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Тема: «Аванпроект середньомагістрального літака пасажиромісткістю 156 чоловік»

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BACHELOR DEGREE THESIS

Topic: "Preliminary Design of a Mid-Range Aircraft with 156 Passenger Capacity"

Fulfilled by:	____________	**Dmytrii NISHCHENKO**
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Kyiv 2023

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Аерокосмічний факультет
Кафедра конструкції літальних апаратів
Освітній ступінь «Бакалавр»
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Освітньо-професійна програма «Обладнання повітряних суден»

ЗАТВЕРДЖУЮ
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__________ Сергій ІГНАТОВИЧ
«___» ____________ 2023 р.

ЗАВДАННЯ

на виконання кваліфікаційної роботи здобувача вищої освіти

НІЩЕНКА ДМИТРІЯ ПЕТРОВИЧА

1. Тема роботи: «Аванпроект середньомагістрального літака пасажиромісткістю 156 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 156, дальність польоту з максимальним комерційним навантаженням 5800 км, крейсерська швидкість польоту 828 км/год, висота польоту 10.5 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 персонального місця для ручної поклажі.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: загальний вигляд літака (А1×1), компонувальне креслення фюзеляжу (А1×1), креслення персональних багажних поличок (А3×1).

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	

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Керівник кваліфікаційної роботи ____________ Тетяна МАСЛАК

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Educational Professional Program "Aircraft Equipment"

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

TASK

for the bachelor degree thesis

Dmytrii NISHCHENKO

1. Topic: "Preliminary design of a mid-range aircraft with 156 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}=828 kmph, flight range L=5800 km, operating altitude H_{op}=10.5 km, 156 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 design of a personal place for hand luggage.
5. Required material: general view of the airplane (A1×1), layout of the airplane (A1×1), design of personal luggage racks (A3×1).

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: ____________ Dmytrii NISHCHENKO

РЕФЕРАТ

Кваліфікаційна робота «Аванпроект середньомагістрального літака пасажиромісткістю 156 чоловік»:

61 с., 12 рис., 5 табл., 10 джерел

Представлена кваліфікаційна робота присвячена проектуванню середньомагістрального пасажирського літака для перевезення 156 осіб з можливістю перевезення ручної поклажі в персональному місці, розміщеному на поличці над головою пасажирів.

В роботі застосовано метод порівняльного аналізу літаків-прототипів для вибору найбільш обґрунтованих параметрів проектованого літака, а також методи інженерних розрахунків для отримання основних геометричних та компонувальних параметрів проектованого літака, визначення основних технічних рішень. В спеціальній частині необхідно розробити концепцію персонального місця для ручної поклажі.

Актуальність роботи полягає у підвищенні ефективності та комфорту пасажирів, а саме спроектоване персональне місце для ручної поклажі забезпечить максимальний об’єм для індивідуального багажу, персональне місце для зберігання речей.

Практичне значення дипломної роботи полягає в підвищенні комфорту та ефективності пасажирських перевезень. Представлені результати роботи можуть бути використані в авіаційній галузі та в навчальному процесі авіаційних спеціальностей.

Кваліфікаційна робота, аванпроект літака, компонування пасажирської кабіни, центрування літака, поличка для багажу, ручна поклажа

ABSTRACT

Bachelor degree thesis "Preliminary design of a mid-range aircraft with 156 passenger capacity"

61 pages, 12 figures, 5 tables, 10 references

The bachelor degree thesis presents a preliminary design of a mid-range aircraft that can transport 156 passengers and accommodate their luggage in personal overhead bins.

The design methodology relies on the analysis of prototypes, advanced technical solutions and engineering calculations to obtain the technical specifications of the aircraft. A special part of the thesis focuses on the concept of a personal space for hand luggage.

The work aims to increase the efficiency and comfort of passengers by offering a personal space for luggage with a separate payment option.

The practical results of the work include the improvement of passenger comfort and transportation efficiency. The work can be applied in the aviation industry and in the education of aviation specialties.

Bachelor degree thesis, prelimininary design of the aircraft, passenger cabin layout, center of gravity position, storage bin, luggage

Format	№	Designation	Name	Quantity	Notes
			<u>General documents</u>		
A4	1	NAU 23 08N 00 00 00 67 TW	Task for work	1	
	2	NAU 23 08N 00 00 00 67	Mid-range passenger aircraft	2	
A1		Sheet 1	General view		
A1		Sheet 2	Fuselage layout		
A4	3	NAU 23 08N 00 00 00 67 EN	Mid-range passenger aircraft	61	
			Explanatory note		
A3	4	NAU 23 08N 00 00 00 67	Personal hand luggage	1	

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Done by	Nishchenko D.P.				Preliminary design of a mid-range passenger aircraft with 156 passenger capacity (List of diploma work)	list	sheet	sheets
Supervisor	Maslak T.P.					Q	9	61
St.control.	Krasnopolskyi V.S.					402 ASF 134		
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INTRODUCTION

The war had a devastating impact on civil aviation in our country, as all passenger flights were canceled and planes were evacuated. However, after the victory, the aviation industry will start to recover and new companies and aircraft will emerge.

Aviation is crucial for global transportation and economy in the modern world. The plane is one of the safest and most convenient modes of travel. The aviation industry advances every year, enhancing the technical features of aircraft. Each new aircraft design integrates cutting-edge technology, inventive engineering and scientific research, creating the foundation for improving the safety, reliability and performance of aircraft.

The aim of this thesis is to develop a modified aircraft based on data from three selected aircraft and to identify the main factors that influence its efficiency and safety. This work will explore current trends and innovations in aviation technology, and will analyze the methods and approaches used in aircraft design. This thesis will investigate various aspects that affect aircraft design such as fuselage structure, wings, engines.

The objective of the thesis will be to design a medium-haul aircraft that can carry 156 passengers. The main idea is to improve the technical quality of luggage compartments for the comfort of passengers and the additional revenue of the company.

1. ANALYSIS OF PROTOTYPES

1.1 Choice of the projected data

To ensure the high quality and safety of the aircraft, the choice of optimal design parameters is extremely important. These parameters include weight characteristics, geometric factors, aerodynamic characteristics, and economic considerations. When designing the appearance of the aircraft at the initial stage, statistical transfer methods, approximate aerodynamics and statistical dependencies are used. Then, in the second step, a complex aerodynamic calculation is carried out using specific formulas to determine the total weight and including experimental data.

As a design basis I took prototypes of aircraft such as: Airbus 319-100, Airbus 320-200, Boeing 737-300. Airbus A319-100 is smaller than Airbus A320-200 and Boeing 737-300. It can hold approximately 124-156 passengers, depending on the configuration, while the Airbus A320-200 and Boeing 737-300 have a larger capacity, around 150-180 passengers.

The Airbus A320-200 has the longest range of the three aircraft. It can fly 6,000 kilometers, while the Airbus A319-100 and Boeing 737-300 have a shorter range of about 4,300-4,800.

All three aircraft are known for their fuel efficiency, but the Airbus A320-200 has the highest efficiency among them. It uses more modern engines and innovative technologies to reduce fuel consumption.

The Airbus A319-100 and Airbus A320-200 aircraft both belong to the Airbus A320 family of aircraft, which means they share many common features and systems. In international airlines, these aircraft are often used in the same configurations, with differences in size. The Boeing 737-300, on the other hand, is a separate model with its own unique characteristics.

Using the information from these aircraft, I will try to design a plane that can rival the competition. The statistical data of the prototypes are presented in table1.1.

Table 1.1

Operational-technical data of prototypes

Parameters	Prototypes		
	A 319-100	A 320-200	B 737-300
The purpose of airplane	Passenger	Passenger	Passenger
Crew, number of pilots	2	2	2
Maximum take-off weight, MTOW, kg	75500 kg	77000 kg	62820 kg
Maximum payload, kg	17700 kg	19900 kg	16890 kg
Number of passengers	140	179	149
Cruise altitudes, km	11.9	11.9	11
Flight range with max paylod, km	6850	6150	4175
Take off distance, m	1850	2090	1680
Number of engines	2 turbofan	2 turbofan	2 turbofan
Type of the fuselage cross-section	circular	circular	circular
Fuselage length, m	33,84	37,6	33,4

The relative location, number, and shape of an aircraft's components determine its configuration. Aerodynamic and flight technical characteristics of the aircraft are affected by both its design and aerodynamic layout. Choosing the optimal configuration increases flight safety, consistency and operational efficiency, thus improving aircraft economy.

1.2 Brief description of the main parts of the aircraft

The aircraft is designed as a low-wing monoplane and has two turbojet engines mounted on the wings. It is equipped with a tricycle landing gear scheme, which includes a nose and two main wheels. The swept wing consists of a centerwing box and two separate outer wing sections. The fuselage has a circular shape. The tail units are made according to the conventional scheme, consisting of a vertical fin with a rudder and a horizontally adjustable stabilizer with elevators.

1.2.1 Fuselage

The fuselage of the aircraft is made in the form of an all-metal semi-monocoque design to minimize drag. The fuselage has windows on both the left and right sides and emergency exits on both sides. Luggage racks are featured on both sides of the cabin, allowing passengers to store their luggage. In the lower part of the luggage compartment there is passenger service units with its own ventilation system, oxygen masks and a flight attendant service panel. In the central part of the ceiling, as a rule, there is a platform for the main interior lighting with additional lights for the passenger compartment. Beneath the pressurized portion of the fuselage are various compartments and sections including front cargo hold, rear cargo hold, and equipment compartment. Each front and rear baggage compartments have hatches on the starboard side and is equipped with a container locking system.

