МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ
Національний авіаційний університет
Кафедра конструкції літальних апаратів

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри, д.т.н., проф.
___________ Сергій ІГНАТОВИЧ
«___» ____________ 2023 р.

КВАЛІФІКАЦІЙНА РОБОТА
ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ
«БАКАЛАВР»

Тема: «Аванпроект середньомагістрального літака пасажиромісткістю 200 чоловік»

Виконав: __________ **Ярослав ЯЦЕНКО**

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

Нормоконтролер: к.т.н., доц. __________ **Володимир КРАСНОПОЛЬСЬКИЙ**

Київ 2023

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
"___" _____________ 2023

BACHELOR DEGREE THESIS

Topic: "Preliminary Design of a Mid-Range Aircraft with 200 Passenger Capacity"

Fulfilled by: _____________ **Yaroslav YATSENKO**

Supervisor:
PhD, associate professor _____________ **Tetiana MASLAK**

Standards inspector:
PhD, associate professor _____________ **Volodymyr KRASNOPOLSKYI**

Kyiv 2023

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

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

ЗАТВЕРДЖУЮ
Завідувач кафедри, д.т.н, проф.
__________ Сергій ІГНАТОВИЧ
«___» ____________ 2023 р.

ЗАВДАННЯ

на виконання кваліфікаційної роботи здобувача вищої освіти

ЯЦЕНКА ЯРОСЛАВА СЕРГІЙОВИЧА

1. Тема роботи: «Аванпроект середньомагістрального літака пасажиромісткістю 200 чоловік», затверджена наказом ректора від 1 травня 2023 року № 624/ст.
2. Термін виконання роботи: з 29 травня 2023 р. по 25 червня 2023 р.
3. Вихідні дані до роботи: максимальна кількість пасажирів 200, дальність польоту з максимальним комерційним навантаженням 5000 км, крейсерська швидкість польоту 850 км/год, висота польоту 10 км.
4. Зміст пояснювальної записки: вступ, основна частина, що включає аналіз літаків-прототипів і короткий опис проектованого літака, обґрунтування вихідних даних для розрахунку, розрахунок основних льотно-технічних та геометричних параметрів літака, компонування пасажирської кабіни, розрахунок центрування літака, спеціальна частина, яка містить проектування концептуального рятувального переносного пристрою.
5. Перелік обов'язкового графічного (ілюстративного) матеріалу: загальний вигляд літака (А1×1), компонувальне креслення фюзеляжу (А1×1), креслення рятувального переносного пристрою (А1×1).

6. Календарний план-графік:

№	Завдання	Термін виконання	Відмітка про виконання
1	Вибір вихідних даних, аналіз льотно-технічних характеристик літаків-прототипів.	29.05.2023 – 31.05.2023	
2	Вибір та розрахунок параметрів проєктованого літака.	01.06.2023 – 03.06.2023	
3	Виконання компонування літака та розрахунок його центрування.	04.06.2023 – 05.06.2023	
4	Розробка креслень по основній частині дипломної роботи.	06.06.2023 – 07.06.2023	
5	Огляд літератури за проблематикою роботи.	08.06.2023 – 09.06.2023	
6	Розробка креслень по спеціальній частині дипломної роботи.	10.06.2023 – 11.06.2023	
7	Оформлення пояснювальної записки та графічної частини роботи.	12.06.2023 – 14.06.2023	
8	Подача роботи для перевірки на плагіат.	15.06.2023 – 18.06.2023	
9	Попередній захист кваліфікаційної роботи.	19.06.2023	
10	Виправлення зауважень. Підготовка супровідних документів та презентації доповіді.	20.06.2023 – 22.06.2023	
11	Захист дипломної роботи.	23.06.2023 – 25.06.2023	

7. Дата видачі завдання: 29 травня 2023 року

Керівник кваліфікаційної роботи ____________ Тетяна МАСЛАК

Завдання прийняв до виконання ____________ Ярослав ЯЦЕНКО

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty
Department of Aircraft Design
Educational Degree "Bachelor"
Specialty 134 "Aviation and Aerospace Technologies"
Educational Professional Program "Aircraft Equipment"

APPROVED BY
Head of Department,
Professor Dr. of Sc.
________ Sergiy IGNATOVYCH
«___» ____________ 2023

TASK

for the bachelor degree thesis

Yaroslav YATSENKO

1. Topic: "Preliminary design of a mid-range aircraft with 200 passenger capacity", approved by the Rector's order № 624/ст from 1 May 2023.
2. Period of work: since 29 May 2023 till 25 June 2023.
3. Initial data: cruise speed V_{cr}=850 kmph, flight range L=5000 km, operating altitude H_{op}=10 km, 200 passengers.
4. Content (list of topics to be developed): introduction, main part: analysis of prototypes and brief description of designing aircraft, selection of initial data, wing geometry calculation and aircraft layout, landing gear design, engine selection, center of gravity calculation, a special part that contains the conceptual design of an emergency portable device.
5. Required material: general view of the airplane (A1×1), layout of the airplane (A1×1), drawing of a conceptual emergency portable device (A1×1).

6. Thesis schedule:

№	Task	Time limits	Done
1	Selection of initial data, analysis of flight technical characteristics of prototypes aircrafts.	29.05.2023 – 31.05.2023	
2	Selection and calculation of the aircraft designed parameters.	01.06.2023 – 03.06.2023	
3	Performing of aircraft layout and centering calculation.	04.06.2023 – 05.06.2023	
4	Development of drawings on the thesis main part.	06.06.2023 – 07.06.2023	
5	Review of the literature on the problems of the work.	08.06.2023 – 09.06.2023	
6	Development of drawings for a special part of the thesis.	10.06.2023 – 11.06.2023	
7	Explanatory note checking, editing, preparation of the diploma work graphic part.	12.06.2023 – 14.06.2023	
8	Submission of the work to plagiarism check.	15.06.2023 – 18.06.2023	
9	Preliminary defense of the thesis.	19.06.2023	
10	Making corrections, preparation of documentation and presentation.	20.06.2023 – 22.06.2023	
11	Defense of the diploma work.	23.06.2023 – 25.06.2023	

7. Date of the task issue: 29 May 2023

Supervisor: ____________ Tetiana MASLAK

Student: ____________ Yaroslav YATSENKO

РЕФЕРАТ

Кваліфікаційна робота «Аванпроект середньомагістрального літака пасажиромісткістю 200 осіб» містить:

58 сторінок, 8 рисунків, 6 таблиць, 11 літературних посилань

Представлена робота присвячується проектуванню середньомагістрального літака, призначеного для перевезення 200 пасажирів.

Метою роботи є створення аванпроекту середньомагістрального пасажирського літака та визначення його основних льотно-технічних характеристик. Основним предметом розробки є рятувальний переносний пристрій.

У роботі використовується метод порівняльного аналізу літаків -прототипів для вибору найбільш обґрунтованих технічних рішень, а також методи інженерних розрахунків для отримання основних параметрів проектованого літака.

У спеціальній частині необхідно розробити концептуальний рятувальний переносний пристрій. Головна актуальність роботи полягає в зниженні травмованості пасажирів, оскільки переносний пристрій допоможе забезпечити життєздатність організму, навіть якщо пасажир знаходиться далеко від свого сидіння.

Практичне значення кваліфікаційної роботи полягає в підвищенні ефективності пасажирських перевезень. Результати роботи можуть бути використані в авіаційній галузі та в навчальному процесі студентів авіаційних спеціальностей.

Аванпроект літака, компонування пасажирської кабіни, центрування літака, рятувальне обладнання, переносний пристрій

ABSTRACT

Bachelor thesis «Preliminary design of a mid-range aircraft with 134 passenger capacity» consists of:

58 sheets, 8 figures, 6 tables, 11 references

A medium-haul passenger aircraft designed to carry 200 passengers is being developed.

The objective of the work is to create a preliminary design of a medium-haul passenger aircraft and determine its key flight and technical characteristics. The main focus of the project is on a portable rescue device.

The project employs a method of a comparative analysis of prototype aircraft to select the most justified technical solutions, as well as engineering calculation methods to obtain the primary parameters of the designed aircraft.

In the special part, a conceptual portable rescue device needs to be developed. The main significance of this work lies in reducing passenger injuries, as the portable device will help sustain the passengers' vital functions even when they are far away from their seats.

The practical value of the thesis lies in enhancing the efficiency of passenger transportation. The results of the work can be applied in the aviation industry and in the educational process for aviation students.

Aircraft prelimininary design, passenger cabin layout, center of gravity position, emergency equipment, portable rescue device

Format	№	Designation	Name	Quantity	Notes
			<u>General documents</u>		
A4	1	NAU 23 14Y 00 00 00 70 TW	Task for work	1	
	2	NAU 23 14Y 00 00 00 70	Mid-range passenger aircraft	2	
A1		Sheet 1	General view		
A1		Sheet 2	Fuselage layout		
A4	3	NAU 23 14Y 00 00 00 70 EN	Mid-range passenger aircraft	58	
			Explanatory note		
A1	4	NAU 23 14Y 00 00 00 70	Emergency portable device	1	

					NAU 23 14Y 00 00 00 70 EN
	Sh.	№ doc.	Sign	Date	
Done by		Yatsenko Y.			Preliminary design of a mid-range passenger aircraft with 200 passenger capacity (List of diploma work)
Supervisor		Maslak T.P.			list: Q; sheet: 9; sheets: 58
St.control.		Krasnopolskyi V.S.			**402 ASF 134**
Head of dep.		Ignatovich S.R.			

CONTENT

INTRODUCTION

Airplanes, as transport for movement, are safe, the fastest and at the same time more expensive. Flights take place in the air, high above the ground, and in order to reduce the risks of disasters, many organizations and people are involved, who control the condition of the aircraft from the beginning of the design to the execution of flights. Under these conditions, this type of transport has a high ticket price for a flight on airlines.

