assumed on the wall, then the distance between them is taken as b).

Knowing the axial force $N_п$, it is possible to select the appropriate parameters of the frame belts.

In cases where increasing air loads are decisive, as a result of the increasing distance between the frames, the parameters of normal frames are symmetrical along the entire bypass and the calculated value of surface pressure $p^{th}=p^{pr}\cdot f\cdot 0{,}3\cdot 10^5\cdot 1{,}5=0{,}45\cdot 10^5$ Pa. Then the load will act on the frame:

$$q_{\min}=p^{th}a,$$

and the voltage is determined by the formula

$$\sigma=\frac{q_{\min}R}{F_{сеч}},$$

where F_{sec} is the cross-sectional area of the frame.

As the size of the fuselage increases, so does the size of its individual elements, including the heights of the walls of the frames. With a wall height of 120 ... .150 mm [10] and above, it is more expedient to make the frames composite: from the rim and the compensator - it is easier in technological (it is easier to ensure the exact shape of the elements and to compensate for assembly errors) and in constructive terms (possibly more flexible variation in thickness, shape of elements, their rigidity, etc.) (Fig. 3.3).

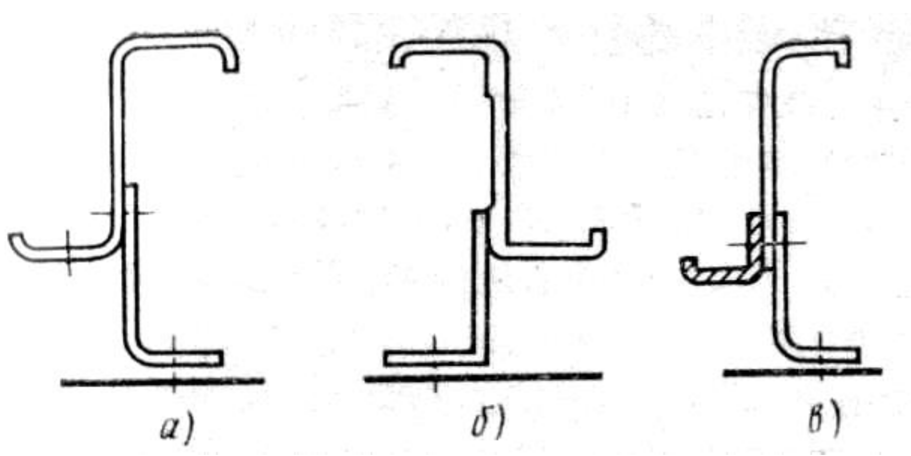


Fig. 3.3 - Frame’s examples

Figure 3.4 shows cross-sectional diagrams of four frames. Comparison of the results of fatigue tests of the frames of these schemes shows that the limiters (see Fig. 3.4, b, c) and especially symmetrical (see Fig. 3.4, d)

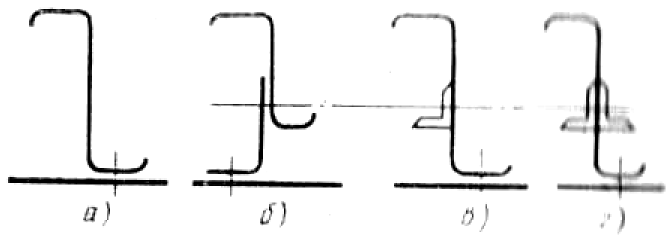


Fig. 3.4 - Cross-sectional diagrams of frames with increased durability.

Significantly increase the durability of the frame with a slight increase in its weight. The weakening by notches can cause an undesirable wrinkling effect in the upper part of the wall, springing it and wave formation in the skin near the frames. All this taken together leads to a decrease in the resource of the structure. To avoid this, it is advisable not to overestimate the permissible critical stresses in the elements weakened by cutouts when choosing the parameters of the panel and frames. The graph in Fig. 3.5 allows you to select the parameters of the allowable stress cuts for cases of double-sided wall reinforcement with a profile and for a composite wall. The use of traps in the form of shaped patches can also be considered an effective means of combating cracks, but provided that the probable direction of their propagation is correctly det ermined (Fig. 3.6).

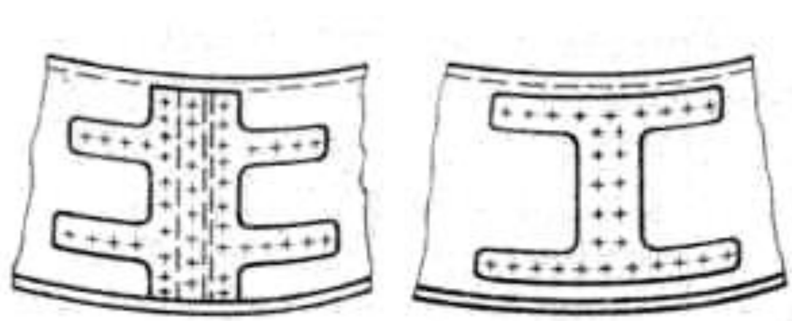


Fig. 3.5 - Graph for selection of cut parameters

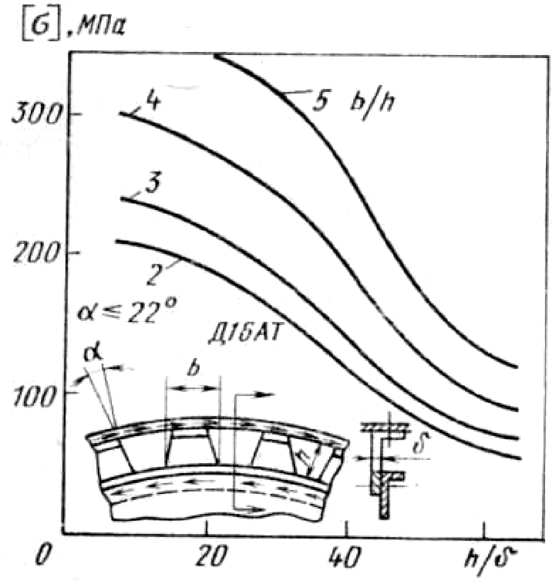


Fig. 3.6 - Shaped linings - in frames for permissible stresses. Crack traps

3.3. Normal frame design

The improvement in fatigue characteristics entails an increase in mass and a more complex manufacturing technology, and this primarily applies to composite frames. Therefore, it is extremely important in the development of this type of structure to implement the most fully rational design principles. We list a number of measures, the usefulness of which is confirmed by practice [15]:

a) stresses over the section are evenly distributed if the rim is made of a profile, and the compensator is made of sheet material of approximately the same thickness with the skin. In this case, the compensator performs not only a technological function, but also, being an elastic element, restrains an excessive increase in rigidity;

b) it is better not to make relief holes in the rim, since the crack that occurs in the compensator always goes to the relief hole. In addition, obtaining holes with simultaneous bending along R_f and flanging is extremely difficult from a technological point of view. At the same time, punching the hole when bending the wall sheet along R_f causes uneven stretching of the material in the upper (to the rim) and lower (inner) parts of the wall;

c) the radius at the top of the cutouts for stringers should preferably be at least 8 mm (Figure 3.6). Small radii are always potential sources of cracking;

d) rivets should be installed at a distance of 0.5t from the axis of the notch (see Figure 3.6). This prevents directional crack propagation;

e) excessive height of the compensator requires additional measures to ensure its rigidity, leads to irrational use of the material, therefore it is advisable to limit $h_k \leq (0.3... 0.4)\ h_{st}$. It is quite possible to assume that a high expansion joint height reduces the stability of the wall;

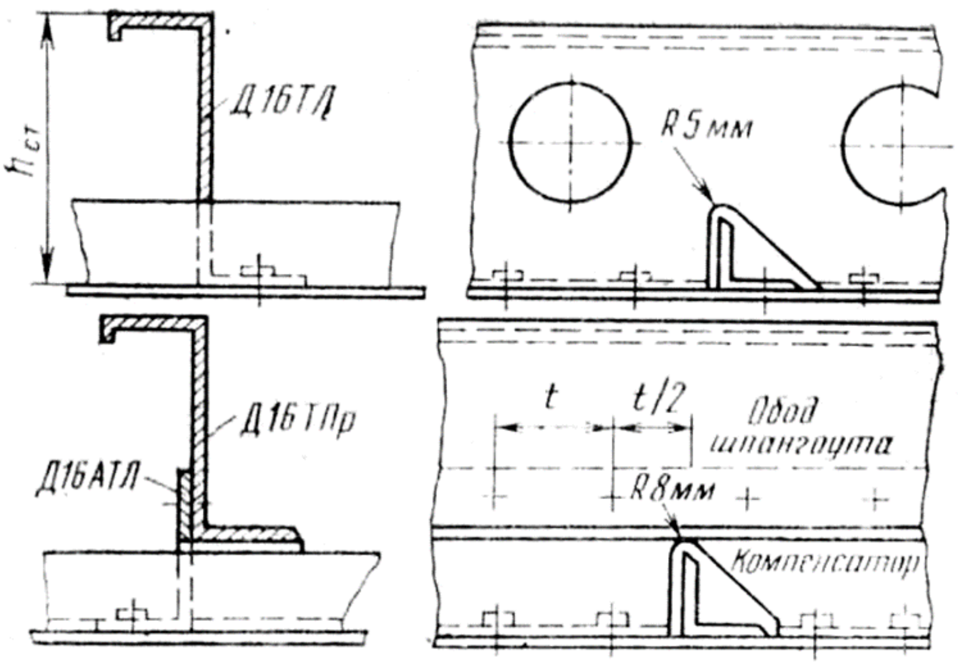


Fig. 3.6 - Cutouts in frames

f) if it is necessary to reduce the mass of the frame, change its rigidity, then this should be done on the rims; Naturally, if the expansion joint is made of a profile, then after a comprehensive assessment of the result, taking into account the pitch of the stringers, the type of panels and other factors, the expansion joint can also be modified.

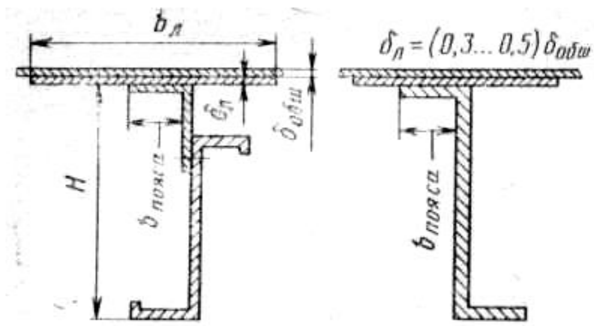


Fig. 3.7 - Reinforcing pads

Lining tapes are installed under the skin (often with glue), while observing certain parameter ratios. If the tape, sheathing and frame are made of the same material, i.e. $E_{sk} = E_l = E_{fr}$, then the thickness of the tape is $\delta_l \geq \delta_{sk}$ and at the same time b_l / $b_p \approx 4$ ... 5. In this case, stringers are undercut or milled. For $\delta_l \leq 1$ mm, this operation is not necessary. If $E_l > E_{fr}$, then $\delta_l < \delta_{sk}$ (2..3 times) and b_l / bp ≈ 3 ... 4. In some cases, the tape is made curly, with scallops, the protrusions of which fall against the rivets, which significantly reduces the concentration of stresses. It is interesting to note that the installation of spacer strips can significantly reduce the local stress level, for example, from 80 ... 90 MPa in the middle of the span between the frames to 40 ... 45 MPa directly at the belt and up to 30 MPa on the frame itself. Knowing this stress distribution, you can simplify the approach to identifying weak points and increase the strength of the structure.