1.2.2 Wing

The wing features an aerodynamic design that utilizes a cantilever structure. It incorporates a supercritical airfoil, which is well-suited for short to long range flights. The engines are positioned under the wings on both sides. The wing's characteristics remain relatively consistent across different cruising speeds and altitudes, resulting in reduced drag throughout its operating range. To accommodate the flaps and their control system, the thickness of the rear wing spar has been increased, providing ample space. The long-span leading-edge slat is divided into five sections, and the engine nacelle is located under the wing, ensuring high-speed cruising performance. The inner and outer trailing edge devices use large Fowler flaps. Each wing surface is equipped with five spoilers. The wing structure consists of ribs, spars, stringers and skin. The clearance between the wing's underside and the ground is relatively small.

1.2.3 Flight control system

The Fly-by-wire control system regulates the entire flight process from departure to arrival. It consists of two independent systems with remote control technology, which significantly increases flight safety, relieves the pilot and reduces the weight of the control system. Two measures were implemented to improve the reliability of the fly-by-wire system. First, the signal wires to each rudder are isolated from each other, and second, the aileron and spoiler wires are routed both in front of and behind the front wing truss. To protect against lightning strikes, all remote-control cables are housed in a shielded metal conduit.

The control mechanism differs from the traditional joystick and steering wheel configuration, using a side joystick instead, which helps reduce the weight of the system. The side joystick controller includes a tilt and forward joystick, a pitch and roll sensor unit, and an artificial sensor system. When the autopilot is engaged, an electromagnetic spool lock locks the joystick in the center position. An electronic circuit connects two sets of fly-by-wire controllers. To resolve conflicts arising from the simultaneous instructions of both pilots, a comparator is built into the electronic circuitry. The electronic control system allows the combination of two input commands. If a pilot wishes to override the other pilot's inputs, they can simply hold down the Take Control button to override the other side's controls.

There are three hydraulic systems, distinguished by color coding: green, yellow, and blue. The green and yellow systems are interconnected and each motor powers one of them. The blue hydraulic system is powered by a pneumatic turbine. In normal operation, two generators are driven by the engine, while the auxiliary power unit drives the third generator. In addition to ground use, an auxiliary power unit can serve as an in-flight backup power source.

1.2.4 Landing gear

This aircraft is equipped with a retractable tricycle landing gear with two main wheels. Each unit consists of a two-wheeled trolley, with four main wheels in total. Tricycle landing gear are located under the wings, closer to the fuselage. The landing gear retract into the fuselage during flight to minimize drag.

The front part of an airplane landing gear is called the nose strut. It is a one-wheeled unit installed under the nose of the aircraft fuselage. The front undercarriage facilitates handling from the ground and provides stability during takeoff and landing. Like the main landing gear, the nose gear retracts into the fuselage during flight.

The landing gear is equipped with a hydraulic system. When the pilot commands the landing gear to extend or retract, the hydraulic actuators deliver the power needed to move the landing gear. The release and retraction process is carefully coordinated to ensure smooth movement of the landing gear and alignment with the aircraft structure.

To reduce drag and improve aerodynamics, the aircraft is equipped with doors, which close after retraction of the landing gear. These doors open during the extraction or retraction process to allow the landing gear to be retracted and extended. Once the landing gear is fully extended or retracted, the doors close, maintaining the streamlined shape of the aircraft.

The landing gear is equipped with an advanced braking system that provides effective braking during landing and ground operations. This system includes multiple disc brakes, hydraulic actuators and anti-lock brakes. The braking system is controlled by pilots using the aircraft's brake controls, and is complemented by other systems such as automatic brakes and anti-lock braking to improve safety.

Pilots have a special control panel to control the operation of the landing gear. This panel allows you to control the functions of the extension, retraction and braking of the chassis. In addition, pilots have a visual and acoustic display in the cockpit that provides real-time information about the status of the landing gear, such as raised or lowered, locked or unlocked, or whether malfunctions have been detected.

1.2.5 Tail unit

The overall design of an aircraft largely depends on the tail, which is an important component. Its main function is to provide stability, control and maneuverability throughout the flight. Consisting of several important elements such as the vertical stabilizer, horizontal stabilizer, elevator, and rudder, the empennage works together to ensure aircraft stability and control under various flight conditions.

The rudder (fig.1.1), also known as the fin, has two main purposes. First, it provides stability by countering any yaw. Second, it houses the rudder, which allows the pilot to control the yaw motion of the aircraft. Located on the trailing edge of the vertical stabilizer, the rudder allows the pilot to adjust the yaw motion of the aircraft.

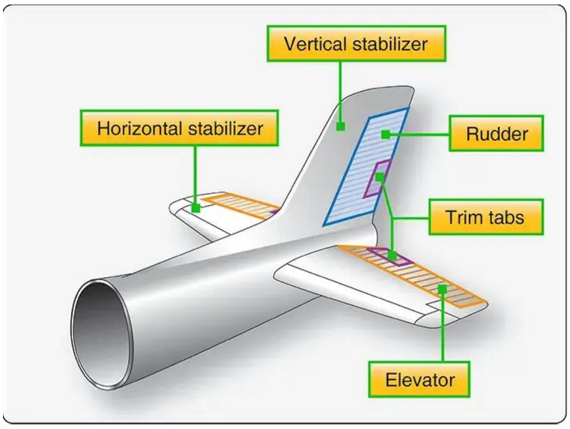

Fig. 1.1. Tail unit structure.

The horizontal stabilizer is located at the rear of the fuselage and is connected to the vertical stabilizer. It is responsible for the stability. It keeps the aircraft level during normal flight and counteracts any tendency to go up or down. Elevators, which are movable control surfaces attached to the trailing edge of the elevator, allow the pilot to control the pitch of the aircraft. Additionally, the tailplane design focused on aerodynamic efficiency to minimize drag and improve overall performance.

Conclusion to the part

In this section, I have chosen prototypes for the designing aircraft such as the Airbus A319-100, Airbus A320-200, and Boeing 737-300, and provided a brief description of each. Additionally, I have described a projected aircraft, which is a low-wing monoplane equipped with two turbojet engines. Furthermore, I have outlined the purposes and features of the wing, fuselage, flight control system, landing gear, and tail unit.

2. PRELIMINARY DESIGN OF A MID-RANGE PASSENGER AIRCRAFT

2.1. Geometry calculations for the main parts of the aircraft

2.1.1 Wing geometry calculation

The weight of the wing, expressed as m_0, and the specific load applied to it, expressed as P_0, are used to determine the geometric properties of the wing.

The calculated area of the plane wing is equal to:

$$S_w = \frac{m_0 \cdot g}{p_0} = \frac{82867 \cdot 9.8}{5.922 \cdot 1000} = 137.13\,\text{m}^2,$$

where S_w – wing area, m^2; g – acceleration due to gravity m/s^2.

Relative wing extensions area is 0.1

The wingspan of the aircraft design has been determined as:

$$l = \sqrt{S_w \cdot \lambda_w} = \sqrt{137.13 \cdot 9.48} = 36.05\,\text{m},$$

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

The calculated root chord is equal to:

$$C_{root} = \frac{2S_w \cdot \eta_w}{(1+\eta_w) \cdot l} = \frac{2 \cdot 137.13 \cdot 4}{(1+4) \cdot 36.05} = 6.086\,\text{m},$$

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

The calculated tip chord is equal to:

$$C_{tip} = \frac{C_{root}}{\eta_w} = \frac{6.086}{4} = 1.52\,\text{m},$$

where C_{tip} – tip chord, m.

On board chord for trapezoidal shaped wing was calculated according to the formula:

$$b_{ob} = C_{root} \cdot \left(1 - \frac{(\eta_w - 1) \cdot D_f}{\eta_w \cdot l_w}\right) = 6.086 \cdot \left(1 - \frac{(4-1) \cdot 3.95}{4 \cdot 36.05}\right) = 5.58\,\text{m},$$

where b_{ob} – wing board chord, m; D_f – fuselage diameter, m.

When choosing a wing propulsion system, we evaluate the required number of spars and their location. To determine the mean aerodynamic chord, I use a geometric approach (figure 2.1).

To check the correctness of the drawing, we will also calculate MAC according to the formula:

$$b_{MAC} = \frac{2}{3}\frac{C_{root}^2 + C_{root}C_{tip} + C_{tip}^2}{C_{root} + C_{tip}} = \frac{2}{3}\frac{6.086^2 + 6.086 \cdot 1.52 + 1.52^2}{6.086 + 1.52} \approx 4.26\,\text{m}.$$

From the drawing we can see that mean aerodynamic chord is equal to:

b_{MAC} = 4.259 m

The next step will be the calculation of the geometry of the ailerons and high-lift devices.

Ailerons (fig. 2.2) are control surfaces on aircraft wings, usually near the trailing edge. The main purpose of the ailerons is to control the roll of the aircraft. By deflecting the ailerons up or down, the pilot can create differential lift on the wings, causing the aircraft to roll left or right.