The objective of this enginerring project is to explore the development of a next-generation near-to-medium range aircraft and address the crucial aspect of enhancing flight safety. By combining cutting-edge technologies, innovative design approaches, and strict safety protocols, we aim to revolutionize the aviation industry by introducing a highly secure and efficient aircraft.

Through this research project, it was the task to contribute to the development of a medium range aircraft that not only offers exceptional performance and efficiency, but also prioritizes the safety of passengers and crew. By leveraging technological advancements and adopting a comprehensive approach to flight safety, i believe that the future of aviation can be redefined, setting new standards for the industry as a whole.

Therefore, the goal of qualification work will be to create a long-range aircraft for 200 passengers.

ANALYSIS OF PROTOTYPES OF DESIGNING AIRCRAFT

1.1 The choice of prototypes

In order to design a high-quality and reliable aircraft, it is important to understand the functions it will perform and the characteristics and structure it will have. To achieve this task, we need to choose prototypes for analyzing their design features and understanding my own objectives. The exterior appearance will be created by transferring individual components from the prototypes and subsequently refined through complex calculations on aerodynamics, economic viability, center of gravity, and user convenience.

The statistical data and technical parameters will be based on the analysis of such prototype aircraft as: Boeing 737-900 , Airbus 321 , A 310-300 (table 1.1).

Table 1.1

Operational-technical data of prototypes

Parameters	**Prototypes**		
	B 737-900	A 321	A 310-300
The purpose of airplane	Passenger	Passenger	Passenger
Crew/flight attend. persons	2/5	2/6	2/7
Maximum take-off weight, MTOW, kg	79 000	89 000	164 000
Maximum payload, kg	36 510	40 900	81 400
Passenger's seat	177	185	218
Flight altitude, m	12 500	11 900	12 200
Flight range, km	5080	5000	5600
Number and type of engines	3× GE CF6-6D	3×R-RRB211-2B	2×JT9D / PW4000
FR of the fuselage	37.45 m	35 m	27.75 m
Sweepback angle^0	27	28.5	29

The selection of parameters for an aircraft is based on its aerodynamic and operational characteristics, which are closely tied to the aircraft's layout and aerodynamic design. Choosing the appropriate parameter scheme is crucial as it directly impacts the safety and economic efficiency of the aircraft. By carefully selecting the parameters, it becomes possible to enhance the overall safety and improve the economic performance of the aircraft.

1.2 Brief description of the main parts of the aircraft

The aircraft is designed as a cantilever low-wing monoplane with bypass turbojet engines positioned under the wings. It features a swept wing with a high aspect ratio. The fuselage has a circular cross-section, while the empennage follows a conventional-type construction. The adjustable vertical stabilizer is mounted on the fuselage, providing stability. Both the rudder and elevators are equipped with aerodynamic balancing to improve their efficiency and control. The main and nose landing gear consist of multiple bogies to support the aircraft during takeoff and landing.

1.2.1 Fuselage

One of the key benefits distinguishing it from other contemporary airliners is its incorporation of a wide range of lightweight yet highly durable alloys and composite materials in its design. Composite materials are used for components such as passenger cabin floor beams and aerodynamic fairings. These materials constitute ten percent of the total weight of the aircraft's structure, resulting in substantial reductions in both the weight of the aircraft and its operational costs.

The central section of the fuselage features a circular cross-section and transitions into a tapered tail cone that houses the auxiliary power unit.

1.2.2 Wing

The wing of the aircraft features a supercritical airfoil profile that has been specifically optimized for a cruise speed of Mach 0.78.

In the wing fairing, beneath the fuselage, there is an emergency aircraft turbine. This small propeller extends from the aircraft during emergency situations, providing a minimal power supply.

The wings are designed with reduced thickness and increased span compared to previous airliners. This design choice enhances the aircraft's payload and range capabilities, improves takeoff performance, and enables it to achieve higher cruising altitudes. Additionally, the wings are utilized as fuel storage, with long-range models capable of carrying up to 36,500 liters of fuel.

1.2.3 Crew cabin

The cockpit of the aircraft is designed to meet the highest standards of comfort and functionality. It offers excellent visibility, low noise levels, efficient air conditioning, and adjustable seat positions. Instrument panels display essential flight, navigation, and engine operation information. Color displays facilitate pilots' understanding of various data, including the aircraft's overall condition, the need for repairs, control and communication system functioning, and engine operation.

Equipped with LCD displays and Fly-By-Wire controls, the aircraft aims to achieve 10% better fuel efficiency compared to competitors like the A330 and MD-11. Although the aircraft features a Fly-by-Wire control system, traditional steering columns are retained for the convenience of the pilots. The cockpit layout is designed to be simplified and user-friendly.

The Fly-by-Wire control system includes flight parameter protection, which prevents the control sticks from exceeding predetermined flight configuration limits and prevents dangerous maneuvers. However, in emergencies, the system can be deactivated by the pilot's command.

The aircraft provides rest areas for the crew. The seating area at the front of the fuselage consists of two chairs and two beds, while several seats are available at the rear. Resting places for flight attendants are also provided between the passenger compartment and the fuselage, both in the front and rear sections of the aircraft. The crew enters the compartment via staircases located in the front and tail of the aircraft. The rest area is designed to accommodate 6 or 7 flight attendants.

1.2.4 Passenger furnishing

The cabin of these aircraft is designed to provide comfort and a pleasant atmosphere for passengers. It features comfortable reclining seats, a modern lighting system, and power outlets for charging mobile devices. Wide-screen monitors are also available for passengers to enjoy the onboard entertainment system. Passengers in all classes receive high-quality service and are served full hot meals appropriate to their class of service.

In the economy class, the seating arrangement follows as 3 + 2 configuration. While there are no power sockets for charging, each seat is equipped with USB ports located under the monitors, allowing passengers to charge their mobile devices. The screens also have a standard audio jack, making it convenient to use headphones without an adapter.

Passengers are provided with a variety of amenities, including full hot meals, panini sandwiches, as well as a selection of tea, coffee, and juice.

Economy class passengers can enjoy additional services such as online check-in, an increased baggage allowance, and allowances for carry-on luggage free of charge.

1.2.5 Control system

During the design of the first commercial airliner with a fly-by-wire control system, the decision was made to retain the traditional steering columns, unlike the side-stick controllers (RUS) used in many fly-by-wire fighter jets and most Airbus airliners.

In addition to the conventional steering wheel control system, the cockpit features a simplified layout that maintains similarities with previous aircraft models. This choice was made to ensure familiarity and ease of transition for pilots.

The fly-by-wire control system is equipped with a flight parameter protection system, which prevents the control levers from exceeding predetermined flight configuration limits and safeguards against dangerous maneuvers. However, the pilot has the authority to disable this system through manual command if necessary.

1.2.6 Landing gear

The aircraft also features the largest landing gear and the biggest tires ever used in a commercial jetliner. The two-wheel bogies are designed to spread the load of the aircraft over a wide area without requiring an additional centerline gear. This helps reduce weight and simplifies the aircraft's braking and hydraulic systems.

Conclusion to the part

Within this analytical segment, we have opted for prototype airplanes like the Boeing 737-900, Airbus 321, and A 310-300, and presented a concise overview of each model. Moreover, we have depicted a forthcoming aircraft design characterized by a low-wing monoplane configuration and dual turbojet engines. Furthermore, it have been the functions and characteristics of the wing, fuselage, flight control system, landing gear, and tail section.

2. PRELIMINARY DESIGN OF A MID-RANGE PASSENGER AIRCRAFT

2.1 Geometry calculations for the main parts of the aircraft

The layout of an aircraft encompasses the arrangement and positioning of its various components, as well as the distribution of different types of loads such as passengers, luggage, and cargo. When selecting the layout and parameters of the aircraft, the primary focus is on meeting operational requirements.

During the preliminary design phase of the aircraft, careful consideration is given to the main geometrical parameters of each component. This includes calculations for wing design and high lift devices, fuselage geometry and cabin layout, landing gear design, and tail unit design.

The choice of engines for the aircraft will be made from a list of engines currently in operation, taking into account factors such as performance, efficiency, and compatibility with the aircraft design.

By carefully evaluating and calculating these aspects, the aim is to create an aircraft that meets the operational requirements while ensuring optimal performance, safety, and functionality.

2.1.1 Wing geometry calculation

During the preliminary design stage, one common approach is to select the airfoil for the wings from a wide range of options available in aeronautical literature. These airfoils have well-documented geometric and aerodynamic characteristics, allowing designers to make informed decisions based on their specific design requirements.

By utilizing these computer programs and drawing upon the wealth of knowledge available in aeronautical literature, designers can make informed choices and develop a solid foundation for the subsequent stages of the aircraft design process.

Wing area is calculated from the wing loading and gross weight which have been already decided.

Geometrical characteristics of the wing fig. 2.1 are determined from the take of weight m_0 and specific wing load P_0.

$$S_w = \frac{m_0 \cdot g}{p_0} = \frac{101422 \cdot 9.8}{5971} = 193.07 \text{ m}^2$$

where m_o – take off mass of the aircraft; g – gravitational acceleration, P_o – wing loading at cruise regime of flight.

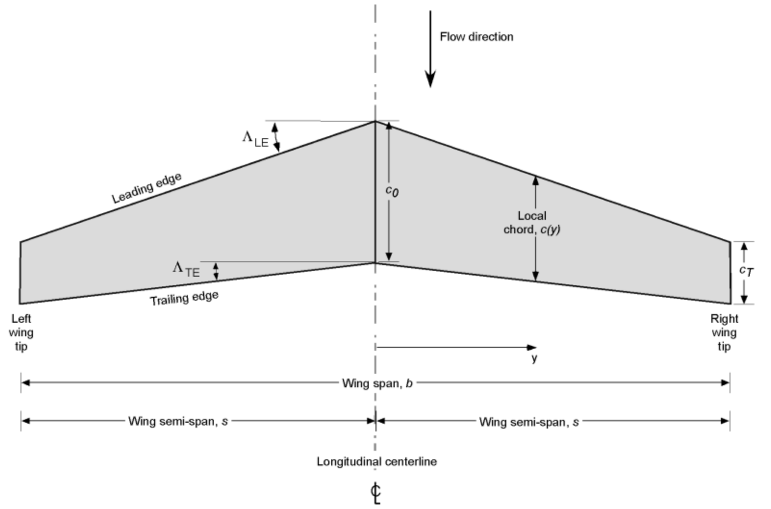

Fig. 2.1. Geometry of the wing.