3.4. Cross-section selection

With a general bending of the fuselage, stringers and skin load standard (ordinary) frames with a linear vertical load determined by the formula [16]:

$$q_y = \left(\frac{M_z}{J_z}\right)^2 \cdot \frac{h_{пр}}{E} \cdot d_2 \cdot y,$$

Where M_z – bending moment acting on the fuselage;

J_z – moment of inertia of the fuselage section;

d_2 - frame pitch;

E – modulus of elasticity of material D16T;

$+y$ – distance from the neutral axis (passing through the center of gravity) Oz

$$h_{пр} = \frac{F_{oc} + n \cdot F}{S},$$

where F_o – sheathing cross-sectional area, mm^2;

F_c – sectional area of the stringer, mm^2;

n – number of stringers;

S – fuselage section perimeter, mm;

$$h_{пр} = \frac{3,14 \cdot 2,9 \cdot 0,0024 + 36 \cdot 0,002023}{3,14 \cdot 2,9} = 0,0102 м$$

$$q_y = \left(\frac{3835000}{0,0586}\right)^2 \cdot \frac{0,0102 Н}{72 \cdot 10^9 м} \cdot 0,5 \cdot 1,45 = 449 \text{ —}$$

The greatest bending moment in the fuselage section can be determined by the formula:

$$M^c_{max} = 0,23 \cdot q_{max} \cdot R^2$$

where R – fuselage radius in a given section, mm;

$+q_{max}$ – maximum linear vertical load.

$$q_{max} = \delta_{обш} d_2 \cdot \left(\frac{M_z}{J_z}\right)^2 \cdot \frac{R}{E},$$

$$q_{max} = 0,0024 \cdot 0,5 \cdot \left(\frac{3835000}{0,0586}\right)^2 \cdot \frac{1,45 Н}{72 \cdot 10^9 м} = 105$$

Determine the greatest bending moment in the fuselage section:

$$M^c_{max} = 0,23 \cdot 105 \cdot 1,45^2 = 50 Нм$$

The maximum stresses in the frame section are calculated by the formula:

$$\sigma_{шп}^{max} = \left(\frac{M_{max}^{C}}{J_{x}^{шп}} \right) \cdot y_{ц.т}$$

where $J_{x}^{шп}$ – moment of inertia of the frame section.

Fig. 3.8 shows a cross-section of a typical frame. Let's take the following parameters for this section:

H_6 = 100 mm

B_4 = 39 mm

B_5 = 28 mm

d = 2.5 mm

R1 = 8 mm

R2 = 5.5 mm

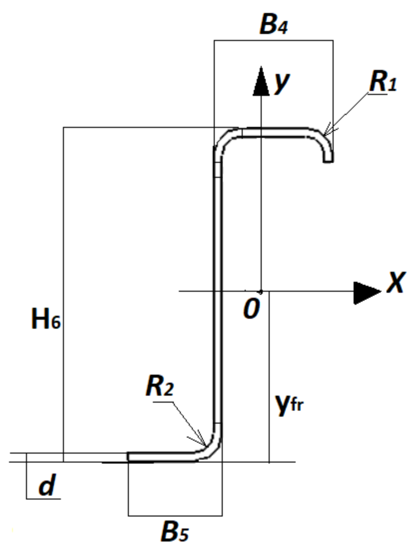


Fig. 3.8 - Frame cross section

Find the position of the center of gravity of the frame section [17]:

$$x_{cg} = \frac{F_1 \cdot x_1 + F_2 \cdot x_2 + ... + F_n \cdot x_n}{F_1 + F_2 + ... + F_n}$$

$$y_{cg} = \frac{F_1 \cdot y_1 + F_2 \cdot y_2 + ... + F_n \cdot y_n}{F_1 + F_2 + ... + F_n}$$

where F_1, F_2, F_n – area of section elements, mm^2;

y_1, y_2, y_n; x_1, x_2, x_n – coordinates of the center of gravity of the section elements, mm.

$$x_{cg} = \frac{50 \cdot 3 \cdot 25 + 144 \cdot 3 \cdot 1,5 + 30 \cdot 3 \cdot 15}{50 \cdot 3 + 144 \cdot 3 + 30 \cdot 3} = 8,55 \text{ mm}$$

$$y_{cg} = \frac{50 \cdot 3 \cdot 148,5 + 144 \cdot 3 \cdot 75 + 30 \cdot 3 \cdot 1,5}{50 \cdot 3 + 144 \cdot 3 + 30 \cdot 3} = 81,56 \text{ mm}$$

Determine the moment of inertia of the frame section:

$$J_{x\,fr}^{fr} = F_{cg} \cdot y^2$$

where F_{fr} – cross-sectional area of the frame, mm^2;

$+ y_{ц.т}$ – coordinates of the center of gravity of the frame section along the y-axis, mm.

$$J_x^{fr} = 672 \cdot 81,56^2 = 4470167 \text{ mm}^4,$$

$$\sigma_{fr}^{max} = \left(\frac{50}{447 \cdot 10^{-8}} \right) \cdot 0,08156 = 0,91 \text{ MPa}.$$

Critical buckling stresses of the frame:

$$\sigma_{fr}^{cr} = 1,2 \cdot E \cdot \left(\frac{J_x^{fr}}{R^2 \cdot d_2 \cdot d} \right)^{\frac{1}{2}}$$

where R – radii of the frame, m.

$$\sigma_{fr}^{cr} = 1,2 \cdot 72 \cdot 10^9 \cdot \left(\frac{447 \cdot 10^{-8}}{1,45^2 \cdot 0,5 \cdot 0,003} \right)^{\frac{1}{2}} = 3252 \text{ MPa}$$

We see that $\sigma_{\text{шп}}^{\text{кр}} > \sigma_{\text{шп}}^{\max}$, then the parameters of the section and the pitch of the frames are selected correctly.

3.5. Frame's creation according to calculations

First of all, for frame's creation is necessary to construct nominal surface of the aircraft skin (Fig. 3.5). According to appendix A skin diameter D_{sk} = 6.2m.

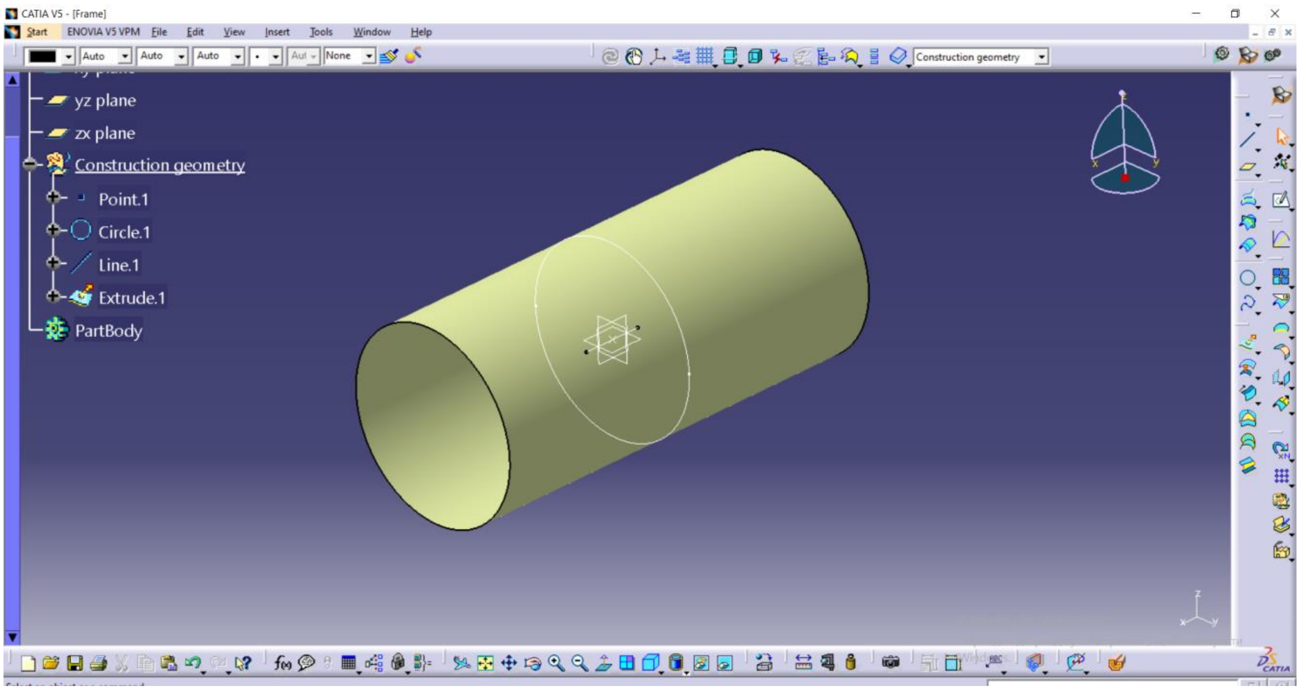


Figure 3.5 - Skin surface construction

The diameter of the skin remains unchanged along the entire length, since for my thesis I chose the section of the aircraft, which is located at the rear.

Along the entire length of the aircraft, the frames are located at a distance of 254 mm from each other, and in my work I consider the design of a typical frame at the beginning of the section.

The integral frame consists of four parts - two lateral parts, a crown and a lower one. The parts are connected to each other with special overlays, and in my work I will build a crown.

First, we will postpone a line at a distance of 254 mm, which will be a reference point for building the frame, but since we have a semi-monocoque fuselage structure, it is necessary to build the frame at a distance from the skin, since they are attached to it with the help of expansion joints. And as a consequence, the outer diameter of the frame is 3048 mm (Fig. 3.6).

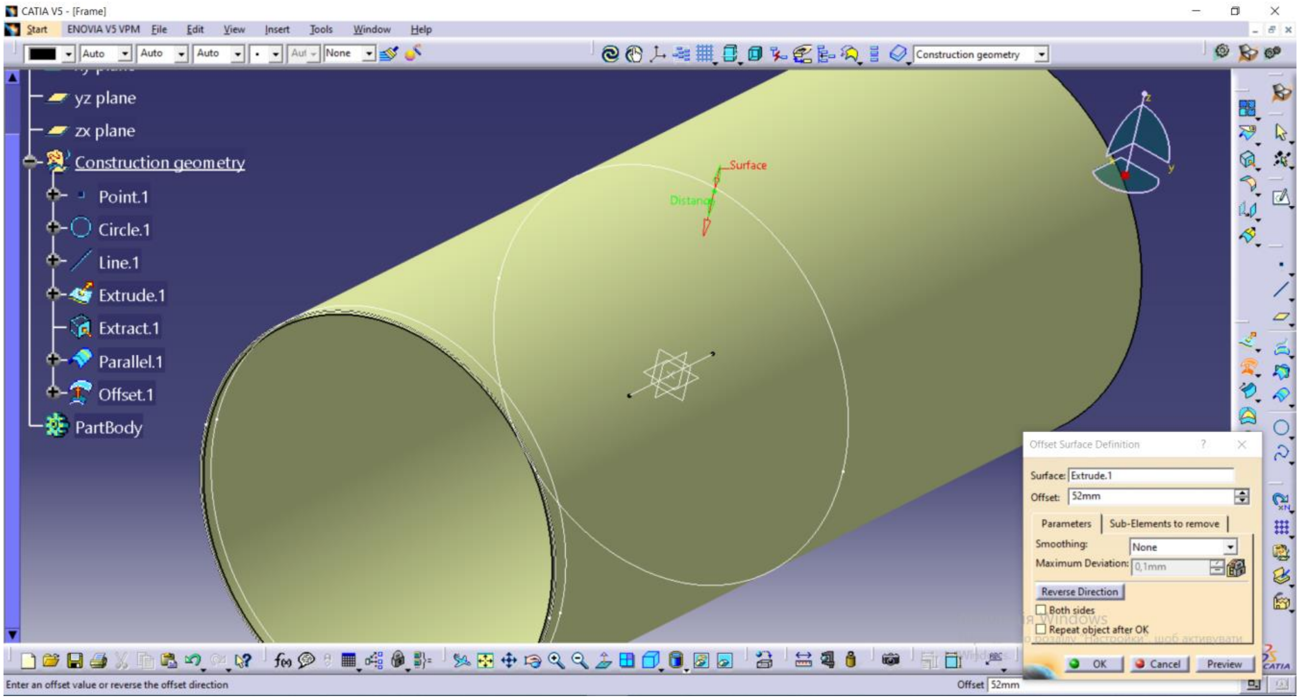


Fig. 3.6 - Outer surface of the frame construction

According to the calculations at the paragraph 3.4 let's construct surfaces for the frame. If the high of the frame is equal to 100 mm, then the inner diameter will construct by offset from the outer surface on 100 mm. And we will have upper and lower surfaces of frame (Fig 3.7).