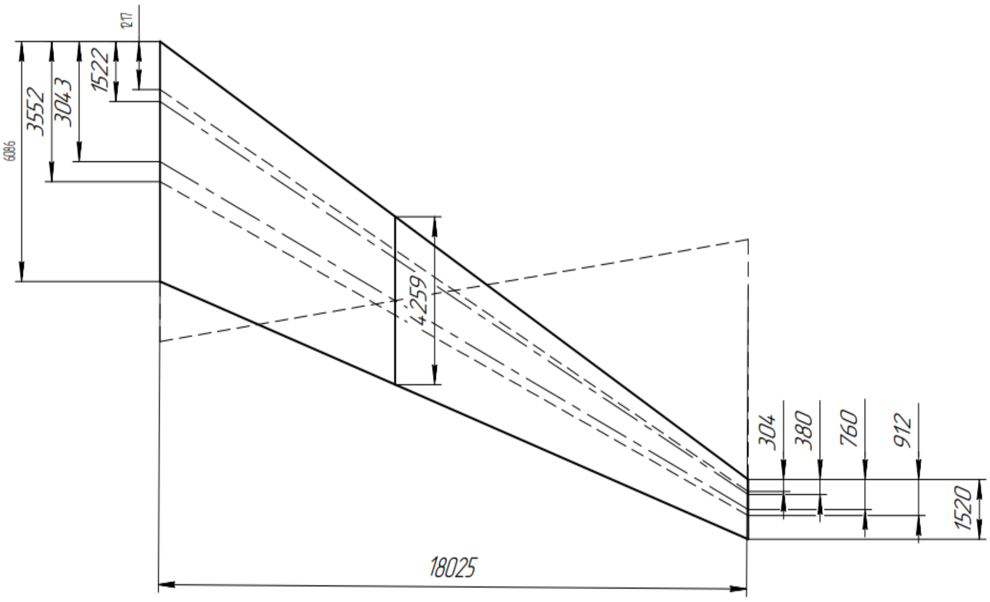

Fig. 2.1. Determination of mean aerodynamic chord.

The following formulas are used to determine the geometry of the ailerons.

Ailerons span of the aircraft design has been determined as:

$$l_{ail} = (0.3\ldots0.4)\cdot\frac{l_w}{2} = 0.35\cdot\frac{36.05}{2} = 6.308\,\text{m},$$

where l_{ail} – ailerons span, m.

The calculated aileron area is equal to:

$$S_{ail} = (0.05\ldots0.08)\cdot\frac{S_w}{2} = 0.065\cdot\frac{137.13}{2} = 4.456\,\text{m}^2,$$

where S_{ail} – ailerons area, m.

The aileron chord is determined using the following formula:

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

where C_{ai} –aileron chord, m.

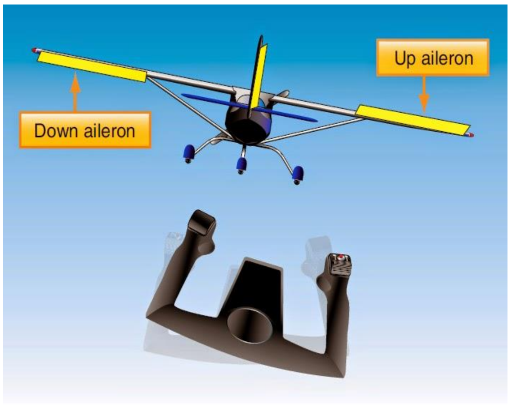

Fig. 2.2. Control surfaces on the wing.

Flaps and slats are aerodynamic devices on aircraft wings designed to increase lift and improve aircraft performance during takeoff, landing and low speeds.

The geometrical parameters of the slats are as follows:

Calculated chord of slat is equal to:

$$C_s = C_{root} \cdot 0.12 = 6.086 \cdot 0.12 = 0.73\,\text{m}$$

where C_s – chord of slat, m.

The geometrical parameters of the flaps are as follows :

Calculated length of flap is equal to:

$$l_f = (0.3 \ldots 0.4) C_w = 0.35 \cdot 2 = 0.7\,\text{m}\,.$$

where l_f – length of flap, m.

We will determine the geometric parameters of the ailerons using the formulas below:

The estimated length of the aileron trim tabs for the project aircraft is equal to:

$$l_{tr} = (0.04 \ldots 0.06) S_{ai} = 0.05 \cdot 4.456 = 0.222\,\text{m}\,,$$

where l_{tr} –length of the aileron trim tab, m.

Area of ailerons trim tab.

Since the plane has two engines, we will use the following formula:

$$S_{tail} = (0.04\ldots0.06)S_{ail} = 0.055 \cdot 4.456 = 0.245\ \mathrm{m}^2,$$

where S_{tail} – area of ailerons trim tab, m^2.

Range of aileron deflection upward $\delta'_{ail} \geq 20^\circ$; downward $\delta''_{ail} \geq 10^\circ$.

The purpose of determining the geometric parameters of the wing lift is to achieve the calculated values of the take-off and landing coefficients of the wing lift at a given lift speed and the selected type of wing.

Prior to conducting the subsequent calculations, it is necessary to choose the profile type from the profile catalog and indicate the value of the maximum lift coefficient $C_{y\max}$. Additionally, the required augmentation of this $C_{y\max}$ coefficient for high-lift devices must be determined by employing the $C_{y\max}$ formula.

$$\Delta C_{y\max} = \frac{C_{y\max l}}{C_{y\max} b_w}$$

In modern design, the relative chord ratio of high-lift wing devices is determined by aircraft parameters $b_f = 0.3\ldots0.4$ – for three slotted flaps and Fowler's flaps and $b_f = 0.1\ldots0.15$ – slats.

2.1.2 Fuselage layout calculation

In the development and construction of aircraft, one of the approaches is the calculation and definition of the shape of the fuselage. The fuselage, the most important structural part of the aircraft, is important for the safety and comfort of the passengers and also determines the main characteristics of the aircraft, such as its weight, aerodynamic properties and interior space. Several factors are taken into account when calculating the hull shape, including internal and external loads, aerodynamic requirements, and ergonomic and functional aspects. The requirements and tasks of the airframe of the aircraft are analyzed, for example, the number of passengers, the flight range and other factors.

When calculating the airframe, static and dynamic resistance, aerodynamic stability and controllability, noise and vibrations must be taken into account.

In our case, we will determine the following geometric features of the fuselage using standard formulas.

Substituting our values into the formula for obtaining the length of the fuselage, we obtained:

$$l_f = \lambda_f \cdot D_f = 3.95 \cdot 8.57 = 33.85 \, \text{m}.$$

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

According to our calculations the fuselage nose part fineness ratio is equal to:

$$\lambda_{fnp} = 1.2 \ldots 2.5.$$

According to our calculations the fuselage rear part fineness ratio is equal to:

$$\lambda_{fnp} = 2 \ldots 5.$$

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

$$l_{fnp} = \lambda_{fnp} \cdot D_f = 1.5 \cdot 3.95 = 5.925 \, \text{m}.$$

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:

$$l_{frp} = \lambda_{frp} \cdot D_f = 2.5 \cdot 1.3 = 3.25 \text{ m},$$

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

In the case of passenger and cargo aircraft, the size of the passenger lounge or cargo cabin initially determines the center section of the fuselage. One of the main parameters that determines the middle part of the airliner is the height of the passenger cabin.

The width of the cabin where seats are located in one row (3+3) is:

economy class seat width $b_{3ec} = 1455 \ldots 1650$ mm;

business class seat width $b_{3bu} = 1500 \ldots 1770$ mm.

The distance from the outside of the seat handle to the inside of the fuselage wall $\delta_1 = 40 \ldots 50$ mm. The distance between the inner and outer wall of the fuselage $\delta_{wall} = 80 \ldots 120$ mm. For two seats on one block distribution, we can take the width as:

economy class seat width $b_{3ec} = 960 \ldots 1090$ mm;

business class seat width $b_{2bu} = 1020 \ldots 1200$ mm.

For the width of the aisle we can take as:

$b_{ais-ec} = 400 \ldots 510$ mm;

$b_{ais-bu} = 500 \ldots 600$ mm.

For the economy class with the scheme of allocation of seats in a row (3 + 3) determines the appropriate width of the cabin fig. 2.3, I choose the following parameters:

The estimated width of the economy class according to the formula is equal:

$$B_{ec} = n_{bl3} \cdot b_{3ec} + n_{aisle} \cdot b_{aisle} + 2 \cdot \delta_1 + 2 \cdot \delta_{wall} = 2 \cdot 1600 + 450 + 2 \cdot 50 + 2 \cdot 100 = 3950 \text{ mm}$$

where n_{bl3} – number of three-seat blocks; b_{3ec} – width of three-seat blocks for economy 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.

The estimated width of the business class according to the formula is equal:

$$B_{bu} = n_{bl3} \cdot b_{3bu} + n_{aisle} \cdot b_{aisle} + 2 \cdot \delta_1 + 2 \cdot \delta_{wall} = 2 \cdot 1600 + 1 \cdot 500 + 2 \cdot 40 + 2 \cdot 80 = 3940 \text{ mm}$$

where b_{3bu} – width of three-seat blocks for business class, mm.

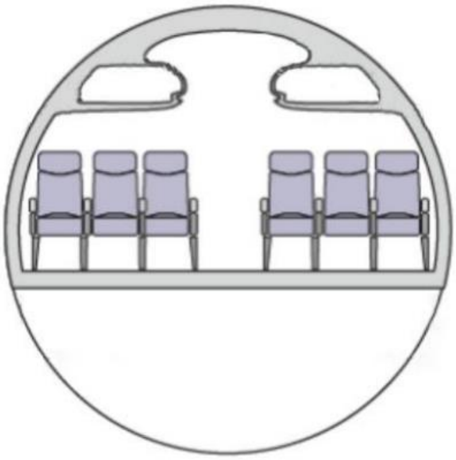

Fig. 2.3 Cabin cross-section.

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

$$L_{ec} = l_1 + L_{sp}(n-1) + l_2 = 1200 + (24-1) \cdot 870 + 259 = 21460 \text{ mm},$$

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.