After the calculation, we compare the area of our wing with a wing area of prototypes and if it necessary we could recalculate it.

So, we take the wing area

$$S_{wing} = 193{,}07 \text{m}^2;$$

Wing span is:

$$l = \sqrt{S_w \cdot \lambda_w} = \sqrt{193.07 \cdot 8.3} = 40.03 \text{ m};$$

where l – wing span, m; λ_w – wing aspect ratio.

Root chord is:

$$C_{root} = \frac{2S_w \cdot \eta_w}{(1+\eta_w) \cdot l} = \frac{2 \cdot 193.07 \cdot 4.5}{(1+4.5) \cdot 36.05} = 7.96 \text{ m};$$

where C_{root} – root chord, m; η_w – wing taper ratio.

Tip chord is:

$$C_{tip} = \frac{C_{root}}{\eta_w} = \frac{7,96}{4,5} = 1,68 \text{ m};$$

where C_{tip} – tip chord, m.

Wing construction and spars position.

In order to select the wing's structural configuration, it is crucial to identify the internal design type. The torsion box design, incorporating two (or three) spars, was opted for to fulfill the strength requirements while maintaining a relatively lightweight structure.Relative coordination of the spar's position is equal:

-for a wing with two spars: x_{1spar}=0.2 C_i; x_{2spar}=0.6 C_i from the leading edge of current chord in the wing cross-section,

The geometrical method of mean aerodynamic chord determination has been taken, which is presented at Fig. 2.2.

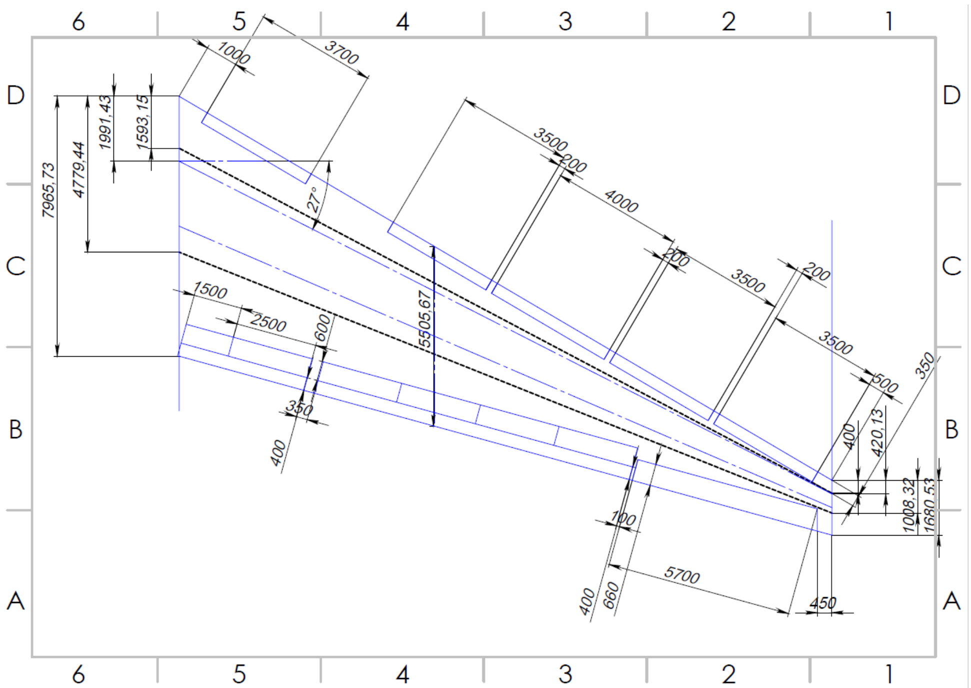

Fig. 2.2. Geometrical method of mean aerodynamic

Mean aerodynamic chord definition.

Once the geometric characteristics of the wing have been determined, we can proceed to estimate the geometry of the ailerons and high-lift devices.When selecting the power scheme of the wing, we determine the number and placement of longerons, as well as the locations for wing segmentation. In modern aircraft, a xenon double or triple longeron wing configuration is commonly employed. For our aircraft, we have chosen a configuration with two longerons.

It can be taken the geometrical method for the mean aerodynamic chord determination.

Mean aerodynamic chord is equal $b_{MAC} = 5.505m$.

Also we could calculate the MAC by the approximately formulas:

For trapezoidal wing shape:

$$b_{MAC} = \frac{2}{3}\frac{C_{root}^2 + C_{root}C_{tip} + C_{tip}^2}{C_{root} + C_{tip}} = \frac{2}{3}\cdot\frac{7.96^2 + 7.96\cdot 1.68 + 1.68^2}{7.96 + 1.68} \approx 5.505\,\mathrm{m}$$

Ailerons design. Once the geometric characteristics of the wing have been determined, we can proceed to assess the geometric properties of the ailerons and high-lift devices.

The primary function of the ailerons is to generate a rolling moment and facilitate the desired rate of roll for the aircraft.

Ailerons geometrical parameters are determined by the next formulas:

Ailerons span:

$$l_{ail} = (0.3\ldots0.4)\cdot\frac{l_w}{2} = 0.3\cdot\frac{40.03}{2} = 5.7\ \text{m}$$

where l_{ail} – ailerons span, m.

Ailerons chord:

$$C_{ai} = 0.23C_w = 0.23\cdot 2 = 0.46\ m$$

where C_{ai} – aileron chord, m.

Aileron area:

$$S_{ail} = (0.05\ldots0.08)\cdot\frac{S_w}{2} = 0.05\cdot\frac{193.07}{2} = 4.8\ \text{m}^2$$

where S_{ail} – ailerons area, m.

Ailerons are equipped by the secondary control surfaces (aerodynamic balance).

Inner axial balance:

$$S_{in\ axial} = \ (0.3..0.31)\ S_{aileron};$$

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

In third-generation airplanes, there is a trend towards reducing the relative wing span and aileron area. To achieve effective lateral control of the aircraft, spoilers are used in conjunction with ailerons. This allows for an increase in the span and area of high-lift devices, which enhances the aircraft's takeoff and landing performance.Aerodynamic compensation of the aileron.

Area of aileron’s trim tabs:

For the aircraft with two engines:

$$S_{trim\ tabs} = \left(0.04..0.06\right) S_{ail} = 0.04 \cdot 4.8 = 0.192 \text{ m}^2$$

Range of aileron deflection: upward $\delta_{aileron} \geq 25^\circ$ downward $\delta_{aileron} \geq 15^\circ$

2.1.2 Fuselage layout

The fuselage layout fig 2.3 is designed to provide comfortable accommodation for passengers in the cabin (in the case of passenger aircraft) or to ensure proper positioning of cargo on pallets or in unit load devices (for cargo aircraft).

During the preliminary design of the fuselage structure, a typical semimonocoque design is often employed. The fuselage structure consists of bulkheads (formers and frames), stringers, longerons, and skin. The formers shape the fuselage and provide support for the stringers and skin. They are installed parallel to each other and connected with the stringers. Frames bear the main loads and handle concentrated loads from other components, such as the wing, tail, landing gear attachments, entrance doors, emergency exits, and cargo doors. The first frame at the front of the fuselage is the pressurized bulkhead, which ensures the cabin's sealing. At the rear part of the fuselage, the aft pressure bulkhead is located just before the auxiliary power unit (APU), closing off the pressurized cabin.

Technologically, the fuselage is divided into different sections: the front compartment (cockpit), the middle section (passenger compartment or cargo cabin), and the rear part (tail unit). The cockpit occupies the front section, with space beneath it housing various electrical instruments, devices, and the landing gear nose wheel. The central part is dedicated to the passenger compartment (or cargo compartment), along with a baggage compartment below the floor and the main landing gear wheel well. The tail section consists of compartments for equipment, systems, smaller forms, spars, and stringers. The APU is usually located at the tail.

When selecting the fuselage parameters, aerodynamic requirements, such as streamlined shape and cross-sectional area, are taken into account. A circular cross-section is considered the most efficient as it provides minimum weight and maximum strength. Meeting strength requirements and reducing weight are important factors in aircraft design.

Geometric parameters, including fuselage diameter, length, fineness ratio, nose part, and tail unit geometry, are also carefully considered. The length of the aircraft's fuselage is determined by the aircraft's purpose, number of passengers, cabin layout, as well as the aircraft's center of gravity position and landing angle of attack.

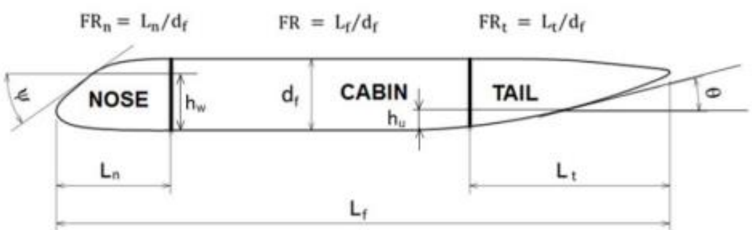

Fig. 2.3. Main geometrical parameters of fuselage.

Length of the aircraft fuselage:

$$l_f = \lambda_f \cdot D_f = 3.54 \cdot 12 = 42.5 \text{ m};$$

where D_f – fuselage diameter, m; l_f – length of fuselage, m; λ_f – fuselage aspect ratio.

The estimated length of the nose part of the aircraft fuselage is equal to:

$$l_{fnp} = \lambda_{fnp} \cdot D_f = 1.45 \cdot 3.54 = 5.2 \text{ m};$$

where l_{fnp} – length of fuselage nose part, m; λ_{fnp} – fuselage nose part fineness ratio.