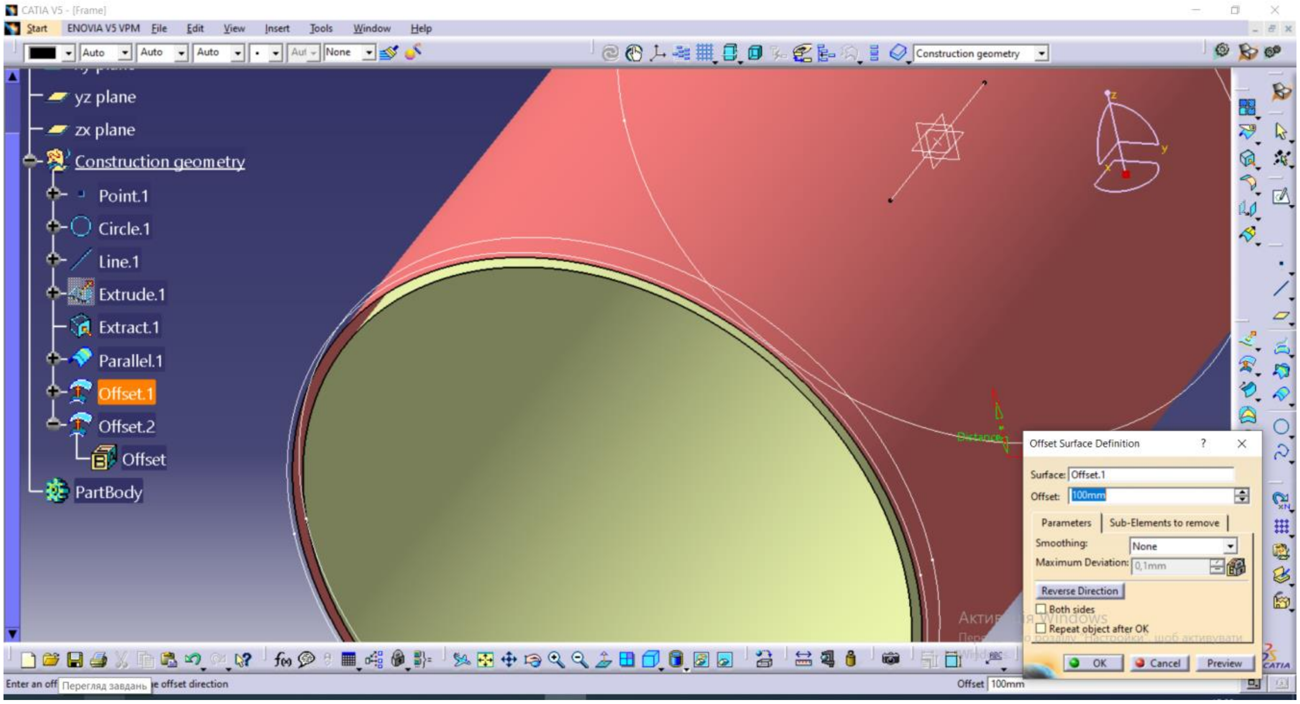


Fig. 3.7 - Surfaces of frame

Then I will cut surfaces by planes and curve for comfortable continuing of construction (Fig 3.8). As skin surface is equal 6200 mm, then the length of the circle C we will find by the formula:

$$C = 2\pi R = \pi D$$

$$C = 6200\pi = 19477.87 \text{ mm}$$

And frame consists of four equal parts with the length L = 19477.87/4 = 4869,5 mm

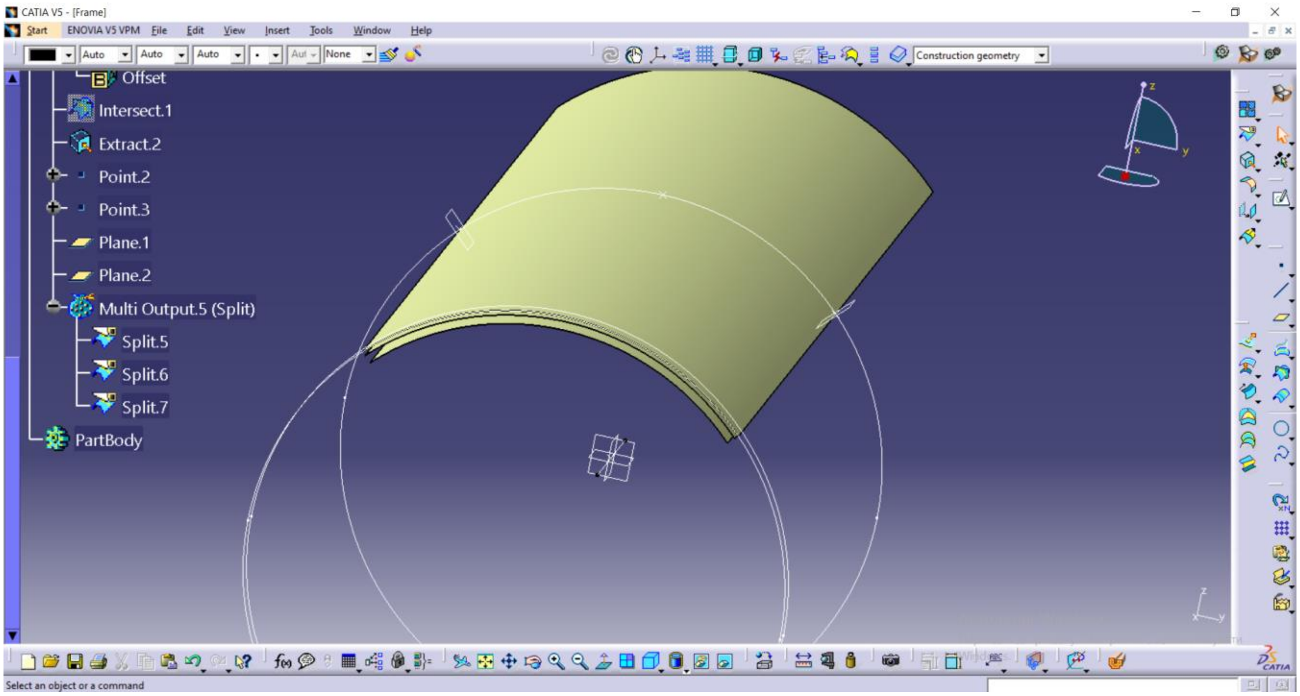


Fig. 3.8 - Surfaces cutting

Then I constructed cross-section profile with the help of sketch future. If all geometry is created correct, sketch analyze will show iso-constrained and geometry will green (Fig. 3.9).

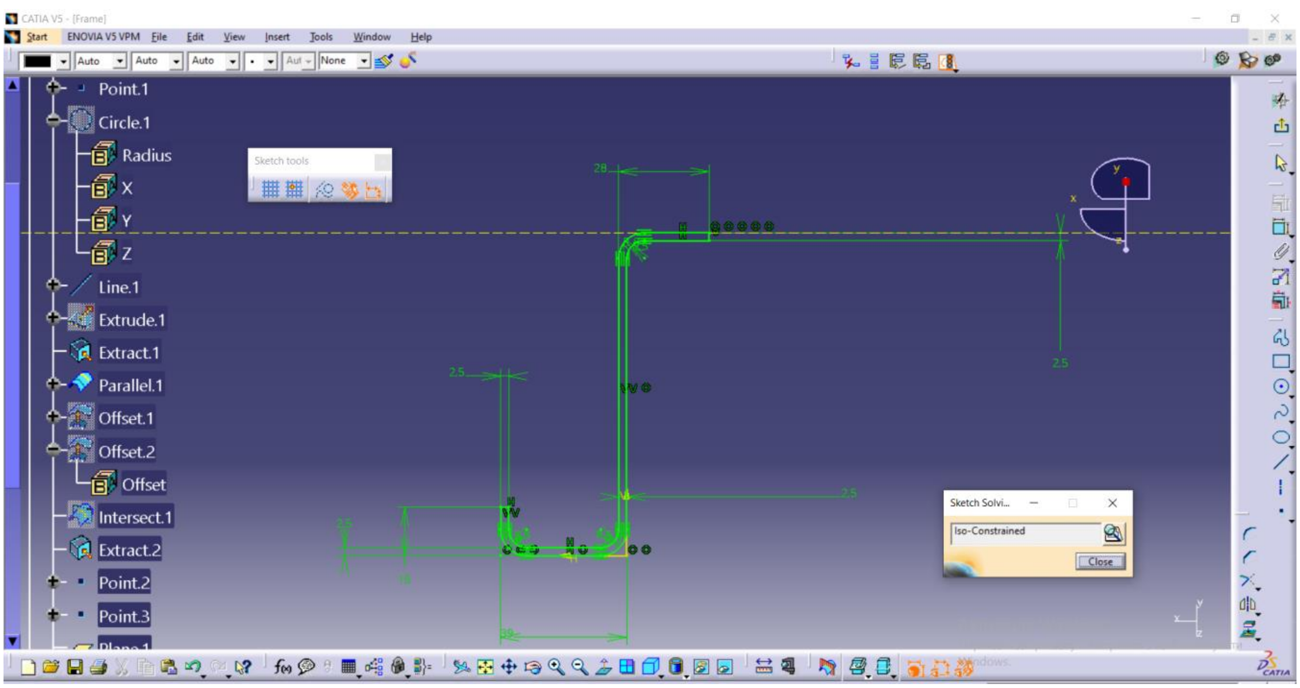


Fig. 3.9 - Well-constructed sketch

Next step after profile creation will be solid creation. A solid body must be created, since work with the constructed frame in the future is only possible on the condition that it is a solid body, and not a surface. I did it by Rib operation (Fig 3.10). For rib necessary to have guide curve and profile.