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

$$L_{bu} = l_1 + L_{sp}(n-1) + l_2 = 1250 + 1 \cdot 960 + 250 = 2460 \text{mm}.$$

where L_{bu} – length of business class cabin.

2.1.3 Luggage compartment

The luggage compartment of an aircraft is an enclosed space where checked baggage, cargo and other thingth of passengers are stored during the flight. It is usually located under the main passenger compartment on commercial aircraft, although some aircraft may have overhead bins or other storage areas.

The standard unit of floor load is equal to K = 400… 600 kg/m^2

Then, the calculated area of cargo hold is equal to:

$$S_{cargo} = \frac{M_{bag}}{0.4K} + \frac{M_{cargo\&mail}}{0.6K} = \frac{20\cdot 156}{0.4\cdot 500} + \frac{15\cdot 156}{0.6\cdot 500} = 23.4\,\mathrm{m}^2,$$

where S_{cargo} – cargo compartment volume, m^3; M_{bag} – mass of the baggage, kg; $M_{cargo\&mail}$ – mass of the cargo and mail, kg.

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

$$v_{cargo} = \upsilon \cdot n_{pass} = 0.2\cdot 156 = 31.2\,\mathrm{m}^3.$$

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

2.1.4 Galleys and wardrobes

Galleys and wardrobes are important components of aircraft. Aircraft galleys serve as kitchen and provide a variety of facilities and equipment for preparing and serving food and beverages to passengers and crew. These kitchens are equipped with compact ovens, ranges and other appliances for heating and cooking. They also have food and beverage storage areas including fridges and freezers to ensure freshness.

Trolleys, trolleys and trays are used for serving prepared meals, drinks and other essentials on board.

This aircraft is designed with two galleys and two wardrobes, located in the nose and tail of the aircraft.

Estimated volume of the galleys on the plane:

$$v_{galley} = v_g \cdot n_{pass} = 0.11 \cdot 156 = 17.16\,\text{m}^3,$$

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

Estimated area of the buffets on the plane :

$$S_{galley} = \frac{v_{galley}}{H_{cab}} = \frac{17.16}{2.151} = 7.98\,\text{m}^2,$$

where S_{galley} – galley area, m^2.

Estimated area of wardrobe on the plane:

$$S_{war} = (0.035\ldots0.04)n_{pass} = 0.037 \cdot 156 = 5.77\ \text{m}^2,$$

where S_{war} – area of wardrobe, m^2.

2.1.5 Lavatories

Lavatories or washrooms, are an important part of an aircraft's interior design to meet the needs of passengers during the flight. Toilets are generally found throughout the aircraft cabin. The exact number and location of toilets depends on the size and configuration of the aircraft. Aircraft toilets are compact and designed to maximize space. They are usually equipped with a toilet, sink and mirror.

The quantity of restroom facilities depends on the passenger count and the duration of the flight. This aircraft has four toilets.

Calculated area of lavatory is equal to:

$$n_{lav} = \frac{n_{pass}}{40} = \frac{156}{40} = 3.9$$

where n_{lav} – number of lavatories.

Area of lavatory is equal to:

$$S_{lava} = 9.50 \cdot 1.150 = 1.092 \text{ m}^2$$

where S_{lava} – area of lavatory.

2.1.6 Layout and calculation of basic parameters of tail unit

One of the primary considerations in aerodynamic design is determining the optimal placement of the tail. To provide longitudinal stability during flight its center of gravity should be placed in front of the aircraft focus. The longitudinal stability index is determined by the distance between these points, relative to the average value of the wing's aerodynamic chord. From statistic data of the static moment coefficient for both the horizontal tail (A_{htu}) and the vertical tail (A_{vtu}), along with typical arm correlations (H_{tu} and V_{tu}). By referring to the table, we can make an initial estimation of the geometric parameters.

The values of L_{HTU} and L_{VTU} are dependent on various factors. Firstly, they are influenced by the length of the nose and tail sections of the fuselage, as well as the wing's sweptback configuration and its location. Additionally, the stability and control conditions of the airplane also play a role in determining these values.

Length of the vertical tail unit is equal to:

$$L_{HTU} = 2.6 \cdot b_{MAC} = 2.6 \cdot 4.259 = 11.07 \text{ m},$$

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

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

$$A_{HTU} = (0.65 \ldots 0.8),$$

$$S_{HTU1} = \frac{b_{MAC} \cdot S_w \cdot A_{HTU}}{L_{HTU}} = \frac{4.259 \cdot 137.13 \cdot 0.7}{11.07} = 36.93 \, \text{m}^2,$$

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

$$S_{HTU2} = (0.18 \ldots 0.25) S_w = 0.2 \cdot 137.13 = 27.42 \text{ m}^2,$$

Finally $S_{HTU} = 30.67 \text{ m}^2$,

The length of the vertical plumage is approximately equal to the length of the horizontal plumage:

$$L_{VTU} \approx L_{HTU} = 11.07 \text{ m},$$

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

$$A_{vtu} = (0.08 \ldots 0.12),$$

$$S_{VTU1} = \frac{l_w \cdot S_w \cdot A_{VTU}}{L_{VTU}} = \frac{0.1 \cdot 137.13 \cdot 36.05}{11.07} = 44.94\,\text{m}^2,$$

where S_{VTU} – area of vertical tail unit, m^2; L_{VTU} – length of vertical tail unit, m; A_{VTU} – coefficient of static moment of vertical tail unit.

$$S_{VTU2} = (0.12 \ldots 0.2) S_w = 0.16 \cdot 137.13 = 21.94\,\text{m}^2,$$

Finally $S_{VTU} = 31.83\, m^2$

Calculation of the elevator area:

$$S_{el} = (0.3 \ldots 0.4) S_{HTU} = 0.32 \cdot 30.67 = 9.81\,\text{m}^2,$$

where S_{el} – elevator area.

The calculated area of the rudder is equal to:

$$S_{rud} = (0.2 \ldots 0.22) S_{HTU} = 0.22 \cdot 30.67 = 6.74\,\text{m}^2,$$

where S_{rud} – rudder area, m^2.

Determination of the elevator balance area:

$$S_{eb} = (0.22 \ldots 0.25) S_{el} = 0.23 \cdot 9.81 = 2.256\,\text{m}^2,$$

where S_{abel} – area of aerodynamic balance,m^2.

Determination of the rudder balance area:

$$S_{rb} = (0.2 \ldots 0.22) S_{rud} = 0.22 \cdot 6.74 = 1.482\,\text{m}^2,$$

where $S_{abrudder}$ –rudder balance area, m^2.

Calculation of the altitude elevator trim tab area:

$$S_{te} = 0.08 \cdot S_{el} = 0.08 \cdot 9.82 = 0.78 \text{ m}^2,$$

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

Calculation of the rudder trim tab area:

$$S_{tr} = 0.06 \cdot S_{rud} = 0.06 \cdot 6.74 = 0.4 \text{ m}^2,$$

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

Tail unit span determination:

$$L_{ro} = (0.32 \ldots 0.5) l_w = 0.4 \cdot 36.05 = 12.42 \text{m},$$

where L_{ro} – tail unit span, m.

2.1.7 Landing gear design

The distance from the center of gravity to the main landing gear is determined by the following formula:

$$B_m = (0.15 \ldots 0.2) b_{MAC} = 0.185 \cdot 4.259 = 0.787 \text{m},$$

where B_m – main wheel axes offset, m.

The estimated wheel base is equal to:

$$B = (0.3 \ldots 0.4) l_f = 0.35 \cdot 33.85 = 11.85 \text{m},$$

where B – wheel base, m.

Distance between the center of gravity and nose landing gear:

$$B_n = B - B_m = 11.85 - 0.787 = 11.063 \text{m},$$

where B_n – nose wheel axes offset, m.

We will calculate the wheel track according to the following formula:

$$T = (0.7 \ldots 1.2)B = 0.9 \cdot 11.85 = 10.665 \text{ m},$$

where T – wheel track, m.

Nose wheel loading is calculated according to the following formula:

$$F_{nose} = \frac{Bm \cdot m_0 \cdot 9.81 \cdot K_g}{B \cdot z} = \frac{0.787 \cdot 82867 \cdot 9.81 \cdot 1.8}{11.85 \cdot 2} = 48590.3 \text{ N},$$

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

Main wheel loading is calculated according to the following formula:

$$F_{main} = \frac{(B - B_m)m_0 \cdot 9.81}{B \cdot n \cdot z} = \frac{(11.85 - 0.787) \cdot 82867 \cdot 9.81}{11.85 \cdot 2 \cdot 4} = 94867 \text{ N},$$

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

After the calculations, we can choose tires. Aviation tires are an important part of flight safety and performance. They play a critical role in ensuring safe take-off, landing and taxiing. These specialty tires are designed to withstand the unique demands and challenges of aviation, including high speeds, heavy loads, extreme temperatures and multiple landing surfaces.

A common classification of aircraft tires is by type classified by the Tire and Rim Association of the United States. In our case, I choose radial flight tires(fig.2.4) (three-piece type). All recently developed sizes belong to this classification. This group was developed to meet the highest speeds and loads of current aircraft.