Calculated length of the fuselage rear part is equal to:

$$l_{frp} = \lambda_{frp} \cdot D_f = 1.6 \cdot 3.54 = 5.7 \text{ m};$$

where l_{frp} – length of fuselage rear part, m; λ_{frp} – fuselage rear part fineness ratio.

The size of the passenger cabin plays a crucial role in the design of a fuselage for passenger aircraft.

Cabin width.

For the economic class cabin, I design the passenger seat as 3 + 2 each row.

The appropriate width of economic class cabin:

$$B_{ec} = n_{bl3} \cdot b_{3ec} + n_{bl2} \cdot b_{2ec} + n_{aisle} \cdot b_{aisle} + 2 \cdot \delta_1 + 2 \cdot \delta_{wall} =$$
$$= 1 \cdot 1450 + 1 \cdot 900 + 1 \cdot 460 + 2 \cdot 50 + 2 \cdot 100 = 3240 \text{ mm}$$

where n_{bl3}– number of three-seat blocks; b_{3ec}– width of three-seat blocks for econom class, mm; n_{bl2}– number of two-seat blocks; b_{2ec}– width of two-seat blocks for econom class, mm; n_{aisle} – number of aisles; b_{aisle}– width of aisle, mm; δ_1 – distance from the outside of the seat handle to the inside of the wall, mm; δ_{wall} – distance between the inner and outer wall, mm.

Cabin height.

When determining the length of the fuselage, there are two main considerations: achieving the desired mid-section size from one perspective and accommodating layout requirements from another perspective.

For passenger and cargo aircraft, the mid-section of the fuselage is primarily determined by the size of the passenger cabin or cargo hold. One crucial parameter for determining the mid-section of a passenger aircraft is the height of the passenger cabin.

From a design standpoint, a round cross-section is often desirable as it provides strength and minimizes weight. However, for passenger and cargo accommodations, this shape may not always be the most practical. In many cases, a combination of intersecting circles or an oval shape is more suitable for the fuselage. It's important to note that an oval shape may not be suitable for production as the upper and lower panels can bend under additional pressure, necessitating extra reinforcement such as bilge beams and other structural enhancements.

Once the cabin width is defined, the height of the cabin becomes another important consideration for passenger comfort. For domestic and short-to-medium range passenger aircraft, the minimum cabin height is typically set at 1950 mm.

Cabin height is:

$$H_{cab} = 1.48 + 0.17 B_{ec} = 1.48 + 0.17 \cdot 3.7 = 2.12 \text{ m}$$

where B_{ec} –width of economic class cabin.

Windows are placed in one row on each side of the fuselage. The shape of windows are rectangular with rounded corners. Because aircraft windows are easily leading to stress concentration, the corners of the windows are rounded. The windows located between two bulkhead and in my design, the distance between two windows is about 550 mm.

Length of the cabin. The passenger seats are installed along the length of the passenger cabin with correct seat pitch, which depend on the flight duration and class of the cabin.

The estimated length of the economy class cabin for the aircraft is equal to:

$$L_{ec} = l_1 + L_{sp}\left(n-1\right) + l_2 = 1200 + \left(40-1\right)\cdot 825 + 300 = 33675 \text{ mm}$$

where L_{ec} – length of economy class cabin, m; l_1 – distance from the wall to the back of the seat in first row, mm; l_2 – distance from the back of the seat in last row to the wall, mm; n – number of rows; L_{sp} – seat pitch, mm.

2.1.3 Baggage compartment

Under the floor of the passenger cabin, baggage compartments are installed to accommodate luggage and other cargo. The placement of baggage compartments is crucial as it directly affects the aircraft's center of gravity during flight. Improper placement of cargo and passengers can lead to potential emergency situations, highlighting the importance of accurately calculating cargo placement and setting weight limits.

By carefully determining the positioning of cargo and establishing weight limitations, the aircraft's balance and stability can be maintained, ensuring a safe and controlled flight. These calculations and considerations help prevent potential issues related to the aircraft's center of gravity and contribute to the overall safety of the flight.

Given the fact that the unit of load on floor K = 400… 600 kg/m^2

The area of cargo compartment is defined:

$$S_{cargo} = \frac{M_{bag}}{0.4K} + \frac{M_{cargo\&mail}}{0.6K} = \frac{20\cdot 200}{0.4\cdot 600} + \frac{15\cdot 200}{0.6\cdot 600} = 29.2 \text{ m}^2$$

where M_{bag} – mass of baggages of all passengers , m- mass of baggage for one passenger for free, n_{pass} – number of passengers, $M_{cargo\ \&mail}$ – mass of additional cargo and mails on the board of aircraft., approximately 15 kilograms for each passenger.

Cargo compartment volume is equal:

The estimated volume of the cargo compartment in our case is equal:

$$\nu_{cargo} = \upsilon \cdot n_{pass} = 0.2 \cdot 200 = 40\ \mathrm{m}^3;$$

where V_{cargo} – cargo compartment volume, m^3; υ – cargo volume coefficient, m^3; n_{pass} – number of passengers.

Luggage compartment design similar to the prototype

2.1.4 Galleys and buffets

If the flight duration is less than 3 hours, it is common practice to provide passengers with only water and tea, excluding the distribution of food. In such cases, the focus is on offering basic refreshments to keep passengers hydrated.

For flights with a duration of less than one hour, the provision of buffets and toilets may not be feasible due to the limited time available. Instead, the emphasis is placed on ensuring efficient boarding and disembarking procedures.

In terms of galley placement, it is preferable to position kitchen cupboards near the entrance, ideally between the cockpit and the passengers or cargo area. It is essential to have separate doors for the galley to ensure easy access and efficient service.

When determining the volume of the galley fig.2.4, international standards recommend an approximate volume of 0.1 cubic meters per passenger. Therefore, the specific volume of the galley would depend on the number of passengers being accommodated on the aircraft.

Fig. 2.4. Scheme of galley.

Estimated volume of the galleys on the plane:

$$v_{galley} = v_g \cdot n_{pass} = 0.1 \cdot 200 = 20 \text{ m}^3,$$

where v_{galley} – galley volume, m^3; v_g – galley volume coefficient, m^3; n_{pass} – number of passengers.

The total area of galley floor:

$$S_{galley} = \frac{v_{galley}}{H_{cab}} = \frac{20}{2.12} = 9.91 \text{ m}^2,$$

where S_{galley} – galley area, m^2.

Buffet design is similar to the prototypes.

2.1.5 Lavatories

The number of toilet facilities on an aircraft is typically determined by considering the number of passengers and the expected flight duration. International aviation regulations and standards provide guidelines for the minimum number of toilets based on these factors - ratio from flight hours and minimum passngers for one toilet:

t> 4:00 one toilet for 40 passengers,

t = 2 ... 4 hours and 50 passengers

t <2 hours to 60 passengers.

Calculated area of lavatory is equal to:

$$n_{lav} = \frac{n_{pass}}{50} = \frac{200}{50} = 4,$$

where n_{lav} – number of lavatories

The number of lavatories I choose according to the original airplane and it is equal 4.

Area of lavatory:

$$S_{lava} = 1 \cdot 1.150 = 1.15 \quad \text{m}^2,$$

where S_{lava}– area of lavatory.

Width of lavatory: 1m. Toilets design similar to the prototype.

Galley and lavatory design are similar to the prototype.

2.1.6 Layout and calculation of basic parameters of tail unit.

The selection of the tail unit (TU) fig. 2.5 position is a crucial aspect of the aerodynamic layout in aircraft design. It plays a significant role in achieving longitudinal stability during maneuvering flight.

To ensure longitudinal stability, it is essential to position the aircraft's center of gravity (CG) ahead of the aerodynamic center (AC), also known as the aircraft's focus. The distance between these points, referred to as the "arm" for the aerodynamic moment of the lift force, is determined in relation to the mean value of the wing's aerodynamic chord. This arm distance directly influences the degree of longitudinal stability.

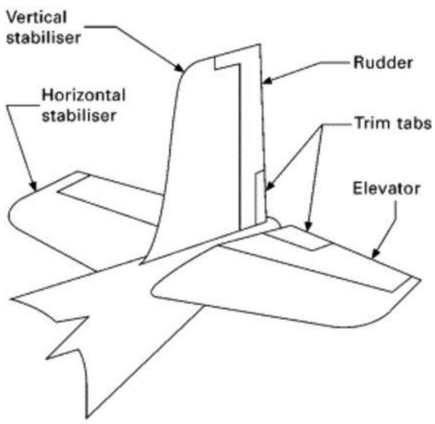

Fig.2.5. Tail unit structure.

Determination of the TU geometrical parameters.

Usually the areas of vertical S_{VTU} and horizontal S_{HTU} of TU is:

$$S_{HTU} = (0.18..0.25)S;\ S_{VTU} = (0.12..0.20)S;$$

In the first approach we may count that $L_{HTU} \approx L_{VTU}$ and we may find it from the dependences:

Light airplane :

$$L_{HTU} = (2.0..2.3)\ b_{mac} = 2.2 \cdot 5.505 = 12.11 \text{ m};$$

where L_{HTU} – length of horizontal tail unit, m;

Trapezoidal scheme, normal scheme:

$$L_{VTU} = (0.2..3.5)\ b_{mac} = 2.2 \cdot 5.505 = 12.11 \text{ m};$$

$$L_{VTU} \approx L_{HTU} = 12.11 \text{ m}$$

where L_{HTU} and L_{VTU} - arms of horizontal TU and vertical TU.

The area of horizontal plumage is calculated according to the following formulas:

$$A_{HTU} = (0.65\ldots0.8)$$

$$S_{HTU}1 = \frac{b_{MAC} \cdot S_w \cdot A_{HTU}}{L_{HTU}} = \frac{5.505 \cdot 193.07 \cdot 0.65}{12.11} = 57.03\,\text{m}^2,$$

where S_{HTU} – area of horizontal tail unit, m^2; A_{HTU} – coefficient of static momentum of horizontal tail unit.