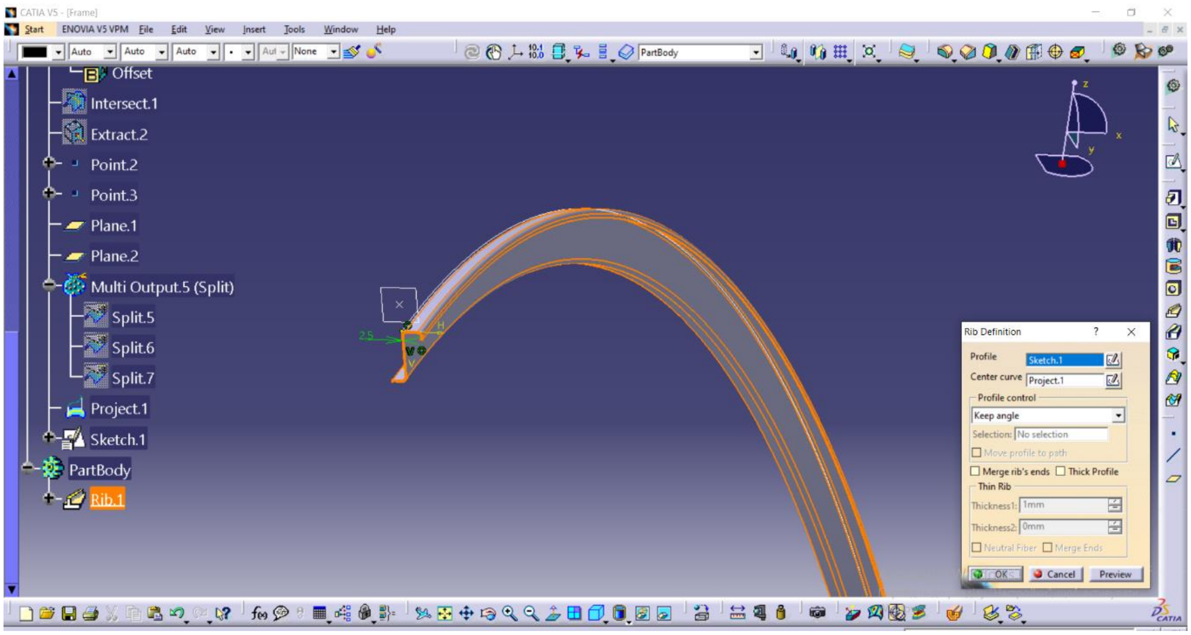


Figure 3.10 - Frame’s solid creation

Considering that the whole frame consists of four parts, and I built only one, it is necessary to build coordination holes in order to connect all the parts later when assembling the aircraft (Fig 3.11). In the same way I created hole on the other side.

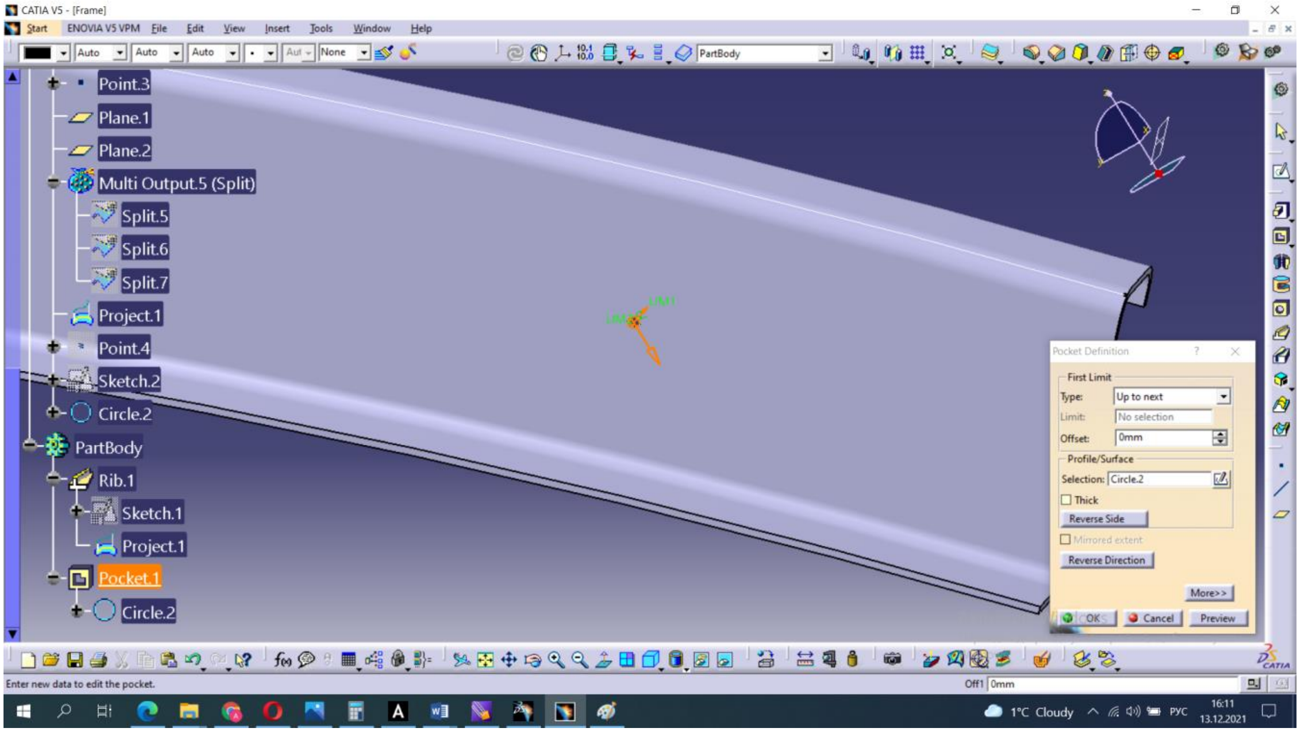


Fig. 3.11 - Coordination hole creation

The coordination holes are needed when assembling parts into an assembly. According to them, mechanics can determine whether it is possible to assemble parts and install them correctly.

3.6. Frame assembly construction

The bulkhead members and stringers provide support for the aircraft skin which is formed of a series of separate pieces applied over the various members and joined together with skin splice plates. The skin and splice plates fasten to the bulkhead members via shear ties which transfer load from the aircraft skin into the aircraft body frame. The areas where the skin splice plates are joined to the skin and the shear ties are critical fatigue points subject to potential failure (Fig. 3.12).

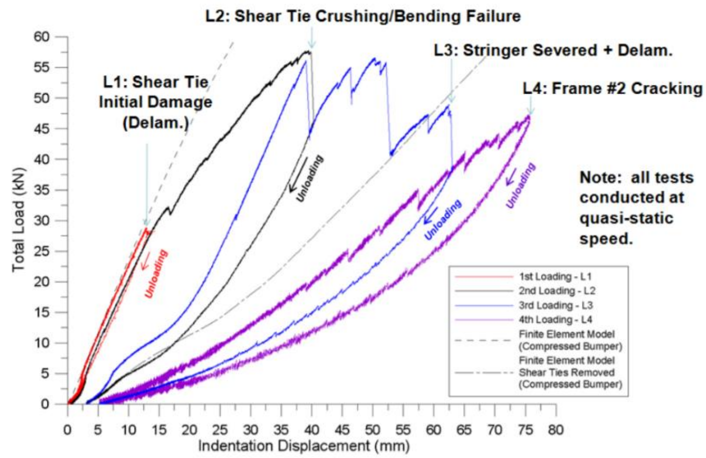


Fig. 3.12 - Progressive Load vs. Displacement for Frame

Shear ties reduce loads acting on frames. Due to this, the lifespan of the frame is increased.

So, for my frame assembly I uses shear ties.

After all construction steps I did the structural analysis for frame assembly (Fig. 3.13)

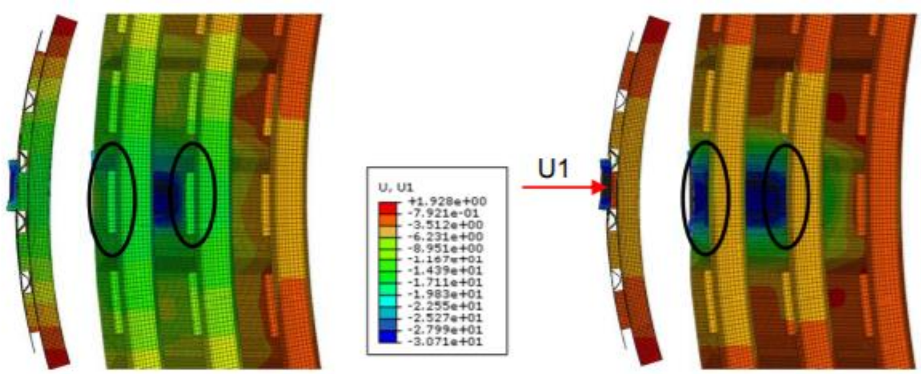


Fig. 3.13 - Load cases

As you can see on the picture every structural element has so high importance for construction strength. If any detail is deleted, the loads will change. It can lead to fatigue cracks, and critically accelerate the wear of the structure.

3.7. Methods of manufacture of the frames

Quite high requirements are imposed on the frames in terms of the accuracy of the shapes and sizes that determine the body contour, and especially to the docking surfaces and docking holes. High requirements for frames are also imposed on the quality and roughness of the surface, as well as other indicators (the location of the cutouts for the stringers, the offset of the edge of the shelves, the bulging of the material at the bottom of the profile, etc.).

The technology for manufacturing frames depends on the design and technological characteristics. The manufacturing scheme at the initial stage is associated with the type of workpieces. For simple frames, consisting of one profile in cross-section, rolled sheets, standard profiles are used as blanks. The presence of one or more welded joints, when the frames consist of a number of segment elements, has a significant impact on the fabrication scheme of frames.

If the frame blank is a rolled sheet, the manufacturing scheme consists in marking and cutting the sheet according to templates or calculated dimensions, bending these sheets into a ring with their simultaneous profiling on special profile bending machines, welding at the joints of the profiles. After welding, annealing and stripping of the seams, it is necessary to carry out the final calibration, after which the grooves are cut out and their plumbing work is done. If there are holes in the structure, then it is advisable to make them before bending, in sheet blanks. Frames of significant diameters (more than 1500 mm) usually consist of several segmented sections. In this case, the segments, in addition to bending them on roller machines, can be made by stamping (Fig. 3.14), when simultaneously with the shaping of the profile, the corrugations on the shelves are cut off. The assembly and welding of the segments is carried out after annealing and cleaning the edges in special simple devices that provide the basing, the necessary joining of the segments and the possibility of their reliable welding into an annular frame. After annealing and cleaning the seams, the finished frame goes to the operations of coating and final control.

Fig. 3.14 – Stamping machine

A productive method for calibrating frames after welding is stretching on presses PK.D-3 (Fig. 3.14) type with the help of expanding sectors that move apart under the action of a wedge of the movable crosshead of the press. Mechanical processing of grooves, holes, seating (butting) surfaces must be carried out prior to calibration.

Fig. 3.14 - Type PK.D-3 press

In a number of cases, for frames, circular blanks are used, obtained by flexible into a ring of strip blanks of square or rectangular cross section, followed by welding and hot stamping of a square cross section into a profile one. Annular blanks of rectangular or partially profiled cross-sections are intended in most cases for power and docking frames, often having complex profile sections. The technology for the manufacture of such frames consists in machining on a rotary machine in order to obtain the required profile and on milling and drilling machines in order to manufacture local complications of the shape.