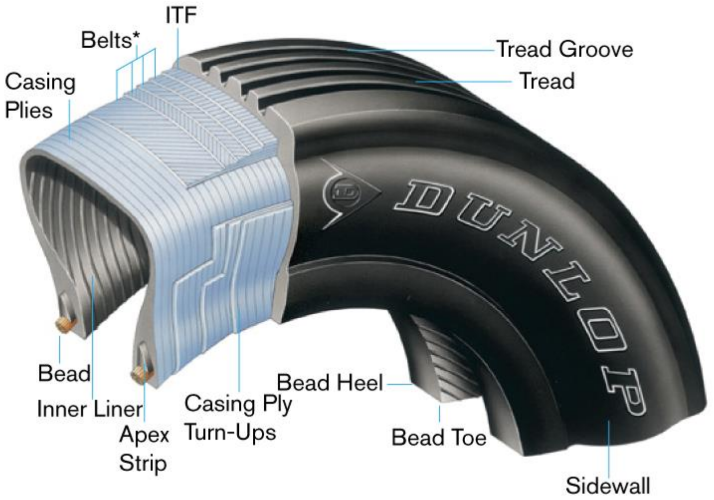

Fig. 2.4 Types of tires.

According to the Good year aircraft tire data book I chose these tires:

Main tire: 50 × 18R22;

Auxiliary tire: 30 × 8.8R15;

I decided to choose carbon brakes, carbon brakes are an important part of modern aircraft brake systems and are known for their exceptional performance and reliability. These brakes use a combination of carbon fibers and a resin matrix to create a highly efficient braking mechanism.

2.1.8 Choice of power plant

An aircraft's power plant is responsible for generating the energy it needs to move the aircraft through the air and operate various systems. It plays an important role in determining the aircraft's characteristics, range and capabilities. Over time, due to advances in technology, aircraft propulsion systems have made significant advances, resulting in more efficient, more reliable, and better performing systems.

This aircraft could be equipped by the engine IAE V2500 or CFMI CFM56-5B. I prefer to use IAE V2500 in my airplane. It is dual rotor engine with bypass ratio 5,4:1 and compression ratio 35,8. Trust to drag ratio of this engine is equal 4,68.

Length 3.2m. Diameter 1,682m. Weight 2500 kg. Maximum thrust 140.56 kN.

2.2Center of gravity calculation

2.2.1 Trim-sheet of the equipped wing

The weight of a fitted wing includes the weight of its structure, the weight of equipment carried on the wing, and the weight of fuel. Regardless of whether the attachment point is the wing or the fuselage, the main gear and rear wheel are included in the weight calculation for the equipped wing. The weight calculation includes the names of objects, their respective weights and the coordinates of their center of gravity. The reference point for the centre wing section coordinates is determined by projecting the nose point onto the mean aerodynamic chord (MAC) of the XOY surface. For the tail of the aircraft, positive values of the center of gravity coordinates are considered.

For aircraft with underwing engines, see table 2.1 for a list of items and their weights. Table 2.1 also contains a list of objects and their weights for aircraft with wings. The total weight of the aircraft is 82,867 kg.

Table 2.1

Trim-sheet of equipped wing

N	Objects names	Mass		C.G coordinates Xi, m	Mass moment, Xi * mi
		units	Total mass		
1	Wing (structure)	0.10634	8812.07678	1.83	16138.17
2	Fuel system	0.0099	820.3833	1.81	1484.95
3	FCS, 30%	0.0018	149.1606	2.5	381.16
4	Electrical equipment, 10%	0.00322	266.83174	0.43	113.64
5	Anti-ice system	0.00872	722.60024	0.43	307.75

End of the table 2.1

6	Hydraulicsyste,70%	0.01155	957.11385	2.55	2445.8
7	Powerplant	0.0887	7350.3029	-1.6	-11760.48
8	Equipped wing without LG	0.23023	19078.46941	0.47	9111.01
9	NoseLG	0.0055	455.7685	-12.86	-5861.18
10	MainLG	0.0312	2585.4504	0.82	2120.06
11	Fuel	0.33428	27700.78076	2	55401.56
	Total	0.60121	49820.469	1.22	60771.46

To determine the coordinates of the center of gravity of the equipped wing, the following formulas are used:

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

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.

2.2.2Trim-sheet of the equipped fuselage

The presented table 2.2 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.

Table 2.2

Trim-sheet of equipped fuselage

N	Objects names	Mass		C.G coordinates Xi, m	massmoment
		Units	totalmass		
1	Fuselage	0.06798	5633.29866	19.5	109849.32
2	Horizontal tail	0.00863	715.14221	32	22884.55
3	Vertical tail	0.00852	706.02684	31.5	22239.84
4	Radar	0.0031	256.8877	1	256.88
5	Radio equipment	0.0023	190.5941	1	190.59
6	Instrumen tpanel	0.0054	447.4818	2	894.96
7	Aeronavigatione quipment	0.0047	389.4749	2	778.94
10	Flightcontrol system 70%	0.0042	348.0414	16.925	5890.60
11	Hydraulic system 30%	0.01155	957.11385	23.695	22678.81
12	Electrical equipment 90%	0.02898	2401.48566	13.925	33440.68
13	Not typical equipment	0.0033	273.4611	3	820.38
14	Lining and insulation	0.0065	538.6355	16.925	9116.4
15	Anti ice system, 20%	0.00436	361.30012	27.08	9784.01
16	Air conditioning system, 40%	0.008720	722.60024	16.925	12230.01
17	Passenger seats (bussiness)	0.001158483	96.00001076	5.925	568.8
18	Passenger seats (economicclass)	0.01216407	1007.999989	20	20159.99
19	Seats of flight attendence	0.000289621	24.00002341	1.82	43.68
20	Seats of pilot	0.000241351	20.00003332	1.48	29.6
21	Emergency equipment	0.001446476	119.8651267	8.1	970.9
22	Lavatory1, galley 1	0.006	497.202	2.96	1471.71
23	Lavatory2, galley 2	0.006	497.202	30	14916.06
24	Operational items	0.002165	179.407055	26	4664.58
25	Additional equipment	0.00331	274.28977	5	1371.44

26	Equipped fuselage without payload	0.201015	16657.51	17.72	295252.81
27	Passengers economy	0.133804772	11088	20	221760
28	Passengers bussiness	0.011150398	924	5.92	5474.7
29	Onboard meal	0.002823802	234	30	7020
30	Baggage	0.037650693	3120	18	56160
31	Cargo, mail	0.007843894	650	18	11700
32	Flight attend	0.002896207	240	17	4080
33	Crew	0.0018584	154	2.4	369.6
34	TOTAL	0.399	33067.51	18.19	601817.11

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:

$$X_{MAC} = \frac{m_f \cdot X'_f + m_w \cdot X'_w - m_0 \cdot C}{m_0 - m_w} = \frac{601817.1 + 60771.46 - 82867 \cdot 0.25 \cdot 4.178}{82867 - 49820.47}$$
$$= 17.4309976 \text{m}$$

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. $C = (0{,}22 \ldots 0{,}25) B_{MAC}$ –low wing.

2.2.3 Calculation of center of gravity positioning variants

The list of mass objects for centre of gravity variant calculation given in table 2.3 and center of gravity calculation options given in table 2.4,completes on the base of both previous tables.

Table 2.3

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)	19078.47	17.91	341667.77
Nose landing gear (extended)	455.77	5.00	2278.84
Main landing gear (extended)	2585.45	17.86	46176.14
Fuel reserve	2873.83	19.43	55841.34
Fuel for flight	24826.95	19.43	482412.47
Equipped fuselage (without payload)	16657.51	17.72	295252.82
Passengers economy	11088	20.00	221760
Passengers bussiness	924	5.93	5474.70
On boar dmeal	234	30.00	7020
Baggage	3120	18.00	56160
Cargo, mail	650	18.00	11700
Flight attend	240	17.00	4080
Crew	154	2.40	369.60
Nose landing gear (retrected)	455.7685	4	1823.07
Main landing gear (retrected)	2585.4504	17.86	46176.14

Table 2.4

Airplanes C.G. position variants

№	Name	Mass, $m_i$kg	Mass moment	Centre of mass	Centre of gravity position
1	Take off mass (L.G. extended)	82887.98	1530193.68	18.46	24.65
2	Take off mass (L.G. retracted)	82887.98	1529737.91	18.45	24.52
3	Landing weight (LG extended)	58061.03	1047781.21	18.04	14.72
4	Ferry version (without payload, max fuel, LG retracted)	66631.98	1223543.21	18.36	22.30
5	Parking version (without payload, without fuel foe flight, LG extended)	41651.03	741216.91	17.8	8.73

Presented results of the center of gravity calculation demonstrates the correct wing attachment to the fuselage and the most forward and most aft center of gravity position of the aircraft are located between 8.73 and 24.65 parts of mean aerodynamic chord from the leading edge.

Conclusions to the project part

During this project work, two-class passenger plane for 156 passengers with a take-off weight of 82867 kg was calculated. This aircraft has 2IAE V2500 turbofan engines and a tri-prop landing gear with Goodyear tires. The parameters of the wing, fuselage, tail and landing gear were also calculated. The number of kitchens, toilets, wardrobes and their size were determined. In addition, the range of center of gravity position was calculated and drawings of general view and layout of the aircraft were performed.

3. NEW DESIGN OF THE PASSENGER PERSONAL STOWAGE BINS

3.1 Introduction

In the modern world, aviation plays an important role in the daily lives of people. Passenger airliners are an integral part of convenient long-distance travel. However, growing demands for passenger comfort and convenience constantly pose new challenges for airlines.

One of the most important aspects of passenger comfort is the preservation of their personal belongings and luggage during flight. In this regard, the development of a new design for passenger personal luggage compartments becomes a relevant issue. Traditional overhead luggage compartments have proven to be inconvenient and limited for passengers over time. The complexity of their use and limited capacity create the need for a new approach to the design of these compartments.

The new design of passenger personal luggage compartments is aimed at improving the design taking into account the experience of passengers. It aims to provide more space for storing personal belongings and luggage, increase safety when retrieving luggage, and also provide protection against theft.