The area of vertical tail unit is calculated according to the following formulas:

$$A_{VTU} = (0.08\ldots0.12),$$

$$S_{VTU1} = \frac{l_w \cdot S_w \cdot A_{VTU}}{L_{VTU}} = \frac{0.1 \cdot 193.07 \cdot 40.03}{12.11} = 63.81\,\text{m}^2,$$

where L_w, S_w – wing span and wing area, A_{HTU}, A_{VTU} – coefficients of static moments, values of which may be taken from the table.

Values L_{HTU} and L_{VTU} depend on some factors. First of all their value are influenced by: the length of the nose part and tail part of the fuselage, sweptback and wing location, and also from the conditions of stability and control of the airplane.

Determination of the elevator area:

$$S_{el} = (0.3..0.4)\ S_{HTU} = 0.3 \cdot 57.03 = 17.09\ \text{m}^2\ ;$$

where S_{el} – elevator area.

Rudder area:

$$S_{rudder} = (0.2..0.22)\ S_{VTU} = 63.81 \cdot 0.2 = 12.76\ \text{m}^2;$$

where S_{rud} – rudder area, m^2.

Determination of the elevator and rudder balance area:

$$S_{eb} = (0.22\ldots0.25)S_{el} = 0.23 \cdot 17.09 = 3.93\,\text{m}^2$$

$$S_{rb} = (0.2\ldots0.22)S_{rud} = 0.22 \cdot 12.76 = 2.80\,\text{m}^2$$

where S_{rb} –rudder balance area, m^2, where S_{eb}– area of aerodynamic balance, m^2.

Calculation of the altitude elevator trim tab area:

$$S_{te} = 0.08 \cdot S_{el} = 0.08 \cdot 17.09 = 1.36\,\text{m}^2,$$

where S_{te} –elevator trim tab area, m^2.

Calculation of the rudder trim tab area:

$$S_{tr} = 0.06 \cdot S_{rud} = 0.06 \cdot 12.76 = 0.7656\,\text{m}^2$$

where S_{tr} – rudder trim tab area, m^2.

TU span is related to the following dependence:

$$L_{ro} = (0.32\ldots0.5)l_w = 0.4 \cdot 40.03 = 16.01\ \text{m}$$

where L_{ro} – tail unit span, m.

2.1.7 Calculation of basic parameters and layout of landing gear.

During the initial stages of aircraft design, when the center-of-gravity position of the airplane has not yet been established and a complete drawing of the airplane's general view is unavailable, it is still possible to focus on determining specific parameters related to the landing gear.

The distance from the centre of gravity to the main LG:

$$B_m = (0.15\ldots0.2)b_{MAC} = 0.231 \cdot 5.505 = 1.271 \text{ m}$$

where B_m– main wheel axes offset, m.

When considering the placement of the nose gear during takeoff, finding the right balance is crucial. If the distance between the main gear and the nose gear is too large, it can complicate the lifting of the nose gear during takeoff. On the other hand, if the distance is too small, there is a risk of the airplane’s tail striking the ground, especially when the rear of the aircraft is heavily loaded.

It is important to find the optimal distance that allows for a smooth and controlled lift of the nose gear while preventing any tail strikes. Additionally, maintaining an appropriate load on the nose landing gear is essential for the stability of the aircraft during the takeoff run, especially on slick runways and in crosswind conditions.

Finding the right balance in the placement of the nose gear is a critical consideration to ensure safe and stable takeoff operations. This involves careful analysis and design to optimize the aircraft’s performance and handling characteristics during the takeoff phase.

Landing gear wheel base comes from the expression:

$$B = (0.3..0.4)l_f = (6..10)B_m;$$

$$B = 10 \cdot 1.271 = 12,744 \text{ m};$$

where B – wheel base, m.

Large value belongs to the airplane with the engine on the wing.

The last equation means that the nose support carries 6..10% of aircraft weight.

The distance from the centre of gravity to the nose LG

$$B_n = B - B_m = 12,744 - 1,271 = 11,473 \text{ m};$$

where B_m – distance to the center of gravity to the main wheel, m.

Wheel track is:

$$T = (0.7..1.2)B \leq 12 \text{ m};$$

$$T = 0.9 \cdot 12.75 = 11,4696 \text{ m};$$

where T – wheel track, m.

The selection of wheels for the aircraft's landing gear depends on the size of the aircraft and the weight it carries during takeoff. Additionally, when choosing the front support wheel, we also take into account the dynamic loading it will experience.

The type of tires used and the pressure they are inflated to depend on the type of runway surface that will be utilized. We equip the main wheels with brakes, and in some cases, the front wheel is also equipped with brakes.

The load on the wheel is determined:

$$F_{main} = \frac{(B - B_m)m_0 \cdot 9.81}{B \cdot n \cdot z} = \frac{(12.744 - 1.271) \cdot 101422 \cdot 9.81}{12.744 \cdot 2 \cdot 4} = 111965 \text{ N}$$

where F_{main} – main wheel load, N; n – number of main landing gear struts.

The load applied to the main wheel could be calculated as:

$$F_{nose} = \frac{Bm \cdot m_0 \cdot 9.81 \cdot K_g}{B \cdot z} = \frac{1.271 \cdot 101422 \cdot 9.81 \cdot 1.5}{12.744 \cdot 2} = 74422 \text{ N}$$

where F_{nose} – nose wheel load, N; K_g– dynamics coefficient; z – number of wheels.

2.1.8 Choice and description of power plant

CFM56-7 / PW1000G / JT9D-7R4 - is a family of high-bypass turbofan aircraft engines, in various modifications installed on passenger aircraft.

Table 2.1

Characteristics of engines

Name	CFMI CFM56-7	PW1000G	JT9D-7R4
Compressor	1 fan, 3 LP, 9 HP	1 fan, 3 LP, 8 HP	1 fan, 3 LP, 8 HP
Weight	2370 kg	2857 kg	4053 kg
Thrust	82-151 kN	107.82-147.28 kN	214–249 kN
Length	250 cm	340 cm	3.37 cm
Bypass ratio	5.5:1	12.5:1	4,8: 1
Diameter	155 cm	206 cm	2.37
Overall pressure ratio	32.7:1	40.7:1	26.7:1

Two PW1000G engines will be installed on the designing aircraft.

2.2 Center of gravity calculation

2.2.1 Trim-sheet of the equipped wing

The mass of the equipped wing consists of three components: the mass of the wing structure, the mass of the equipment installed within the wing, and the mass of the fuel. This applies regardless of whether the equipment is mounted on the wing or on the fuselage. Additionally, the main landing gear and the front gear are included in the mass register of the equipped wing.

The mass register contains the names of the objects, their respective masses, and the coordinates of their center of gravity. The coordinates of the mass centers are referenced to the projection of the nose point of the mean aerodynamic chord (MAC) onto the XOY surface. Positive values for the coordinates indicate the end part of the aircraft.

For aircraft with engines located under the wing, an example list of mass objects is provided in Table 2.2. Similarly, for aircraft with engines located within the wing, another example list of mass objects is given in the same table. The total mass of the aircraft, including the equipped wing, is specified as 101,422 kg. Coordinates of the center of power for the equipped wing are defined by the formulas:

$$X_w^{'} = \frac{\sum m_i^{'} x_i^{'}}{\sum m_i^{'}}$$

where $X_w^{'}$ – center of mass for equipped wing, m; $m_i^{'}$ – mass of a unit, kg; x_i – center of mass of the unit, m.

Table 2.2

Trim-sheet of equipped wing

N	Object name	Mass		C.G coordinate, m	Mass moment, kgm
		Units	Total mas, kg		
1	Wing (structure)	0.09812	9951.52	2.37	23556.75
2	Fuel system	0.0079	801.23	2.34	1874.58
3	Flight control system, 30%	0.00177	179.51	3.3	592.94
4	Electrical equipment, 10%	0.00314	318.46	0.55	175.3
5	Anti-ice system, 40%	0.00936	949.30	0.55	522.59
6	Hydraulic systems, 70%	0.01169	1185.62	3.3	3916.11
7	Power plant	0.0868	8805.45	-1.6	-14088.73
9	Equipped wing without landing gear and fuel	0.2188	22191.13	0.745	16549.57
10	Nose landing gear	0.0075	762.69	-12.71	-9693.83
11	Main landing gear	0.0322	3265.78	0.82	2677.94
12	Fuel	0.2671	27093.87	2	54187.74
13	Total	0.5256	53313.48	1.195221675	63721.43

2.2.2 Trim-sheet of the equipped fuselage

Origin of the coordinates is chosen in the projection of the nose of the fuselage on the horizontal axis. For the axis X the construction part of the fuselage is given. The example list of the objects for the AC, which engines are mounted under the wing, is given in table 2.2.

Table 2.3 provides a list of aircraft objects with engines located beneath the wing where the origin of coordinates is determined by the projection of the nose part of the fuselage onto the horizontal axis. The X axis represents the structural part of the hull.

The CG coordinates of the FEF are determined by formulas:

$$X_f^{'} = \frac{\sum m_i^{'} x_i^{'}}{\sum m_i^{'}},$$

where $X_f^{'}$ – center of mass for equipped fuselage, m; $m_i^{'}$ – mass of a unit, kg; x_i – center of mass of the unit, m.