Conclusion to the part

At this chapter I have considered the conceptual design of the typical frame at rear part of the aircraft (46 section) of passenger long range aircraft. Typical frames are only used to ensure the shape of the fuselage. They are made in the form of a bent rim made of metal sheet, the shape of which corresponds to the contour of the skin. Divided into reinforcing (cladding is attached only to the stringer), distributive (cladding is attached to the frame and stringer).

Since the frame being developed is simple and has one cross-sectional profile, it is advisable to make a blank from rolled sheet, which is standard. In this case, it would be most expedient to manufacture frame segments by stamping. With this method, it is possible to trim the corrugations on the caps, which greatly facilitates and accelerate manufacturing.

PART 4. ENVIRONMENTAL PROTECTION

4.1. Icing. General information

Any ice formation that can appear on aircraft systems and surfaces in general is called icing. The weather conditions in which ice formations can appear are among the most dangerous for aircraft. Ice formations are komuletive, that is, the longer they accumulate, the greater the danger they pose to the aircraft.

Since icing often leads to accidents, de-icing procedures are an important step in preparing an aircraft for flight.

The most dangerous from the point of view of ice formation are such parts of the aircraft as the leading edge of the wing, engine air intakes and leading edges of the tail.

When ice appears on the control surfaces of the wing and tail surfaces, controllability of the aircraft is partially or completely lost.

ice on the edges of the wing and empennage leads to a breakdown of the flow, that is, to a deterioration in the aerodynamic characteristics of the airfoils. If ice appears on the rudder drives, then there is a possibility that they will jam, which will lead to a poster of stability.

The windshield of the cab can also be covered with ice, which will lead to a decrease in visibility. Also, icing of the aircraft nose, in which the speed and direction sensors are located, which is fraught with the loss of their readings [18].

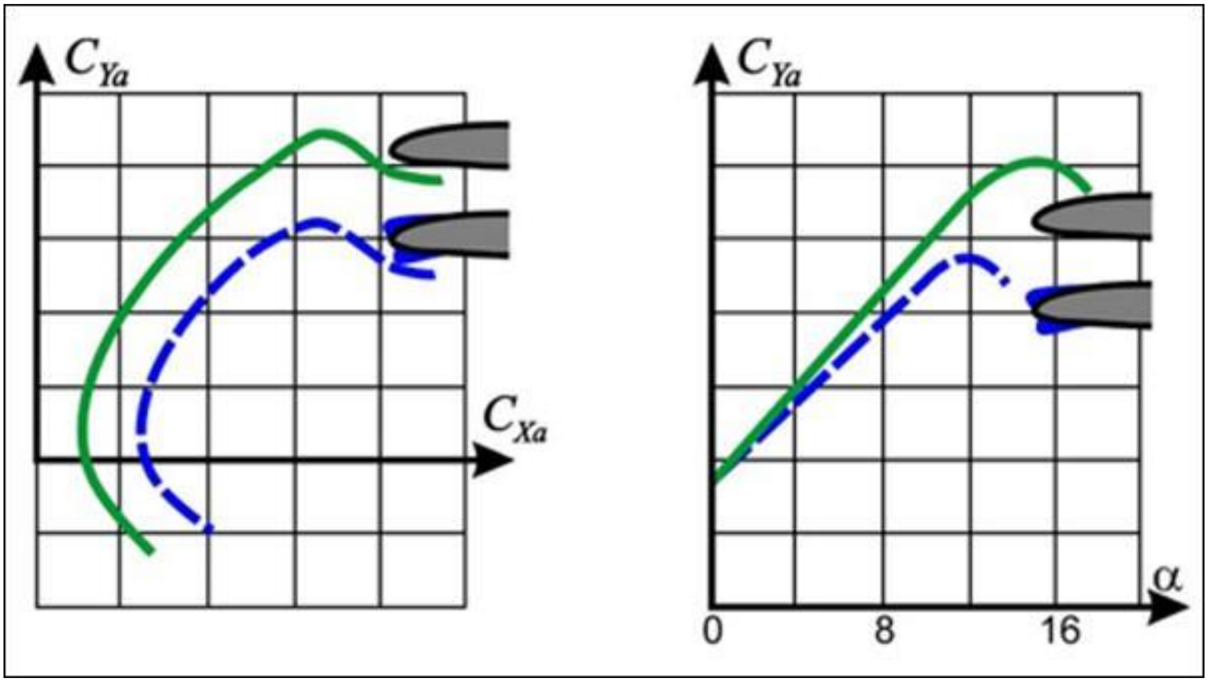


Fig. 4.1 - Wing's profile characteristics changes in the case of icing

There are two types of icing - ground and icing in the air.

4.2. Ground icing

Aircraft operating experience, as well as research in this area, show that for modern aviation, ground icing is still a significant problem and often leads to disasters, despite the fact that the procedures to improve the effectiveness of anti-icing procedures. The surface of the aircraft cools more than the environment in freezing temperatures and clear weather. As a result, the steam turns into a thin layer of ice on the plane.

If the air humidity is increased, and the temperatures are near-zero, then the vapor settles on the surfaces of the aircraft. If the temperature is below zero, then the ice will be dull, and if it is higher, then it will be transparent.

When snow freezes, ice forms on the aircraft not only due to precipitation, but also when slush and snow hit the aircraft body from the ground. An examination of the data obtained from the analysis of incidents associated with icing [19] shows:

- most incidents associated with icing occurred due to poorly performed anti-icing procedures, that is, snow-ice deposits were partially or completely not removed from the aircraft body;

- most incidents due to icing occur during take-off or climb;

- ice on the hull, which has appeared on the ground, can remain on the surface of the aircraft for up to several hours, which complicates the process of lowering the altitude and landing as a whole (Fig. 4.2).

Fig. 4.2 - Ice formed on the aircraft while it is on the ground

All ground icing types can be divided into three groups:

The first group includes such ice formation as frost, crystalline frost and hard deposits. Such formations are formed when steam passes into ice, bypassing the liquid phase.

The second group of ice formation includes crystallized supercooled drops of rain, fog and other types of water in the atmosphere.

The most dangerous is the third group of ice formation, which includes ground and fuel icing. The condition for the appearance of fuel icing is the presence of ordinary drops at high humidity and positive temperatures (up to +15° C). ICE forms on the surfaces of fully sealed fuel tanks that have the highest negative temperatures. The thickness of such layers of ice formations can reach 15 mm, and ice appears immediately over a large area.

The danger of this type of icing lies in the difficulty of detecting it, since ice is often transparent and in the fact that it appears at positive temperatures [20].

4.3. Icing during the flight

In-flight icing occurs in flight conditions when atmospheric precipitation such as cold rain, fog, sleet, etc. The rate of formation of ice deposits on the surface of an aircraft during icing in flight depends on both weather conditions and the characteristics of the aircraft. History knows cases when the ice formation rate reached 25 mm / min. It is important to take into account the fact that aircraft speed does not play a key role in ice formation. So, the higher the speed, the more the surface of the aircraft heats up due to the friction of the body against the air, and the speed of ice creation decreases.

In-flight icing often occurs at low altitudes up to 5000 m, but at high altitudes it is also possible.

4.4. Anti-icing techniques

The introduction of special hydrophobic materials into the design of potentially hazardous aircraft units is the most effective and modern means of deicing. Such materials are in themselves water-repellent 21.

Today, research is being actively carried out on methods for efficient and fast surface treatment to remove ice formation. Different types of procedures are responsible for these stages, that is, the processing of the aircraft before the flight is carried out in two stages. To carry out anti-icing procedures, four types of reagents are used to remove ice (Fig. 4.3).

The first type of reagents is intended for the first stage of removing ice from the surface, and reagents of types II, III and IV are used to ensure the protection of the aircraft body for a certain period.

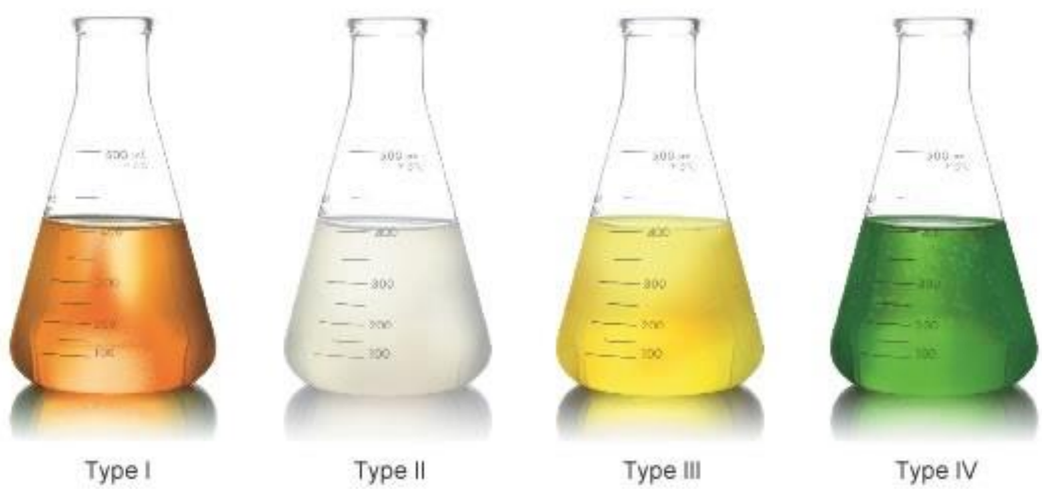


Fig. 4.3 - Types of reagents for anti-icing treatment

The use of the first type of reagent is only possible if the concentrate is diluted with hot water at 60-80 ° C (Fig 4.4). The ratio of reagent and water is selected based on weather conditions. For the convenience of the service personnel, as well as to control the application, dyes are added to the mixture.

Fig. 4.4 - Aircraft treatment with type I anti-icing liquid

The use of the fourth type of reagents is carried out at the second stage of anti-icing procedures. The general composition of the fourth type of reagents differs from the second only the use of more modern components.

The third type of reagent is often used on local airlines because it can provide short-term protection.

The application of a liquid of the fourth type (Fig. 4.5) to the surface of the aircraft takes a longer time in comparison with the first type. This is done in order to provide protection against freezing of water on the surface of the aircraft.

Fig. 4.5 - Aircraft treatment with type IV anti-icing fluid

When reacting with precipitation in flight, the applied protective words gradually "melt", therefore, the developers are actively conducting research to increase the service life of the protective layers. At the same time, it is also necessary to ensure the least impact on the environment. In any case, today, the most effective means of protecting aircraft from icing are anti-icing fluids.

4.5. Anti-icing systems

Since anti-icing liquids tend to dissolve after a certain period of time in flight, anti-icing systems are also installed on airplanes. With the help of system sensors, aircraft components that are prone to icing are monitored. And in situations where it is necessary, the sensors give a signal to turn on the anti-icing systems, which can be divided into mechanical, thermal and chemical.

The method of removing ice from mechanical de-icing systems consists in artificially deforming the surfaces of the aircraft body in order to break ice formations. And the fragments are then blown away by the oncoming air stream. Mechanical systems can be applied to wing and tail surfaces. When the icing process is started, with the help of rubber protectors, which have a system of air chambers inside, the ice is first broken with the help of compressed air, and then, by pressurizing the inner chambers, it is thrown off the surfaces.

To use chemical anti-icing systems, it is necessary at the production stage to cover the required surfaces with a special porous material through which mixtures of reagents and water with a low freezing point can be supplied to the surface. Nowadays, such systems are not widely used and are mainly used as an additional system for cleaning the windshields of the cab.