Innovative materials and technologies can be used in the new design to optimize weight and space. The main goal of the research is to improve passenger personal luggage compartments in order to provide optimal comfort and meet the needs of passengers.

In this work, we will consider the current state of passenger personal luggage compartments, analyze the shortcomings of traditional solutions and propose a new concepts and design solutions aimed at improving their functional characteristics.

3.2 General requirements to the passenger equipment

The aviation industry pays great attention to ensuring the safety and comfort of passengers on board the aircraft. To achieve this, there are strict rules and standards governing the design, construction and operation of passenger equipment. In this paragraph, we will review the general passenger equipment requirements set forth in Advisory Circulars (AC), CS 25 (Certification Specifications), and FAR 25 (Federal Aviation Regulations). By analyzing these regulatory guidelines, we will gain a full understanding of the fundamental principles and considerations that drive the development and certification of passenger equipment in the aviation sector.

Passenger equipment covers the various components and systems on board an aircraft, including seats, restraints, cabin lighting, emergency equipment and more. The purpose of these regulations is to ensure that this equipment meets certain standards for structural integrity, functionality, performance and safety.

Advisory Circulars (ACs) issued by regulatory authorities provide additional guidance and interpretation of certification standards and regulations. These documents offer insight into specific procedures, test methods and acceptable practices related to passenger equipment. By analyzing these advisory circulars, we can gain a deeper understanding of the purpose and application of the requirements, thus assisting in the design, testing and certification processes.

CS 25 (Certification Specifications) and FAR 25 (Federal Aviation Regulations) are internationally recognized standards that define minimum safety standards for transport category aircraft. These standards cover a wide range of topics related to the design and operation of aircraft, including the certification of passenger equipment. Compliance with CS 25 and FAR 25 ensures that passenger equipment meets established safety criteria and is thoroughly tested and evaluated to ensure its suitability for use in commercial aviation.

In this paragraph, we will analyze the general requirements set forth in the advisory circulars, CS 25 and FAR 25.

Through a comprehensive analysis of the above regulatory documents, the aim is to provide a comprehensive overview of the general requirements for passenger equipment in the aviation industry.

For passenger equipment, these documents typically address several key issues, including but not limited to:

Seats: requirements for passenger seats, including structural integrity, occupant protection, emergency evacuation conditions, impact resistance and seat belt design.

Emergency Equipment: Specifications for emergency equipment such as emergency exits, escape slides, life rafts, life jackets and emergency lighting systems to ensure the safety of passengers during emergency situations.

Cabin Interior: Guidelines for cabin interior design, materials used and layout to ensure passenger comfort, accessibility and safety.

Toilets: Toilet design standards, including size, handicap accessibility, sanitation and waste disposal systems.

Safety briefing materials: requirements for safety briefing cards, placards and displays to provide passengers with important safety information before flight.

Cabin Crew Equipment: Instructions for cabin crew equipment, including intercom systems, crew seats, crew rest areas, and other equipment required to support the functions and responsibilities of flight attendants.

These requirements are constantly changing and it is important for aircraft manufacturers, operators and designers to keep abreast of the latest regulations and guidance issued by the relevant authorities to ensure compliance and passenger safety.

Baggage allowances for low-cost flights may vary by airline fig.3.1. However, low-cost airlines tend to have stricter rules and may charge additional fees for exceeding baggage size restrictions. To avoid surprises or additional charges, it's important to read the specific instructions provided by the airline you are flying with.

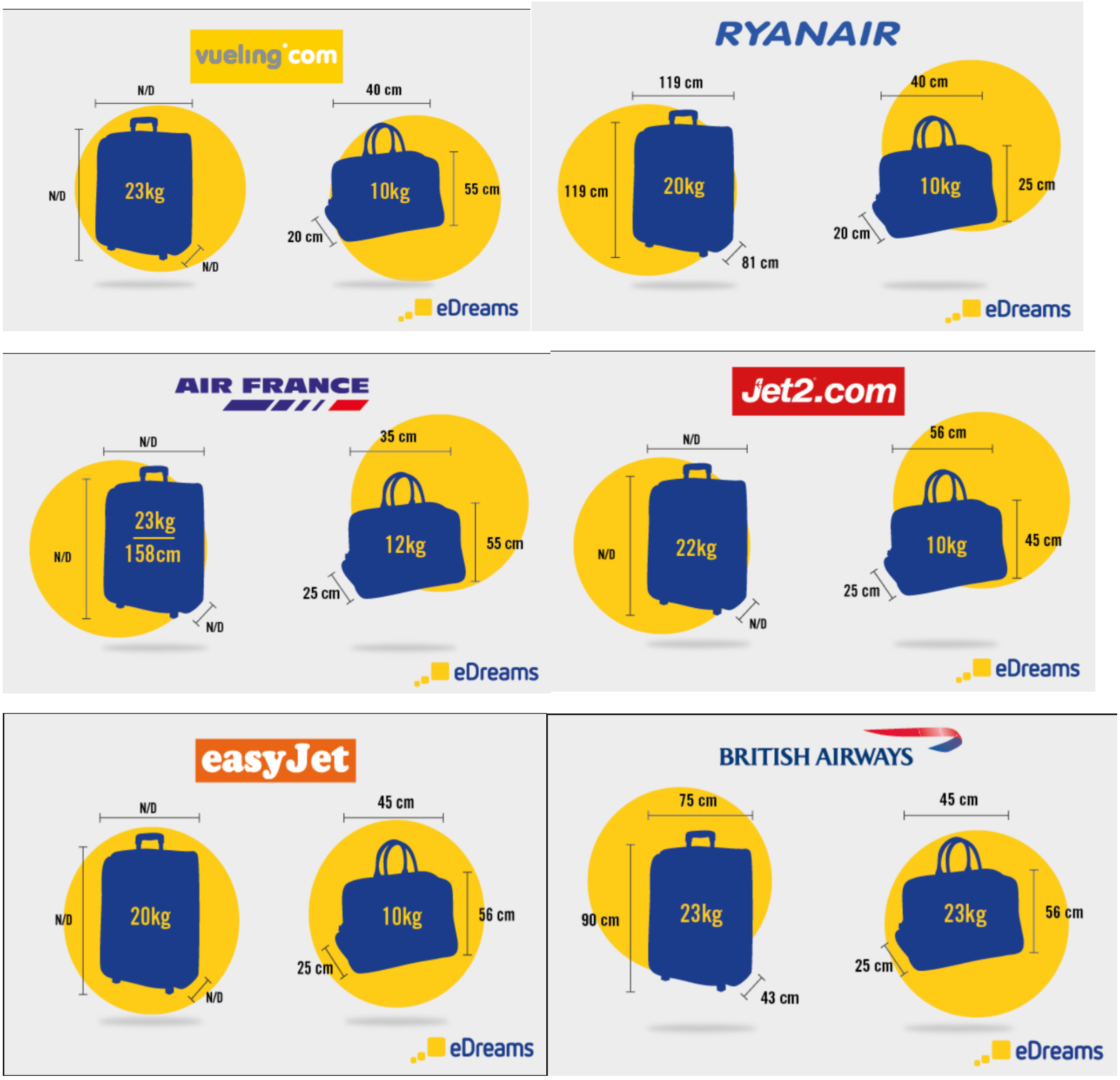

Fig. 3.1. Baggage requirements for some types of low-cost flight.

Low-cost airlines often have restrictions on the size and weight of carry-on and checked baggage. Carry-on bags are those that you can take with you in the cabin, checked bags are those that are larger that you hand over to the airline at check-in.

Carry-on baggage: low-cost airlines often place size restrictions on carry-on luggage to ensure it fits in overhead bins. These limits may vary, but the general size limit is approximately 55cm x 40cm x 20cm. There may also be a weight limit.

Checked Baggage: rules for carrying checked baggage on low-cost flights can vary significantly. Size and weight restrictions may vary by airline and fare class booked. Low-cost airlines generally have lower weight limits and may charge a surcharge for checked baggage. Dimensions for checked baggage might be around 158 cm in total (height + width + length).

It is very important that you familiarize yourself with the baggage policy of the lowcost airline you plan to fly with. By following the airline's instructions, you will avoid inconvenience and unexpected expenses during your trip.

3.3 Types of stowage bins currently in use, procedure of the luggage transportation

There are several types of stowage bins that are commonly used on aircraft. These bins are designed to store passengers' carry-on luggage during flights. The specific types of stowage bins can vary depending on the aircraft manufacturer and model, as well as the cabin configuration.

Overhead Bins: These bins are located above the passenger seats and are the most common type of stowage bins on aircraft. They are designed to accommodate standard-sized carry-on bags and other personal items.

Aft or Rear Bins: Some aircraft have additional stowage bins at the rear of the cabin. These bins provide extra storage space for passengers sitting in the back of the plane.

Under seat Storage: While not technically bins, the space under passenger seats is commonly used for stowing smaller bags, purses, and personal items. This area is easily accessible to passengers during the flight.

Wardrobe Bins: These larger bins are typically found in premium cabins, such as first class or business class. They are designed to store larger items like coats, suits, and other garments on hangers.

Crew Stowage Bins: Separate stowage bins are often designated for the flight crew's personal belongings, located in the flight deck or other designated crew areas.

The baggage handling procedure on an airplane usually involves several steps to ensure the efficient and safe handling of passengers' baggage.

Baggage check-in: passengers arrive at the airport and go to the check-in desk of the respective airline. The staff weighs the luggage, checks compliance with the dimensions and weight restrictions and attaches a luggage tag with a unique barcode or identification number.