After we determined the C.G. of fully equipped wing and fuselage, we construct the moment equilibrium equation relatively to the fuselage nose:

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

From here we determined the wing MAC leading edge position relative to fuselage, means X_{MAC} value by formula:

$$X_{MAC} = \frac{m_f \cdot X_f^{'} + m_w \cdot X_w^{'} - m_0 \cdot C}{m_0 - m_w} = \frac{601817.1 + 60771.46 - 82867 \cdot 0.25 \cdot 4.178}{82867 - 49820.47} =,$$
$$= 17.43099764 \text{ m}$$

where m_0 – aircraft takeoff mass, kg; m_f – mass of fully equipped fuselage, kg; m_w – mass of fully equipped wing, kg; C – distance from MAC leading edge to the C.G, calculated from statistic data and approximately is equal to $C = (0,22...0,25) B_{MAC}$;

Table 2.3

Trim-sheet of equipped fuselage

N	Objects names	Mass		C.G coordinates Xi, m	Mass moment
		Units	Total mass		
1	Fuselage	0.09068	9196.94696	19.5	179340.46
2	Horizontal tail	0.01138	1154.18236	32	36933.83
3	Vertical tail	0.01293	1311.38646	31.5	41308.67
4	Radar	0.003	304.266	1	304.26
5	Radio equipment	0.0022	223.1284	1	223.12
6	Instrument panel	0.0052	527.3944	2	1054.78
7	Aero navigation equipment	0.0045	456.399	2	912.79
10	Flight control system, 70%	0.00413	418.87286	16.925	7089.42
11	Hydraulic system 30%	0.00501	508.12422	23.695	12040.00
12	Electrical equipment 90%	0.02826	2866.18572	13.925	39911.63
13	Not typical equipment	0.0022	223.1284	3	669.38
14	Lining and insulation	0.006	608.532	16.925	10299.40
15	Anti ice system, 20%	0.00468	474.65496	27.08	12853.65
16	Airconditioning system, 40%	0.009360	949.30992	16.925	16067.07
17	Passenger seats (bussiness)	0.001158	117.4956	5.925	696.16
18	Passenger seats (economic class)	0.014364	1456.8327	20	29136.65
19	Seats of flight attendence	0.000289	29.373941	1.82	53.46
20	Seats of pilot	0.000241	24.478301	1.48	36.22
	Emergency equipment	0.00144647	146.704488	8.1	1188.30
	Lavatory1, galley 1	0.0084	851.9448	2.96	2521.75
	Lavatory2, galley 2	0.0084	851.9448	30	25558.34
	Operational items	0.002113	214.3046	26	5571.92
21	Additional eguipment	0.01084	1099.41448	5	5497.07

End of the table 2.3

22	Equipped fuselage without payload	0.236783	24015.005	17.875009	429268.44
	Passengers(economy)	0.13014927	13200	20	264000
23	Passengers(bussiness)	0.01893080	1920	5.925	11376
24	On board meal	0.00279525	283.5	30	8505
25	Baggage	0.05590503	5670	18	102060
26	Cargo, mail	0.02473171	2508.34	18	45150.12
27	Flight attend	0.00354952	360	17	6120
28	Crew	0.00151840	154	2.4	369.6
29	TOTAL	0.47436301	48110.8455	18.0177494	866849.16
	TOTAL fraction for checking	1.00002301	101424.334		

2.2.3 Calculation of center of gravity positioning variants

The list of mass objects for centre of gravity variant calculation given in Table 2.4 and center of gravity calculation options given in table 2.5, completes on the base of both previous tables.

Table 2.4

Calculation of C.G. positioning variants

Name	Mass in kg	Coordinate	Mass moment
Object	m_i	X_i, м	kgm
Equipped wing (without fuel and landing gear)	22191.13	17.19	381410.86
Nose landing gear (extended)	762.69	5.00	3813.47
Main landing gear (extended)	3265.79	17.86	58326.98
Fuel reserve	3503.12	18.44	64603.62
Fuel for flight	23590.76	18.44	435055.07
Equipped fuselage (without payload)	24015.01	17.88	429268.44
Passengers(economy)	13200	20.00	264000.00

End of the table 2.4

Passengers(bussiness)	1920	5.93	11376.00
On board meal	283.5	30.00	8505.00
Baggage	5670	18.00	102060.00
Cargo, mail	2508.34	18.00	45150.12
Flight attend	360	17.00	6120.00
Crew	154	2.40	369.60
Nose landing gear (retrected)	762.69	4	3050.77
Main landing gear (retrected)	3265.78	17.86	58326.98

Table 2.5

Airplanes C.G. position variants

№	Object	Mass, kg	Mass moment, kgm	Center of mass	Centre of gravity position
1	Take off mass (L.G. extended)	101424.33	1810059.15	17.84	0.2551
2	Take off mass (L.G. retracted)	101424.33	1809296.46	17.83	0.2537
3	Landing weight (LG extended)	77833.58	1375004.09	17.66	0.2223
4	Ferry version (without payload,max fuel, LG retracted)	77482.49	1372085.34	17.70	0.2300
5	Parking version (without payload, without fuel foe flight, LG extended)	53737.74	937423.37	17.44	0.1821

Conclusion to the part

Throughout this work the calculations for a single-class aircraft was performed and designed to accommodate 200 passengers. The aircraft is equipped with two PW1000G turbofan engines. Additionally, the aircraft geometry and layout was calculated, the geometry of the wing, fuselage, tail, and landing gear were chosen. The number, design and dimensions of galleys, toilets, and wardrobes were determined. Moreover, the calculations for the center of gravity was assessed and general view of the aircraft and layout was created.

3. CONCEPTUAL DESIGN OF SAFETY SYSTEM FOR PASSENGER AIRCRAFT

3.1. Aviation safety system on board: challenges and solutions

Based on statistical data, a significant proportion (70-80%) of aviation accidents occur during takeoff or emergency landings on land or water. Passenger aircraft designs aim to minimize the impact on passengers and crew during ground or water contact by utilizing the deformation of the lower part of the fuselage, which absorbs a significant amount of kinetic energy upon impact.

Investigations into plane accidents have shown that many passengers survive the initial impact but are unable to evacuate the aircraft in time and perish due to suffocation caused by subsequent fires. Therefore, the primary focus is on prompt emergency evacuation during landing emergencies to save passengers and crew.

Modern technical requirements for passenger emergency evacuation systems include the following:

Passengers must be evacuated from the aircraft to the ground within 90 seconds, using either all exits on one side of the fuselage or 50% of all exits, while maintaining a minimum evacuation speed equivalent to evacuating from one side of the fuselage.

Each emergency exit must be equipped with an inflatable ladder that automatically or semi-automatically assumes its working position within 10 seconds of opening the emergency exit. The ladder should extend to a length that allows it to reach the ground, even if one or more landing gear struts are damaged.

In any position of the aircraft resulting from the failure of one or more landing gear supports, there should be two functional emergency exits for every 100 passengers.

The exit opening mechanisms should be simple and require no more than 150 N of force.

The placement of emergency exits plays a crucial role in ensuring the safety of passenger aircraft operations. These exits are located on both sides of the aircraft, preferably at the front and rear of the passenger cabin. Additionally, entrance doors for passengers, which open outward and have no threshold, also serve as emergency exits. Wide-body aircraft typically have entrance doors on both sides.

Organizing the emergency evacuation of passengers is a complex task that requires tailored methods and solutions for each aircraft's layout and structure. In addition to the main entrances, there are also emergency exits positioned above the wings. Seats near these exits have extra space, and crew members are assigned to assist passengers during evacuation. Rescue ropes are used to descend from the wing to the ground in cases where the aircraft performs an emergency landing with the landing gear deployed.

After all passengers and crew members have evacuated, the captain (left pilot) is the last to leave the distressed aircraft through the cockpit cabin, using a rescue rope. Emergency axes are available in the crew cabin to cut exits in the fuselage skin if emergency exits become jammed. Portable manual fire extinguishers are also provided to suppress fires in the passenger cabin.

During emergency landings on water, the passenger plane remains afloat for several tens of minutes. Prior to landing, emergency fuel drain significantly increases the plane's buoyancy, as the water capacity of the fuel tanks nearly matches the weight of the plane without fuel. Passengers and crew are then directed to life rafts, which are equipped with a first-aid kit containing essential survival supplies such as radio beacons, lanterns, first-aid kits, food provisions, and sea water desalinators. Modern ladders, containers with emergency equipment, and rafts with large working volumes can be folded into compact sizes and placed near ceiling exits, on the cabin floor, or near the evacuation door.

Flight operation manuals for passenger aircraft provide specific instructions and recommendations for each crew member to follow during all stages of flight preparation and piloting, including emergency situations. International regulations mandate that passengers be briefed on safety procedures and the proper use of emergency and rescue equipment before each flight.

3.2. Significance of requirements for emergency passenger equipment

Aircraft engineers have a critical responsibility to carefully consider the placement of emergency equipment to ensure its accessibility and suitability for various potential scenarios. By ensuring easy access to emergency equipment, flight crews can work more efficiently and improve their ability to save lives. It is also essential to protect the emergency equipment from accidental damage, so mechanisms should be in place for quick disconnection and immediate use.

The proposed concept must meet specific requirements for safety equipment, including individual flotation devices, shock-absorbing surfaces, and access to purified air in smoky environments.

Every seated passenger must have access to an individual flotation device, which can be either inflatable or non-inflatable.

Inflatable devices require inflation using compressed gas from a cartridge, while non-inflatable devices (fig.3.1), such as seat cushions, headrests, armrests, or cushions, are also acceptable as long as they meet safety and performance standards. To prevent the loss of a cushion during a dive, a retaining strap can be used, ensuring its availability even when the user is incapacitated or exposed to cold conditions. Each passenger should have their own flotation device.

Flotation cushions typically incorporate features like construction with water-resistant foam materials that provide indefinite buoyancy or open-cell foam cushions covered with tightly woven fabric and sealed seams.