Thermal de-icing systems use hot exhaust gases from engines or electricity. The principle of operation of this system is to periodically blow hot air over the surfaces. That is, during the operation of this system, a certain amount of ice is still allowed to freeze, and the frozen water is carried away by the oncoming stream.

Conclusions to the part

As a result, anti-icing procedures are an important step in preparing an aircraft for flight. Failure to comply with the norms for the application of anti-icing fluids with a high probability can lead to a plane crash.

PART 5. LABOUR PROTECTION

5.1. Introduction

My diploma project includes calculations for frame's construction. One of the main tasks of any enterprise is to ensure proper working conditions. The main tasks of labor protection include the implementation of special processes in various aspects of the enterprise and its staff, which affect the safety of production, life and health.

In this chapter will be consider the working conditions for design engineers in the office room.

5.2. Analysis of working conditions

The workplace of the design engineer is a small room (office), which is part of a large design bureau. This office is designed for two persons, as inside there are two similar workplaces. The geometric parameters of the office are equal 3 mx 4 m x 3 m (length x width x height). These parameters correspond to the law of Ukraine on requirements for a working room [22]. Based on geometric parameters, the area of the room is 22 m2, and the volume of the room is 36 m3. According to [23] the parameters are typical for this type of office. The choice of parameters depends on the type of the room, as it can be not only an office, as in our case, as an open space.

5.2.1. Harmful and dangerous factors analysis

Since the work of an engineer is mainly done on a computer, it is the employer's responsibility to provide good lighting in the office to preserve the worker's vision. Therefore, first of all, I will research the lighting in the office.

The light sources in this office are natural light and fluorescent lamps. The natural light sources are two rectangular windows measuring 2m × 1.5m. As a consequence, the daylight ratio is ≈1.7%, and the practical value of light is 200-250 lx.

The sources of artificial lighting are lamps with high efficiency and are placed in the shape of a rectangle. The greatest efficiency for the office in question can be given by LED lamps, since the value of practical value and light is 300-350 lx, which meets the requirements of [24].

The advantage of using LED bulbs is that they can directly convert electricity into light without wasting huge amounts of energy. And another advantage over fluorescent lamps is their service life. The lifespan of LED lamps can reach 100,000 hours, which is 5 times the lifespan of fluorescent lamps.

Also, given that the design engineer spends his working day mainly at the computer, it is necessary to take breaks every two hours. This rule is established by the norms of legislation [25]. The duration of the break must be at least 15 minutes. And by the [25] standards, it is recommended to do eye exercises during the break to avoid overexertion.

Another important condition for working in an office is to maintain constant air circulation in the room. There are [26] standards regulating the requirements for humidity, air speed and temperature. All of these requirements are based on the type of work carried out in the office. The job of an engineer is classified as light physical. Table 5.1 provides examples of some of the office climate requirements.

Table 5.1– Actual values of temperature, relative humidity and air speed

Season	Category of works	Air temperature, C°	Relative humidity, %	Speed, m/s
Cold	Easy –1 b	18	35	0.25

In rooms where computers are installed, considerable attention should be paid to the microclimate, in particular the humidity of the air. The simplest way to increase the humidity in the room is to use a humidifier, but keep in mind that for them to work correctly, you need to fill in distilled water every day.

To ensure air circulation in the room, modern high-tech ventilation systems are installed in the office in question. These systems are controlled both automatically and mechanically. To ensure the purity of the circulated air in the ventilation system, special filters are installed that "catch" debris and biological particles. Circulation of clean air stimulates the brain of engineers, based on this microclimate requirement and must be met.

5.2.2. The Artificial lighting calculation

To determine the overall luminous flux in the office, it should be borne in mind that normal lighting is determined by the level of visual work (E_{min}) carried out in the office. According to standard [22], the minimum artificial lightning of a room must be at least 400 lx, and the actual illumination is 200-250 lx. Therefore, the total luminous flux is:

$$E_{gen} = \frac{E_n \cdot S \cdot k_1 \cdot k_2}{V}$$

Where

E_n – normalized illumination (E_n=400lx);

S – area of application;

k_1 – Coefficient taking into account the aging of lamps and lighting pollution(k_1=1.2);

k_2 – Coefficient taking into account the uneven illumination space (k_2= 1.1);

V – Ratio of luminous flux, defined according to the reflection coefficient ofwalls, work surfaces, ceilings, room geometry and types of lamps.

Room size up: A = 3 m, B = 4 m, H = 3m.

$$S = A \cdot B = 3 \cdot 4 = 12\ m^2$$

Choose the table using the light flux ratios:

1.Reflection coefficient of whitewashed ceiling ($R_{ceiling}$ = 70%);2.Index of refraction of white walls (R_{wall} = 55%);

3. Reflection coefficient from the dark hardwood floors (R_{floor}= 10%);

4. Index space ($i = \frac{A \times B}{h_p(A+B)}$)

$$h_p = H - h_n$$

Where

h_n– work surface height over the floor (h_n=0.7 m).

Defining the room rate:

$$h_p = 3 - 0.7 = 2.3 \text{ m}$$

The utilization of light flux:

$$i = \frac{3 \cdot 4}{2.3 \cdot (3+4)} \approx 0.75.$$

Now we define the value of the total luminous flux: (V=0.7)

$$E_{gen} \frac{400 \cdot 12 \cdot 1.2 \cdot 1.1}{0.7} = 9051 \text{ lm}$$

To ensure total artificial lighting, selected LED bulbs LED–T8SE–180 and replace fluorescent lamps 18W 990 lm. Luminous flux of one lamp LED-T8SE-180 (20W.). Thus, E_l=1650 lm.

Now we define the number of lamps required to illuminate the room:

$$N = \frac{E_{gen}}{E_l} = \frac{9051}{1650} = 6 \text{ lamps}$$

Thus, to provide light E_{gen}=9051lm output the 6 LED lamps must be used instead of10 fluorescent lamps. Put in 2 rows.

Power of 10 fluorescent lamps:

$W_{gen}=W_N \cdot N=18 \cdot 10 = 180W$

Savings from the use of LED lamps.

$N = W_{gen} / (N_{LED} \cdot P_{LED})=180/(6 \cdot 20)= 1.5$

Analyzing the calculation results, we can conclude that the use of LED lamps is the most appropriate.

5.2.3. General requirements for ensuring safety at the design stage of equipment

- the equipment must be used correctly and for its intended purpose;
- where necessary, protective equipment should be used;
- in case of emergencies, inform the employee responsible for safety at work;
- periodically take a break from work
- place the object in the workplace so that they cannot fall;- it is necessary to keep emergency exits always open;
- avoid creating situations in which a fire can occur;
- when cleaning up messes and using equipment, make sure you wear the proper safety equipment
- prevent Slips and Trips
- avoid Tracking Hazardous Materials
- use Correct Posture when Lifting

5.2.4. Safety requirements before starting work

- if provided, all employees must wear protective clothing at the place of work;
- when working with double-bending mechanisms, employees should avoid loose clothing, ornaments, hair should be collected;
- after work, all tools used by employees must be put in their places in which they are stored;
- all working tools must be kept clean and in working order;
- instructions for their use should be posted in prominent places near the equipment;
- all equipment must be in working order, kept in the conditions specified by the manufacturer;
- employees do not have the right to make modifications to the design of working elements;

- all equipment that is not in use should be turned off.

5.2.5. Requirements for actions of employees in emergency situations

Any manufacturing company must have a clear plan of action for all employees in the event of an emergency. When hiring, employees should be familiar with this manual, as well as the evacuation plan from the premises. Evacuation plans should also be posted on the premises where company employees work. (Fig. 5.1).

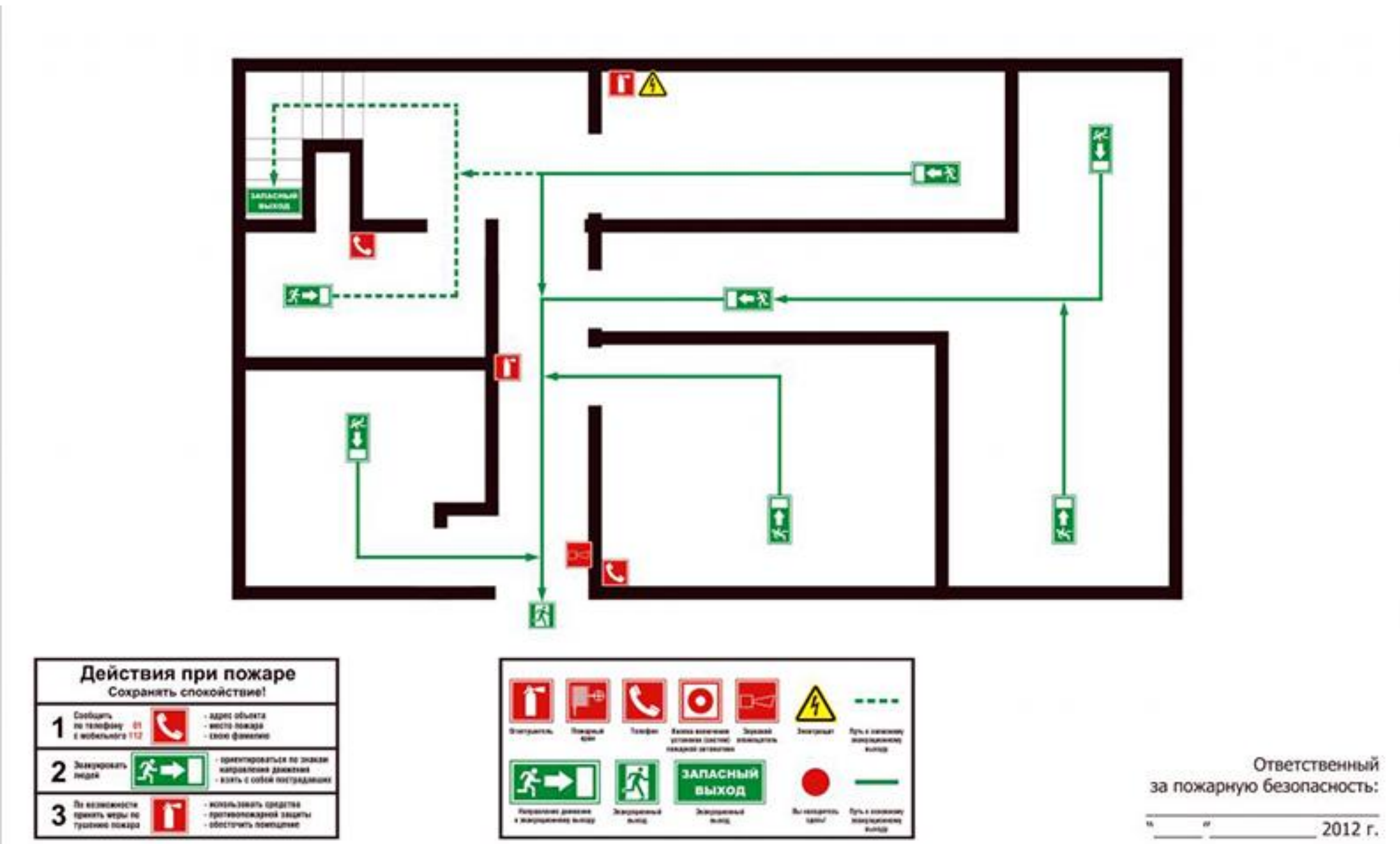


Fig. 5.1 – Evacuation plan

The emergency plan should include:

- options for all possible emergency situations that may arise, the consequences of these situations, written procedures for action;

- contact lists of employees who are responsible for safety at work;

- floor layouts with marked path options to leave the premises in case of emergencies;

-In production, a person should be appointed who will be responsible for coordinating employees in cases of emergencies.