Baggage Sorting: After check-in, baggage is transported to the baggage sorting area. Automated conveyor systems or baggage handling agents manually sort bags by flight and destination.

Baggage security check: Baggage goes through a security check before being loaded onto the plane. It goes through an X-ray machine or undergoes other security measures to detect any prohibited items.

Baggage Loading: When baggage goes through security, it is loaded into containers or trolleys called unit loading devices (ULDs) or directly onto baggage trolleys. Ground handling personnel transport the bags from the sorting area to the aircraft hold.

Aircraft compartment: Baggage is carefully placed in the aircraft's luggage compartment.

Unloading at the destination: upon arrival at the destination airport, the baggage is unloaded from the aircraft and transported to the baggage claim area.

Baggage handlers transfer baggage from the aircraft hold to baggage carts or conveyor belts for transport to the terminal.

Baggage Claim: Passengers proceed to a designated baggage claim area where they locate their baggage using a baggage tag or identification number. Bags are usually delivered on conveyor belts.

Passengers are always advised to check with the relevant airline or airport for any specific instructions or baggage requirements.

3.4 Stowage bin design

In aircraft, there are generally three types of overhead stowage bins used for passenger carry-on luggage: shelf bins, pivot bins, and translating bins. These bins are designed to provide storage space for passengers' belongings during a flight.

Shelf Bins: Shelf bins are the most common type of overhead stowage bins found in aircraft cabins. They are essentially compartments with a hinged door that opens upward. When the door is closed, it forms a shelf on which passengers can place their bags. Shelf bins are typically located above passenger seating rows and are accessible from the aisle. They provide a relatively large storage capacity and are easy to use.

Pivot Bins: Pivot bins are an alternative design to shelf bins. Instead of opening upward like a hinged door, these bins pivot outward from the side of the aircraft cabin. The door swings open horizontally, allowing passengers to store their bags inside. Pivot bins usually have a lower storage capacity compared to shelf bins but offer advantages such as easier access and reduced interference with passengers' headroom.

Translating Bins: Translating bins are a more advanced type of overhead stowage system. These bins move in a horizontal direction to aid passenger access and improve storage efficiency. When a translating bin is opened, it slides or moves inwards towards the cabin ceiling, providing easier access to the storage space. This design allows for larger storage capacity without compromising passenger convenience or cabin headroom. Translating bins are often found in newer aircraft models and can be particularly useful for maximizing available space in narrow-body aircraft.

It's important to note that the specific design and configuration of overhead stowage bins may vary between different aircraft models and airlines.

Passengers can store their bags in special compartments that hang from the roof of the plane above the seats. These compartments are made to fit the bags’ size, shape, and weight. Some business class cabins may have personal storage bins, as shown in patent and fig.3.2. This invention is a personal overhead storage space that opens sideways (to the front or back of the plane) and is supported by the floor of the plane.

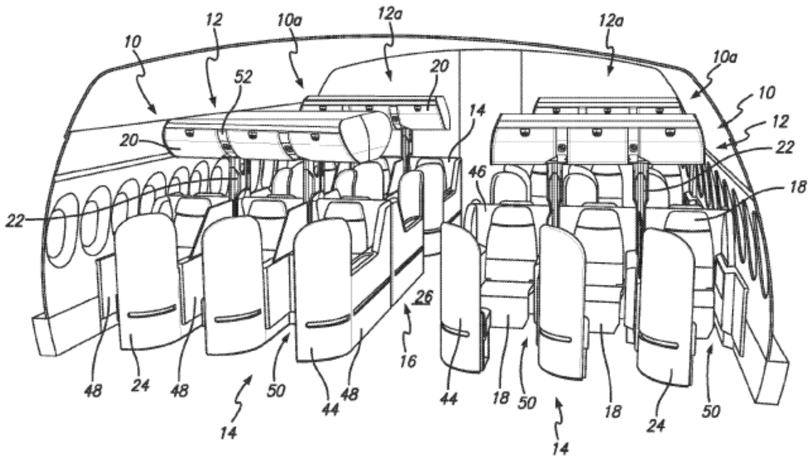

Fig. 3.2. Business class cabin with personal stowage bins.

The invention aims to fit more seats on a plane, especially in business or first class, and give passengers easy and handy storage. The way the seats, seat shells, overhead bins are designed and arranged helps to do this while also making sure passengers are comfortable and safe.

The overhead luggage compartment has limited space and sometimes it can't fit all the hand luggage that passengers bring. One example of a solution for personal baggage storage is a two-level luggage compartment, shown in the fig. 3.3.

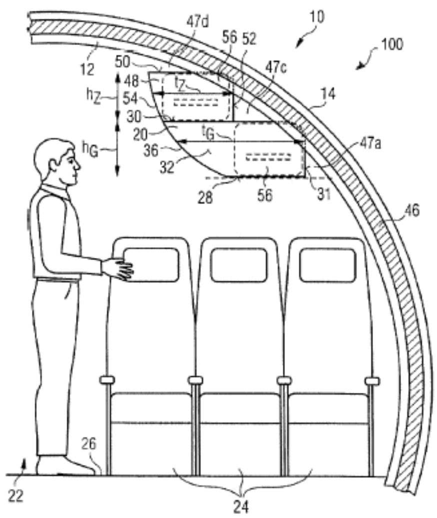

Fig. 3.3. Double deck location of the luggage.

The luggage system is designed to be installed on a plane and to have enough space while also saving space for other parts that are built in the area.

3.5 Development of own design of luggage racks

Let's start with the problem of placing hand luggage in the luggage compartment.

Luggage is frequently arranged in an unbalanced manner, exhibiting various forms and sizes, such as suitcases, backpacks, briefcases, and travel bags (fig. 3.4.). Certain passengers not only stow their belongings in the overhead compartments above their designated seating area but also utilize other compartments.

Fig. 3.4. Overhead storage bins.

Consequently, if a person boards later, they may encounter difficulty finding space for their belongings. Nevertheless, there are passengers who opt to forgo carrying any hand luggage altogether. They bring minimal items on board, and if they do carry something, it is usually manageable enough to be held on their laps or stored beneath the seat in front of them.

To solve this problem, proposition is the follows approach: divide the luggage rack for each passenger to solve the problem of limited space. This will mean that each passenger will have their own shelf where they can put their luggage. The luggage rack will be divided into three identical compartments.

However, when passengers begin to realize that they are assigned a certain size of space, they increase the amount of luggage they begin to carry to fill that space. And this, in turn, increases fuel costs, so passengers will be charged an additional fee. If a passenger wishes to have access to his belongings during the flight, he will be able to purchase this option when purchasing the ticket and will receive his own luggage space.

The standard baggage compartment of the Airbus A320 aircraft was chosen as the basis presented at the fig. 3.5.

Fig. 3.5. Airbus A320 overhead bin – large

Previously for the passengers in one block we have one storage bins with a one big door. At the presented design many changes were made, the height of the luggage compartment was increased and the width was reduced. All dimensions and performed actions are shown in Appendix B. The master-geometry of the bin is shown in the fig.3.6. and in the fig.3.7.

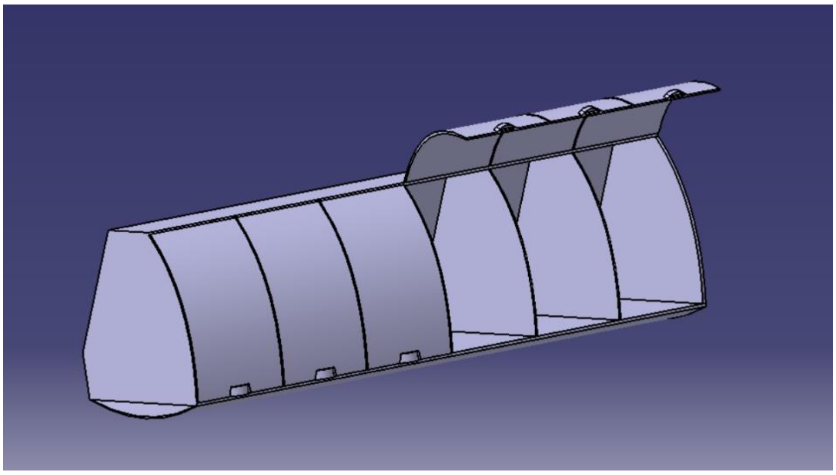

Fig.3.6. 3D model of the passenger bin.

In the luggage compartments of the aircraft, the luggage shelves are attached using a fastening system. This system is used to ensure the safety and reliability of the shelves during flight. This system consists of special mechanical fasteners that attach the shelves to the longitudinal beam in the fuselage and all hinges are attached to the frames.

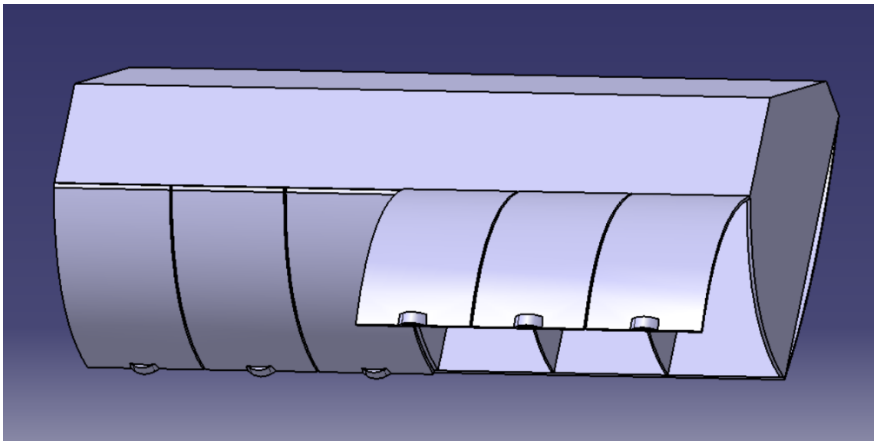

Fig.3.6. 3D model of the luggage compartments.