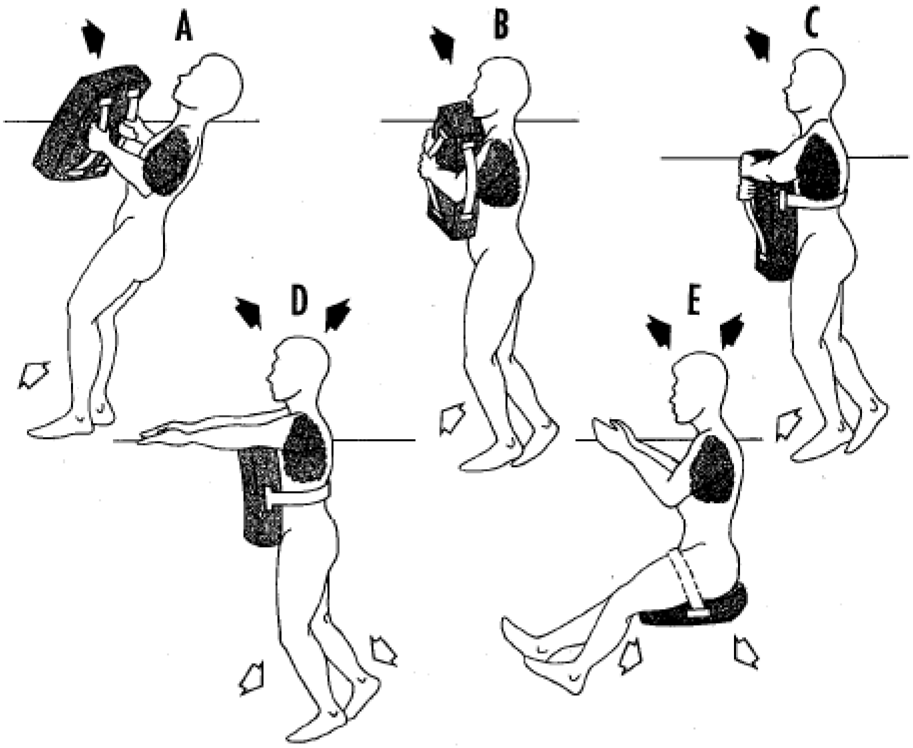

Fig. 3.1. Non-inflatable device.

The materials used in the construction of emergency equipment must be of high quality and proven suitability for life-saving purposes. Non-metallic materials are preferred, and the finished devices must be clean and free from defects that could affect their performance. Coated fabrics and related products, like wear tapes, must be manufactured within 18 months prior to the delivery date or undergo requalification. The materials should not promote fungal growth, and coated fabrics, including seams, must retain at least 90 percent of their original physical properties after accelerated aging tests.

Devices with heat-welded seams must meet specific strength requirements for shear seam strength and tear resistance. The use of tape over heat-welded seams is optional, but if used, the fabric must have a minimum tensile strength. Other materials used in the devices are also subjected to testing requirements. The strap securing the flotation device to the user must have a minimum breaking strength, and the line used in the device must meet certain strength criteria. Non-metallic fittings must maintain their physical characteristics within a specific temperature range, and all metal parts must be corrosion-resistant or adequately protected against corrosion.

Unless the design of the mechanism prevents incorrect usage, the lifebuoy should be capable of fulfilling its intended function even when turned upside down.

To ensure protection against abrasion and rubbing, it is crucial to shield the flotation chambers of type I lifesaving devices. This shielding should prevent any metallic or non-metallic components from causing chafing or abrasion of the material, both during storage and when the device is inflated.

In order to allow users (excluding infants and small children who need adult assistance) to inflate each flotation chamber without prior instruction, a mechanism should be included that enables them to blow into the mouthpiece. The mouthpiece for oral inflation should be easily accessible to the user without obstructing their face or body. For infant-toddler children and children's lifebuoys, caregivers should have access to a readily available mouth pump.

In relation to the inflation valve, certain criteria should be met. The opening pressure of the mouth inflation valve, in the absence of back pressure, must not exceed 3 kN/m2 (0.44 psig). The oral injection valve should remain leak-free when subjected to a back pressure ranging from 0 to 10 psi (0.69 kN/m2). Additionally, the connection between the mouth inflatable valve and the flotation chamber should not fail when a tensile load of 445 N (100 lb) is applied outward and perpendicular to the surface of the flotation chamber at the valve attachment point for at least 3 seconds. To provide support during loading, an adapter with an inside diameter at least 19 mm (3/4 inch) larger than the outside diameter of the valve at the attachment point should be used to reinforce the flotation chamber fabric.

In terms of buoyancy, it is imperative that the lifebuoy generates sufficient upward force. When fully submerged, it should displace an amount of fresh water equal to its weight. To demonstrate buoyancy, standard gas tanks are utilized without any additional oral inflation, starting from a vacuumed flat block.

Rescue equipment designed for adults, adult-child, and children must adhere to certain requirements. The lifebuoy should effectively and swiftly secure the wearer in a face-down position within 5 seconds after immersion in water. It is essential that the lifebuoy provides adequate support to the user's head from the sides and rear, ensuring that the mouth and nose remain above the waterline, and the torso is tilted back at an angle of at least 30 degrees from the vertical position.

For infants and small children, the lifebuoy should have features that prevent the upper body (waist and above) from coming into contact with the water. Additionally, there should be a mechanism in place to secure the user in the correct position and prevent them from unintentionally releasing the securing means.

To ensure stability and avoid overturning or water ingress, the lifebuoy should remain steady even when the user is in the most challenging weight and position achievable with proper use of restraints. Adequate measures should also be implemented to prevent the entry of rainwater or rough water into the lifebuoy.

Key features of holding and wearing a lifebelt should meet specific criteria. When attaching a lifebuoy to a wearer, except for baby carriages, it is recommended to use only one attachment and make one adjustment to ensure a proper fit. It should be demonstrated that an unassisted adult can correctly fit a suitable lifebuoy onto another adult or child within a maximum time limit of 30 seconds. Furthermore, it should be demonstrated that at least 60% of adult subjects can fit an infant-toddler dummy into an infant-toddler lifebuoy within 90 seconds.

The design of the lifebuoy should prioritize comfort, fit, and adaptability, ensuring that it is easy to wear and adjust. Once worn, the lifebuoy should be secure, minimizing the likelihood of accidental release by the user. Any necessary adjustments can be made by the owner or a person assisting a child or infant-toddler while in the water.

The user should have an unobstructed view in both the forward and side directions, with the exception of baby strollers. In the case of a lifebuoy including a carrier for infants and small children, a viewing window should be incorporated to allow a rescuer to observe the child. The design should not impede blood circulation in the carrier or restrict the user's breathing.

Oxygen Masks (fig. 3.2):

To ensure the appropriate oxygen supply for passengers and cabin crew members, the minimum flow rate of supplemental oxygen should meet specific criteria based on the cabin pressure altitude. The objective is to maintain average tracheal oxygen partial pressures at specified breathing rates and tidal volumes. The requirements are as follows:

Altitudes above 3048 m (10,000 ft) up to and including 5639 m (18,500 ft):

Breathing at 15 liters per minute, BTPS (Body Temperature and Pressure, Saturated), with a tidal volume of 700 cm^3 and a constant time interval between breaths. The average tracheal oxygen partial pressure should be 100 mmHg.

Altitudes above 5639 m (18,500 ft) up to and including 12192 m (40,000 ft):

Breathing at 30 liters per minute, BTPS, with a tidal volume of 1100 cm^3 and a constant time interval between breaths.

The average tracheal oxygen partial pressure should be 83.8 mmHg.

Fig. 3.2. Oxygen masks.

In cases where first-aid oxygen equipment is available, each user should receive a minimum oxygen flow rate of 4 liters per minute, STPD (Standard Temperature and

Pressure, Dry). However, there may be provisions to reduce this flow to a minimum of 2 liters per minute, STPD, at any cabin altitude. The quantity of oxygen required is based on an average flow rate of 3 liters per minute per person who needs first-aid oxygen.

Portable oxygen equipment is strategically placed throughout the cabin to ensure the availability of oxygen for first-aid treatment to both passengers and crew. This equipment allows cabin attendants to move freely while having a reliable oxygen supply. The portable oxygen equipment comprises of portable oxygen cylinders and continuous-flow oxygen masks.

There are two mask outlets provided on the equipment. One is labeled as LOW, delivering a flow rate of 2 liters per minute, intended for walkaround use. The other outlet is labeled as HIGH, supplying a flow rate of 4 liters per minute for first-aid purposes. Clear operating instructions are prominently displayed on a placard attached to each oxygen cylinder. It's important to ensure that the portable device meets the necessary requirements for oxygen masks, such as appropriate dimensions, adherence to material specifications, air purity standards, and service life regulations.

3.3. Ensuring passenger safety by the portable device.

Ensuring Passenger Safety with the Portable Device:

In my third section, I present a unique device that serves as a multi-functional rescue system to ensure passenger safety. This device is designed to perform three crucial functions: providing buoyancy in the event of a water landing, preventing injuries during a rough landing or sudden aircraft stop, and supplying clean air in a smoke-filled environment.

The device (fig 3.3) combines the functions of existing equipment pieces: life jackets for buoyancy, specially designed seat walls for injury prevention, and oxygen masks for clean air supply. I personally invented this device, which serves as an external attachment at the back of each seat. It can be easily removed if the pilot reports a dangerous situation, and it will then perform its functions based on the specific catastrophe that has occurred.

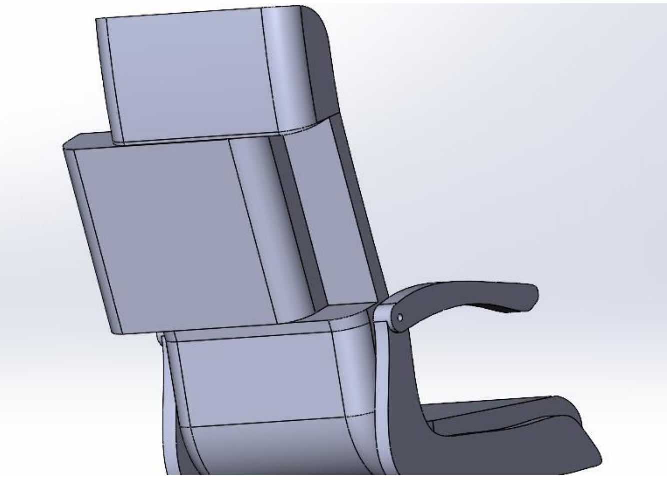

Fig. 3.3. Portable device

The device is positioned between the monitor and the reading table and has a design resembling a seat wall. Its exterior is made of impact-absorbing plastic, while the interior is filled with foam. This construction allows it to effectively absorb impact energy, with the exterior plastic and interior foam working together for this purpose.