Conclusion to the part

Providing lighting, both natural and artificial, is a production necessity for the effective work of engineers, as well as their safety.

Also, to ensure the safety of engineers in case of emergency, it is necessary to take into account the safety requirements when equipping the workplaces of engineers.

GENERAL CONCLUSION

The presented master diploma is performed according to the task and with the direction of my speciality: 134 "Aviation and Rocket-Space Engineering". The goals and aims have been accomplished in time.

The task of the diploma is the selection of the frame parameters, the selection of the most suitable manufacturing method for the frame, as well as the construction of the frame in Catia, taking into account the obtained results.

The first stage of diploma work was to design a long range passenger aircraft with a high number of passengers. The base prototypes was Boeing 777-300, Boeing 777-300ER and Airbus A350-1000. The analysis of prototypes, the statistic data of general aviation and the first iteration of the initial data by the special computer program give the possibility to perform the task of the work. At the main part of the diploma the preliminary design of the aircraft was presented and also the passenger cabin layout and flight cabin layout are shown. The approximate calculations of the main geometrical dimensions of the designing aircraft have been finished. Rolls Royce Trent 892 engine is taken for designed aircraft.

One of the task of the diploma work was to provide stability and control of the aircraft by the correct center of gravity position of the aircraft for different flight and during standing on the ground. This task also was performed, and the center of gravity position is in correct range from the mean aerodynamic chord. To demonstrate the results of calculation the general view and layout of the aircraft was shown on the drawings.

At the second stage of the diploma work the conceptual design of the frame was developed. First of all I analyzed the different types of frame’s construction. For my work I decided to use Z-formed type. The best material for construction is D16T. Also as frame consists of frame segment the best solution for cross-section blank is rolled sheet and type of manufacture – stamping.

REFERENCES

[1] 14 CFR Part 25 - AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

[2] Проектно-технологические и управленческие функции по конструкции самолетов (Попов П.М., Соколова О.)

[3] Karuskevich M.V., Maslak T.P. «Aircraft. Design». Lectures course for the students of speciality 6.070102 «Aeronavigation» – K:NAU, 2013. – 176 p.

[4] Конструкція та міцність літальних апаратів (частина 1): методичні рекомендації до виконання курсового проекту для студентів спеціальності 134 «Авіаційна та ракетно-космічнатехніка» / уклад.: С.Р. Ігнатович, М.В. Карускевич, Т.П. Маслак, С.В. Хижняк, С.С. Юцкевич. – К.: НАУ, 2018.

[5] Vortex Dynamics Study and Flow Visualization on Aircraft Model with Different Canard Configurations

[6] Машиностроение. Энциклопедия / Ред. советгК.В. Фролов (пред.) и др.*М.: Машиностроение* М 38 Динамика и прочность машин. Теория механизмов и машин. Т. 1-3. В 2-х кн. Кн. 1 /К.С. Колесников, Д.А. Александров, В.К. Асташев и др.; Под общ. ред. К.С. Колесникова.

[7] Introduction to Aerospace Structures and Materials by R.C. Alderliesten

[8] T. Megson, Aircraft Structures for Engineering Students.

[9] FAA, Chapter 3. Aircraft Construction.

[10] Житомирский Г.И. Конструкция самолетов: Учебник для студентов авиационных специальностей ВУЗов.-М.: Машиностроение, 1991.

[11] https://ru.wikipedia.org/wiki/Rolls-Royce_Trent (internet-resource)

[12] Alan Williams Ph.D., S.E., C.ENG., in Structural Analysis, 2009

[13] Advanced Mechanics of Materials and Applied Elasticity, 6th Edition

[14] M. C.-Y. Niu, Airframe Structural Design: Practical Design Information and Data on Airframe Structures.

[15] Handbook of Offshore Engineering (2-volume Set)

[16] Non-Linear Static and Cyclic Analysis of Steel Frames with Semi-Rigid Connections. /

[17] «Расчет на прочность шпангоутов: методические указания к выполнению самостоятельных работ по дисциплине «Прочность конструкций»/ А.П. Мазин, О.С. Гоголева; Оренбургский гос. ун-т. – Оренбург: ОГУ, 2010

[18] AC 00–6B: Aviation Weather. Chapter 18.

[19] “Анализ статистики авиакатастроф на основе исследования множества факторов” Д.В. Дьячков, О.В. Золотарев

[20] Руководство по противообледенительной защите воздушных судов на земле [Электронный ресурс] - URL: http://www.aviadocs.net/icaodocs/docs/9640_cons_ru. pdf.

[21] “*Гидрофобизирующие составы для дополнительной защиты алюминиевых сплавов в топливных системах изделий авиатехники”* Кутырев А.Е. Петрова В.А. Миков Д. А.

[22] Інженерне обладнання будинків і споруд. Улаштування блискавкозахисту будівель і споруд. [Текст] : (IEC 62305:2006, NEQ) : ДСТУ Б В.2.5-38:2008. – На заміну РД 34.21.122-87 ; чинний з 2009-01-01. – К. : Мінрегіон України, 2008. – 76 с. – (Національний стандарт України)

[23] Гігієнічна класифікація праці за показниками шкідливості та небезпечності факторів виробничого середовища, важкості та напруженості трудового процесу : Державні санітарні норми та правила від 30.05.2014 р. № z0472-14. Редакція від: 30.05.2014. URL: http://zakon2.rada.gov.ua/laws/show/z0472-14

[24] О минимальных требованиях безопасности при работе с дисплейным оборудованием [Електронний ресурс] : 90/270/ЕЭС. – Чинний від 1990-05-29. – Брюссель.: Совет Европейских сообществ,1990. – URL:

http://docs.pravo.ru/document/view/32704903/. – (Директива ; Міжнародний документ)

[25] Державні санітарні правила і норми роботи з візуальними дисплейними терміналами електронно-обчислювальних машин [Електронний ресурс] : ДСанПіН 3.3.2.007-98. – Чинний від 1998-12-10. – К. : МОЗ України, 1998. – URL: http://mozdocs.kiev.ua/view.php?id=2445. – (Державні санітарні правила та норми)

[26] Природне і штучне освітлення. [Текст] : ДБН В.2.5-28-2018. – На заміну ДБН В.2.5-28-2006; чинний з 2019-03-01. – К. : Мінрегіон України, 2018. – 133 с. – (Державні будівельні норми України)

[27] https://patents.google.com/patent/RU2553531C2/ru (internet-resource)

[28]https://www.sciencedirect.com/topics/engineering/fuselage-frame (internet-resource)

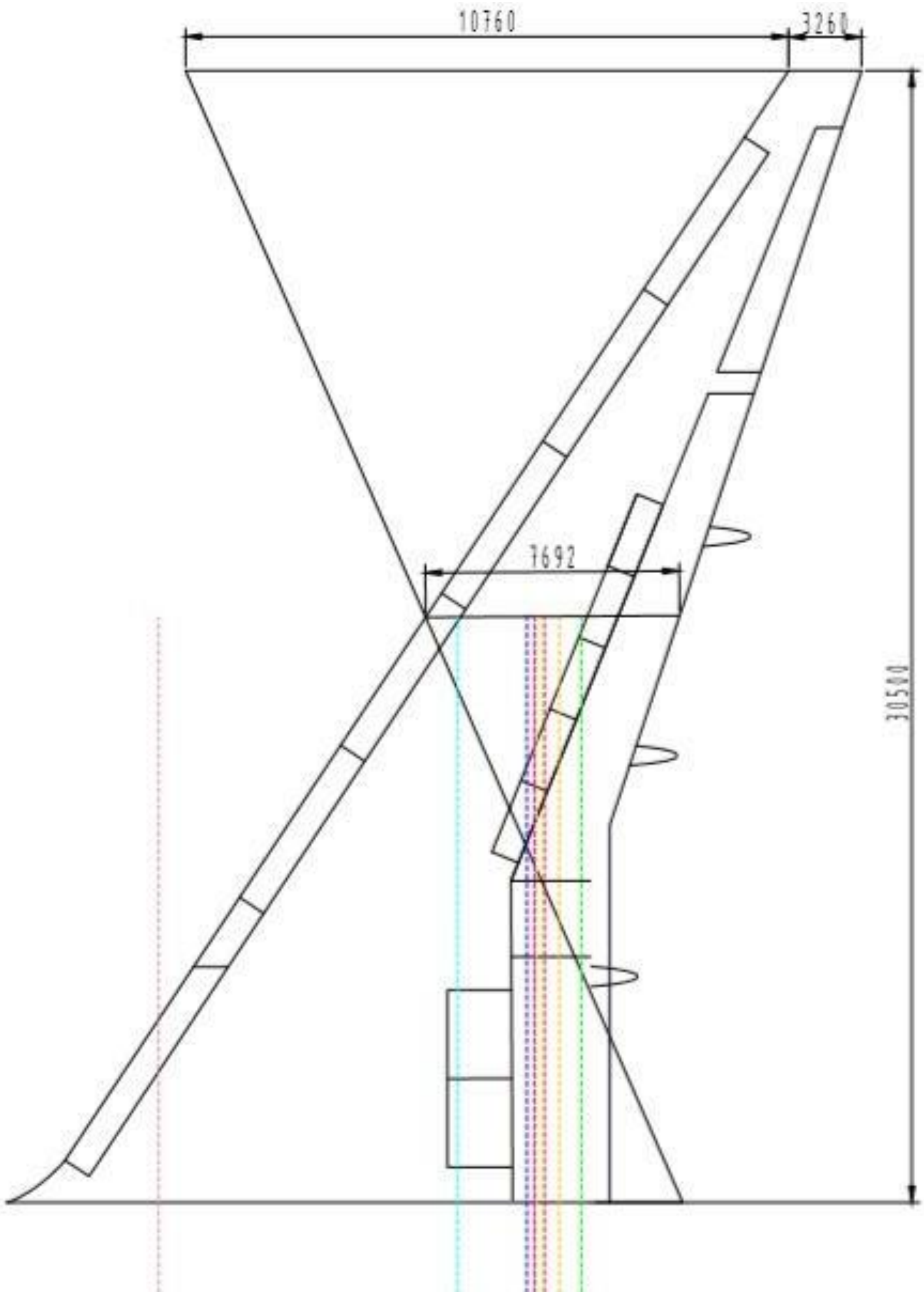
[29] AIRCRAFT DESIGN A Systems Engineering Approach Mohammad H. Sadraey Daniel Webster College, New Hampshire, USA