Luggage racks are designed to withstand heavy loads and vibrations that occur during flight. This is ensured by strong fasteners and the use of special materials that provide high strength.

Aircraft luggage racks typically use a variety of materials to ensure optimal strength, reliability, and lightness of construction.

In this case, luggage shelves made of fiberglass-plastic composites. These materials perfectly combine strength, low weight and resistance to corrosion. Some parts of luggage shelves, such as inserts, handles, covers, are made of special high-strength plastics that have the necessary strength and endurance.

In many aircraft, the mechanism for lifting the luggage rack doors uses a hydraulic system. Control over this system is carried out from the pilot's cabin or from the control panel in the flight attendant's cabin.

However, in my case, the mechanism of the doors of the luggage shelves is manual, it is designed so that the passenger can get to his luggage at any time

In an airplane, the doors of the luggage racks are locked using a mechanism known as "Latch-Locking Mechanism". This mechanism ensures reliable closing and fixing of the door during flight.

The mechanism of the hook-lock bar consists of two main components: the hook and the bar. The hook is located on one side of the door of the luggage racks, and the bar is located on the body of the aircraft. When the door is closed, the hook is inserted into the bar, which ensures its fixation.

The latch hook mechanism is properly tested and used in the aviation industry to ensure the safety of passengers and crew. It allows you to keep the luggage rack doors securely closed during flight to prevent accidental opening and luggage falling out while the aircraft is in motion.

Conclusion to the part

The new design of passenger personal baggage compartments is an important step in improving comfort and convenience for passengers of airline aircraft. Through the use of new technologies, materials and concepts, aircraft manufacturers have been able to improve the accessibility, functionality and aesthetics of luggage compartments, which provides more space for passengers to store their personal belongings during the flight.

The introduction of a new design of passenger personal baggage compartments may incur costs for the conversion of existing aircraft, but these costs may be justified from the point of view of improving passenger satisfaction and meeting the needs of passengers. In addition, it can also positively affect the competitiveness of airlines that provide advanced services and passenger comfort.

GENERAL CONCLUSIONS

In this thesis, a mid-range aircraft for 156 passengers was developed, 3 different aircraft from two manufacturers such as Boeing and Airbus were chosen for the prototypes.

For the designed aircraft, all overall dimensions were calculated and appropriate structural elements and equipment were selected.

A special part of the thesis was the development of personal luggage shelves for hand luggage. The enhanced design of passenger personal baggage compartments significantly impacts the advancement of the aviation industry by enhancing passenger convenience and satisfaction. These advancements aim to optimize space utilization within aircraft, enabling passengers to effectively store their personal items and enhance their overall travel experience. Moreover, the incorporation of novel technologies and features in these compartments fosters efficient space utilization and fosters innovative advancements in aviation technology.

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. Annex 9 to the Convention on the International Civil Aviation. 15th ed. INTERNATIONAL CIVIL AVIATION ORGANIZATION, 2017. 100 p. https://www.icao.int/wacaf/documents

5. Passenger Baggage Rules. *IATA:* https://www.iata.org/en/programs

6. Skyscanner. *Skyscanner*. URL: https://www.skyscanner.net/news/cabin-luggage-guide-hand-baggage-sizes-and-weight-restrictions

7. Airline Baggage Policies: Hand Luggage & Checked Bags | eDreams. *eDreams Travel Blog*. URL: https://www.edreams.com/blog/luggage-restrictions-by-airline/

8. Aero 15 - Overhead Stowage Bins. *The Boeing Company Official Website*.

9. Overhead Airplane Storage Design - Tim Hordern. *Tim Hordern*. URL: http://timhordern.com/overhead-airplane-storage-design/

10. Patent application publication US 2015/0158588 A1 “Luggage system having a component installation space.

Appendix A

INITIAL DATA AND SELECTED PARAMETERS

Passenger Number	156
Flight Crew Number	2
Flight Attendant or Load Master Number	4
Mass of Operational Items	1794.37 kg
Payload Mass	16302 kg

Cruising Speed	828 km/h
Cruising Mach Number	0.7719
Design Altitude	10.50 km
Flight Range with Maximum Payload	5800 km
Runway Length for the Base Aerodrome	3.30 km

Engine Number	2
Thrust-to-weight Ratio in N/kg	2.8100
Pressure Ratio	30
Assumed Bypass Ratio	5
Optimal Bypass Ratio	5
Fuel-to-weight Ratio	0.3

Aspect Ratio	9.48
Taper Ratio	4
Mean Thickness Ratio	0.120
Wing Sweepback at Quarter Chord	28.0
High-lift Device Coefficient	1.160
Relative Area of Wing Extensions	0.040

Wing Airfoil Type supercritical
Winglets installed
Spoilers installed

Fuselage Diameter	3.95 m
Finess Ratio	8.57
Horizontal Tail Sweep Angle	29
Vertical Tail Sweep Angle	34

CALCULATION RESULTS

Optimal Lift Coefficient in the Design Cruising Flight Point 0.49652

Induce Drag Coefficient 0.00914

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

Cruising Mach Number	0.77187
Wave Drag Mach Number	0.78886
Calculated Parameter D_m	0.017

Wing Loading in kPa (for Gross Wing Area):

At Takeoff	6.139
At Middle of Cruising Flight	5.094
At the Beginning of Cruising Flight	5.922

Drag Coefficient of the Fuselage and Nacelles	0.01103
Drag Coefficient of the Wing and Tail Unit	0.00915

Drag Coefficient of the Airplane:

At the Beginning of Cruising Flight	0.03187
At Middle of Cruising Flight	0.03039

Mean Lift Coefficient for the Ceiling Flight 0.49652

Mean Lift-to-drag Ratio	16.34098

Landing Lift Coefficient	1.687
Landing Lift Coefficient (at Stall Speed)	2.531
Takeoff Lift Coefficient (at Stall Speed)	2.062
Lift-off Lift Coefficient	1.505
Thrust-to-weight Ratio at the Beginning of Cruising Flight	0.552
Start Thrust-to-weight Ratio for Cruising Flight	2.188
Start Thrust-to-weight Ratio for Safe Takeoff	2.739

Design Thrust-to-weight Ratio = 2.875

Ratio $D_r = R_{cruise} / R_{takeoff}=$ 0.799

SPECIFIC FUEL CONSUMPTIONS (in kg/kN*h):

Takeoff	36.8672
Cruising Flight	58.6058
Mean cruising for Given Range	62.9712

FUEL WEIGHT FRACTIONS:

Fuel Reserve	0.03468
Block Fuel	0.29960

WEIGHT FRACTIONS FOR PRINCIPAL ITEMS:

Wing	0.10634
Horizontal Tail	0.00863
Vertical Tail	0.00852
Landing Gear	0.03671
Power Plant	0.08870
Fuselage	0.06798
Equipment and Flight Control	0.12725
Additional Equipment	0.00331
Operational Items	0.02165
Fuel	0.33428
Payload	0.19672

Airplane Takeoff Weight	82867 kg
Takeoff Thrust Required of the Engine	119.14 kN

Air Conditioning and Anti-icing Equipment Weight Fraction	0.0218
Passenger Equipment Weight Fraction (or Cargo Cabin Equipment)	0.0153
Interior Panels and Thermal/Acoustic Blanketing Weight Fraction	0.0065
Furnishing Equipment Weight Fraction	0.0121
Flight Control Weight Fraction	0.0060
Hydraulic System Weight Fraction	0.0165
Electrical Equipment Weight Fraction	0.0322
Radar Weight Fraction	0.0031
Navigation Equipment Weight Fraction	0.0047
Radio Communication Equipment Weight Fraction	0.0023
Instrument Equipment Weight Fraction	0.0054
Fuel System Weight Fraction	0.0099

Additional Equipment:

Equipment for Container Loading

No typical Equipment Weight Fraction

(Build-in Test Equipment for Fault Diagnosis, 0.0033

Additional Equipment of Passenger Cabin)

TAKEOFF DISTANCE PARAMETERS

Airplane Lift-off Speed	290.66 km/h
Acceleration during Takeoff Run	2.22 m/s*s
Airplane Takeoff Run Distance	1466 m

Airborne Takeoff Distance	578 m
Takeoff Distance	2045 m

CONTINUED TAKEOFF DISTANCE PARAMETERS

Decision Speed	276.13 km/h
Mean Acceleration for Continued Takeoff on Wet Runway	0.26 m/s*s
Takeoff Run Distance for Continued Takeoff on Wet Runway	2520.26 m
Continued Takeoff Distance	3098.64 m
Runway Length Required for Rejected Takeoff	3211.30 m

LANDING DISTANCE PARAMETERS

Airplane Maximum Landing Weight 62393 kg
Time for Descent from Flight Level till Aerodrome Traffic Circuit Flight 20.8 min

Descent Distance	47.92 km
Approach Speed	256.17 km/h
Mean Vertical Speed	2.05 m/s
Airborne Landing Distance	520 m
Landing Speed	241.17 km/h
Landing run distance	775 m
Landing Distance	1294 m
Runway Length Required for Regular Aerodrome	2161 m
Runway Length Required for Alternate Aerodrome	1838 m

Appendix B

Passenger personal stowage bins