To ensure buoyancy while attached to a person's body, lightweight materials that can absorb impact energy effectively are used. The device is also equipped with a mechanism to provide clean air for breathing. Within the foam material, there is a filter to purify smoke-filled air. The air intake is located at the bottom of the device, while a respirator at the top allows the user to breathe already purified air.

Overall, this portable device addresses the crucial aspects of passenger safety during emergencies, combining buoyancy, injury prevention, and clean air supply into a single innovative solution.

Conclusion to the part

In this part, we mainly engaged in the development of my idea about emergency equipment. We have high hopes for this device, because such means of rescue have not been used before. It has the following advantages over other emergency equipment: in the speed of use, in the portability of the oxygen mask (fire can also be from outside the plane). It should cling to the body in the same way as a type 2 flotation device (non-inflatable), so it can be quickly removed. The time of using the filter will be sufficient for evacuation from the plane and even the use of a breathing apparatus on the ground.

GENERAL CONCLUSION

Throughout the work, extensive research and analysis have been conducted, focusing on various aspects of aircraft design, functionality, and safety measures. The chosen prototype airplanes, namely the Boeing 737-900, Airbus 321, and A 310-300, were thoroughly examined, providing a comprehensive overview of each model. Additionally, a visionary aircraft design was presented, featuring a low-wing monoplane configuration and dual turbojet engines.

The project also involved calculations and considerations for a single-class aircraft designed to accommodate 200 passengers. Along detailed evaluations of wing, fuselage, tail, and landing gear parameters, contributed to the comprehensive analysis. Furthermore, vital determinations were made regarding the quantity and dimensions of essential facilities such as kitchens, toilets, and wardrobes. Additionally, calculations to the aircraft's center of gravity were performed, and detailed aircraft drawings were created. A significant portion of the thesis work was dedicated to the development of a novel emergency equipment concept, highlighting its potential as an unprecedented means of rescue. This innovative device offers several advantages over existing emergency equipment, including its swift usability, portability of the oxygen mask (even in the presence of external fire), and its secure attachment to the body, akin to flotation device. The device's integrated filtration system ensures sufficient time for safe evacuation from the aircraft, and it can even be used with a breathing apparatus on the ground.

Overall, this thesis represents a comprehensive exploration of aircraft design, functionality, and safety measures, encompassing prototype analysis, meticulous calculations, and the development of a groundbreaking emergency equipment concept. The findings and insights gained from this work provide valuable contributions to the field of aviation and its ongoing commitment to enhance passenger safety and comfort.

REFERENCE

1. Конструкція та міцність літальних апаратів (частина 1): методичні рекомендації до виконання курсового проекту для студентів спеціальності 134 «Авіаційна та ракетно-космічна техніка» /уклад.: С.Р. Ігнатович, М.В. Карускевич, Т.П. Маслак, С.В. Хижняк, С.С. Юцкевич. – К.: НАУ, 2018. – 91с.

2. Конструкція та міцність літальних апаратів (частина 2): методичні рекомендації до виконання курсового проекту для студентів спеціальності 134 «Авіаційна та ракетно-космічнатехніка» / уклад.: С.Р Ігнатович, Т.П. Маслак, С.В. Хижняк, С.С. Юцкевич. – К.: НАУ, 2018. – 48 с.

3. Авіаційна та ракетно-космічна техніка: методичні рекомендації до виконання кваліфікаційної роботи / уклад.: С. В. Хижняк, М. М. Свирид, Т. П. Маслак, В. С. Краснопольський. – К. : НАУ, 2022. – 48 с.

4. Основи авіації (вступ до спеціальності): підручник / С.Р. Ігнатович, О.В. Попов, В.О. Максимов та ін. – К.: НАУ, 2023. – 296 с.

5. Aircraft Design: A Conceptual Approach, Sixth Edition, Daniel Raymer, Publication Date: September 30, 2018.

6. Aircraft Design: A Systems Engineering Approach (Aerospace Series) 1st Edition, Kindle Edition by Mohammad H. Sadraey. Wiley, 2012.

7. https://www.easa.europa.eu/en/document-library/certification-specifications/group/cs-25-large-aeroplanes

8. https://www.aeroclass.org/emergency-equipment-in-aircraft/

9. https://www.easa.europa.eu/en/document-library/easy-access-rules/online-publications/easy-access-rules-large-aeroplanes-cs-25?page=27

10. General Aviation Aircraft Design: Applied Methods and Procedures Gudmundsson, S, Wiley, 2014.

11. http://4ua.co.ua/transport/vb3ac68b5c43a89421316d37_0.html

Appendix A

INITIAL DATA AND SELECTED PARAMETERS

Passenger Number-200
Flight Crew Number-2
Flight Attendant or Load Master Number-7
Mass of Operational Items-2143,09
Payload Mass-22990кг

Cruising Speed-850
Cruising Mach Number-0,7870
Design Altitude-10км
Flight Range with Maximum Payload-5000км
Runway Length for the Base Aerodrome-3,30км

Engine Number-2
Thrust-to-weight Ratio in N/kg-3,1100
Pressure Ratio-32,5
Assumed Bypass Ratio-4,5
Optimal Bypass Ratio-4,5
Fuel-to-weight Ratio-0,3600

Aspect Ratio-8,3
Taper Ratio-4,74

Mean Thickness Ratio-0,112
Wing Sweepback at Quarter Chord-27
High-lift Device Coefficient-1,050
Relative Area of Wing Extensions-0,050
Wing Airfoil Type-supercritical
Winglets-yes
Spoilers-yes

Fuselage Diameter-3.54м
Finess Ratio-12
Horizontal Tail Sweep Angle-30
Vertical Tail Sweep Angle-35

CALCULATION RESULTS

Optimal Lift Coefficient in the Design Cruising Flight Point

Induce Drag Coefficient

ESTIMATION OF THE COEFFICIENT $D_m = M_{critical} - M_{cruise}$

Cruising Mach Number-0,78701
Wave Drag Mach Number-0,79595
Calculated Parameter D_m -0,00894

Wing Loading in kPa (for Gross Wing Area):
At Takeoff-5,971
At Middle of Cruising Flight-5,148
At the Beginning of Cruising Flight-5,764

Drag Coefficient of the Fuselage and Nacelles-0,00815
Drag Coefficient of the Wing and Tail Unit-0,00910
Drag Coefficient of the Airplane:
At the Beginning of Cruising Flight-0,02836
At Middle of Cruising Flight-0,02727

Mean Lift Coefficient for the Ceiling Flight-0,44685
Mean Lift-to-drag Ratio-16,38591
Landing Lift Coefficient-1,628
Landing Lift Coefficient (at Stall Speed)-2,441
Takeoff Lift Coefficient (at Stall Speed)-2,014
Lift-off Lift Coefficient-1,470
Thrust-to-weight Ratio at the Beginning of Cruising Flight-0,567
Start Thrust-to-weight Ratio for Cruising Flight-2,123
Start Thrust-to-weight Ratio for Safe Takeoff-2,679
Design Thrust-to-weight Ratio-2,786
Ratio $D_r = R_{cruise} / R_{takeoff}$ Д p=0,792

SPECIFIC FUEL CONSUMPTIONS (in kg/kN*h):
Takeoff-37,5179
Cruising Flight-59,6844
Mean cruising for Given Range-62,8788

FUEL WEIGHT FRACTIONS:
Fuel Reserve-0,03454
Block Fuel-0,23260

WEIGHT FRACTIONS FOR PRINCIPAL ITEMS:
Wing-0,09812
Horizontal Tail-0,01138
Vertical Tail-0,01293
Landing Gear-0,03972
Power Plant-0,08682
Fuselage-0,09068
Equipment and Flight Control-0,13456
Additional Equipment-0,01084
Operational Items-0,02113
Fuel-0,26714
Payload-0,22668
Airplane Takeoff Weight-101422 кг
Takeoff Thrust Required of the Engine-141,30 кН

Air Conditioning and Anti-icing Equipment Weight Fraction-0,0234
Passenger Equipment Weight Fraction-0,0175
(or Cargo Cabin Equipment)
Interior Panels and Thermal/Acoustic Blanketing Weight Fraction-0,0060
Furnishing Equipment Weight Fraction-0,0168
Flight Control Weight Fraction-0,0059
Hydraulic System Weight Fraction-0,0167
Electrical Equipment Weight Fraction-h0,0314
Radar Weight Fraction0,0030
Navigation Equipment Weight Fraction-0,0045
Radio Communication Equipment Weight Fraction-0,0022
Instrument Equipment Weight Fraction-0,0052
Fuel System Weight Fraction-0,0079

Additional Equipment:
Equipment for Container Loading-0,0087
No typical Equipment Weight Fraction-0,0022
(Build-in Test Equipment for Fault Diagnosis,
Additional Equipment of Passenger Cabin)

TAKEOFF DISTANCE PARAMETERS
Airplane Lift-off Speed-290,07км/год
Acceleration during Takeoff Run-2,09 м/сек
Airplane Takeoff Run Distance-1548 м
Airborne Takeoff Distance-578м
Takeoff Distance-2126м

CONTINUED TAKEOFF DISTANCE PARAMETERS
Decision Speed-275,57 км/год
Mean Acceleration for Continued Takeoff on Wet Runway-0,18 м/с*с
Takeoff Run Distance for Continued Takeoff on Wet Runway-3091,66м
Continued Takeoff Distance-3670,66м
Runway Length Required for Rejected Takeoff-3804,36м

LANDING DISTANCE PARAMETERS
Airplane Maximum Landing Weight-82427кг
Time for Descent Flight Level till Aerodrome Traffic Circuit Flight-20,4хв
Descent Distance-48,10км
Approach Speed-267,26
Mean Vertical Speed-2,13м/с
Airborne Landing Distance-524м
Landing Speed-252,26км/год
Landing run distance-861м
Landing Distance-1385м
Runway Length Required for Regular Aerodrome-2313м
Runway Length Required for Alternate Aerodrome-1967м