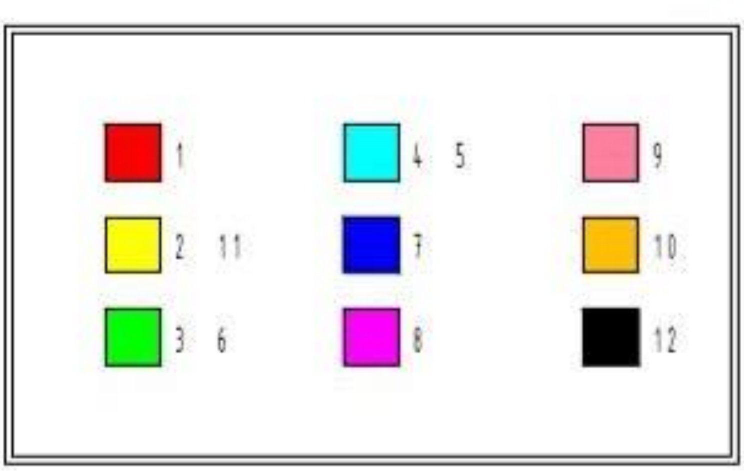
[30] Flight Literacy Recommends Rod Machado's How to Fly an Airplane Handbook

[31] Improving Aileron Effectiveness Based on Changing the Position of Aileron Connectors Ju Qiu and Haisong Ang

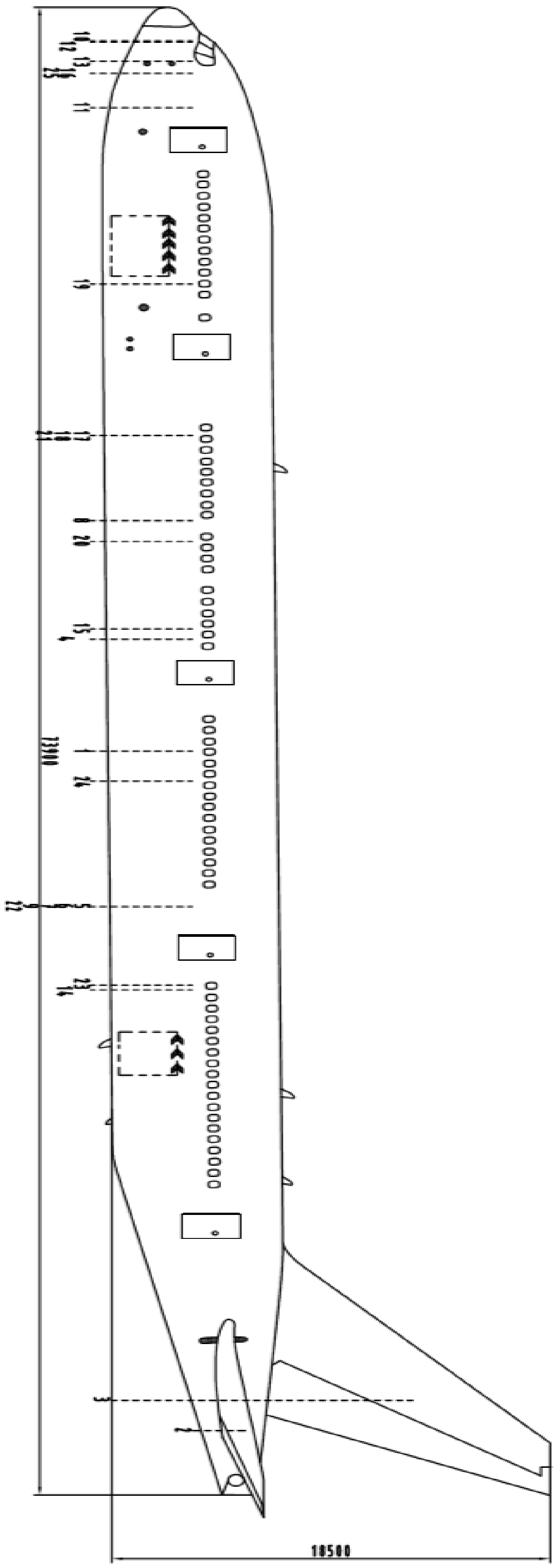
[32] Control Surface Design: Keeping them Balanced. Barnaby Wainfan January 25, 2018

Appendix B





Appendix C



Appendix A

П Р О Е К Т
С А М О Л Е Т А   С   Т Р Д Д
Н А У,   кафедра К Л А

ПРОЕКТ   дипломный   Расчет выполнен   04.03.2020
Исполнитель Довбня Анастасия Викторовна Руководитель Маслак Т.П.

ИСХОДНЫЕ ДАННЫЕ И ВЫБРАННЫЕ ПАРАМЕТРЫ

Количество пассажиров	460
Количество членов экипажа	2
Количество бортпроводников или сопровождающих	12
Масса снаряжения и служебного груза	6335.65 кг
Масса коммерческой нагрузки	48617.80 кг
Крейсерская скорость полета	905.км/ч
Число "М" полета при крейсерской скорости	0.8510
Расчетная высота начала реализации полетов с крейсерской экономической скоростью	13.10 км
Дальность полета с максимальной коммерческой нагрузкой	11000.км
Длина летной полосы аэродрома базирования	3.30 км
Количество двигателей	2
Оценка по статистике тяговооруженности в н/кг	2.3400
Степень повышения давления	34.00
Принятая степень двухконтурности двигателя	3.50
Оптимальная степень двухконтурности двигателя	3.50
Относительная масса топлива по статистике	0.4500
Удлинение крыла	8.70
Сужение крыла	3.30
Средняя относительная толщина крыла	0.110
Стреловидность крыла по 0.25 хорд	35.0 град
Степень механизированности крыла	0.800
Относительная площадь прикорневых наплывов	0.000
Профиль крыла - Суперкритический	
Шайбы УИТКОМБА - не применяются	
Спойлеры - установлены	
Диаметр фюзеляжа	6.20 м
Удлинение фюзеляжа	11.90
Стреловидность горизонтального оперения	35.0град
Стреловидность вертикального оперения	40.0град

Р Е З У Л Ь Т А Т Ы   Р А С Ч Е Т А

Н А У,   КАФЕДРА "К Л А"

Значение оптимального коэффициента подъемной силы в расчетной точке крейсерского режима полета   Cy   0.50390

Значение коэффициента   Cx.инд.   0.00886

ОПРЕДЕЛЕНИЕ КОЭФФИЦИЕНТА Dм = Мкрит - Мкрейс

Число Маха крейсерское	Мкрейс	0.85104
Число Маха волнового кризиса	Мкрит	0.85693
Вычисленное значение	Dм	0.00589

Значения удельных нагрузок на крыло в кПА(по полной площади):

при взлете	5.298
в середине крейсерского участка	4.179
в начале крейсерского участка	5.078

Значение коэффициента сопротивления фюзеляжа и гондол	0.00680
Значение коэфф. профиль. сопротивления крыла и оперения	0.00888

Значение коэффициента сопротивления самолета:

в начале крейсерского режима	0.02701
в середине крейсерского режима	0.02511
Среднее значение Cy при условном полете по потолкам	0.50390

Среднее крейсерское качество самолета   20.07011

Значение коэффициента Cy.пос.	1.259
Значение коэффициента (при скорости сваливания) Cy.пос.макс.	1.889
Значение коэффициента (при скорости сваливания)Cy.взл.макс.	1.612
Значение коэффициента Cy.отр.	1.177
Тяговооруженность в начале крейсерского режима	0.441
Стартовая тяговооруженность по условиям крейс. режима Ro.кр.	2.352
Стартовая тяговооруж. по условиям безопасного взлета Ro.взл.	2.953

Расчетная тяговооруженность самолета	Ro	3.100
Отношение Dr = Ro.кр / Ro.взл	Dr	0.797

УДЕЛЬНЫЕ РАСХОДЫ ТОПЛИВА (в кг/кН*ч):

взлетный	40.0184
крейсерский (характеристика двигателя)	60.9254
средний крейсерский при заданной дальности полета	66.1026

ОТНОСИТЕЛЬНЫЕ МАССЫ ТОПЛИВА:

аэронавигационный запас	0.02964
расходуемая масса топлива	0.36506

ЗНАЧЕНИЯ ОТНОСИТЕЛЬНЫХ МАСС ОСНОВНЫХ ГРУПП:

крыла	0.11261
горизонтального оперения	0.01053
вертикального оперения	0.01043
шасси	0.03305
силовой установки	0.09259
фюзеляжа	0.07888
оборудования и управления	0.09598
дополнительного оснащения	0.00749
служебной нагрузки	0.01887
топлива при Lрасч.	0.39470
коммерческой нагрузки	0.14483

Взлетная масса самолета "M.o" = 335686. кГ.
Потребная взлетная тяга одного двигателя 520.34 kH

Относительная масса высотного оборудования и противообледенительной системы самолета	0.0184
Относительная масса пассажирского оборудования	0.0108
Относительная масса декоративной обшивки и ТЗИ	0.0055
Относительная масса бытового (или грузового) оборудования	0.0154
Относительная масса управления	0.0037
Относительная масса гидросистем	0.0119
Относительная масса электрооборудования	0.0203
Относительная масса локационного оборудования	0.0017
Относительная масса навигационного оборудования	0.0026
Относительная масса радиосвязного оборудования	0.0013
Относительная масса приборного оборудования	0.0030
Относительная масса топливной системы (входит в массу "СУ")	0.0135
Дополнительное оснащение:	
Относительная масса контейнерного оборудования	0.0054
Относительная масса нетипичного оборудования	0.0021

[встроенные системы диагностики и контроля параметров, дополнительное оснащение салонов и др.]

ХАРАКТЕРИСТИКИ ВЗЛЕТНОЙ ДИСТАНЦИИ

Скорость отрыва самолета	305.43 км/ч
Ускорение при разбеге	2.52 м/с*с
Длина разбега самолета	1422. м.
Дистанция набора безопасной высоты	578. м.
Взлетная дистанция	2001. м.

ХАРАКТЕРИСТИКИ ВЗЛЕТНОЙ ДИСТАНЦИИ ПРОДОЛЖЕННОГО ВЗЛЕТА

Скорость принятия решения	290.16 км/ч
Среднее ускорение при продолженном взлете на мокрой ВПП	0.45 м/с*с
Длина разбега при продолженном взлете на мокрой ВПП	2053.28 м
Взлетная дистанция продолженного взлета	2631.66 м
Потребная длина летной полосы по условиям прерванного взлета	2725.77 м

ХАРАКТЕРИСТИКИ ПОСАДОЧНОЙ ДИСТАНЦИИ

Максимальная посадочная масса самолета	230007 кг
Время снижения с высоты эшелона до высоты полета по кругу	24.3 мин
Дистанция снижения	60.99 км
Скорость захода на посадку	262.82 км/ч
Средняя вертикальная скорость снижения	2.10 м/с
Дистанция воздушного участка	522. м
Посадочная скорость	247.82 км/ч
Длина пробега	857 м
Посадочная дистанция	1379 м
Потребная длина летной полосы (ВПП + КПБ) для основного аэродрома	2303 м
Потребная длина летной полосы для запасного аэродрома	1958 м

ПОКАЗАТЕЛИ ЭФФЕКТИВНОСТИ САМОЛЕТА

Отношение массы снаряженного самолета к массе коммерческой нагрузки	3.1274
Масса пустого снаряженного с-та приход. на 1 пассажира	337.14 кг/пас
Относительная производительность по полной нагрузке	488.28 км/ч
Производительность с-та при макс.коммерч. нагрузке	42939.3 кг*км/ч
Средний часовой расход топлива	9839.361 кг/ч
Средний километровый расход топлива	11.14 кг/км
Средний расход топлива на тоннокилометр	229.146 г/(т*км)
Средний расход топлива на пассажирокилометр	21.7958 г/(пас.*км)
Ориентировочная оценка приведен. затрат на тоннокилометр	0.4368 $/(т*км)