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 далекомагістрльного пасажирського літака місткістю до 380 пасажирів»

Виконав: __________ **Ілля КАРПОВИЧ**

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

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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 long range passenger aircraft with capacity up to 380 passengers"

Fulfilled by:	____________	**Illya KARPOVICH**
Supervisor:		
PhD, associate professor	____________	**Volodymyr KRASNOPOLSKYI**
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

КАРПОВИЧА ІЛЛІ ОЛЕГОВИЧА

1. Тема роботи: «Аванпроект далекомагістрального пасажирського літака місткістю до 380 пасажирів», 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: крейсерська швидкість V_{cr} = 890 км/год, дальність польоту L = 12000 км, крейсерська висота польоту H_{op} = 12,6 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 розробку та проєктування механізму для завантаження пасажирського вантажу в вантажне відділення літака.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: загальний вигляд літака (А1×1), компонувальне креслення фюзеляжу (А1×1), складальне креслення механізму для завантаження пасажирського вантажу (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. Аналіз механзмів роботи з вантажем.	08.06.2023 – 09.06.2023	
6	Розробка механізму для завантаження пасажирського вантажу.	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 ___________ Володимир КРАСНОПОЛЬСЬКИЙ

Завдання прийняв до виконання ___________ Ілля КАРПОВИЧ

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

Illya KARPOVICH

1. Topic: "Preliminary design of the long-range passenger aircraft with 380 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} = 890 km/h, range of flight L = 12000 km, cruise height of flight H_{op} = 12,6 km.

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, special part: development and design of the mechanism for loading passenger cargo into the cargo department of the aircraft.

5. Required material: general view of the airplane (A1×1), layout of the airplane (A1×1), design of the mechanism for loading of passenger cargo (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. Analysis of cargo handling mechanisms.	08.06.2023 – 09.06.2023	
6	Development of a mechanism for loading passenger cargo.	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: ___________ Volodymyr KRASNOPOLSKII

Student: ___________ Illya KARPOVICH

РЕФЕРАТ

Пояснювальна записка кваліфікаційної роботи бакалавра «Аванпроект далекомагістрльного пасажирського літака місткістю до 380 пасажирів»:

50 с., 2 рис., 10 табл., 10 джерел

Ця кваліфікаційна робота присвячена розробці далекомагістрального пасажирського літака з максимальною вмістимістю 380 осіб. У цьому дослідженні було використано метод порівняльного аналізу прототипів літаків для вибору найнеобхідніших та обґрунтованих параметрів проектування літака. Крім того, були використані інженерні розрахунки для отримання основних геометричних та компонувальних характеристик проектуваного літака.

У спеціальній частині цієї роботи презентовано новий механізм для навантаження пасажирського багажу, який має велике значення у зменшенні трудових навантажень на працівників, скороченні часу, необхідного для завантаження та розвантаження, а також підвищенні ефективності роботи у відділенні багажу. Практичне значення цієї кваліфікаційної роботи проявляється у поліпшенні продуктивності та швидкості роботи у відділенні багажу на довгих перельотах.

Результати, які були представлені, можуть бути застосовані в навчальному процесі на спеціальностях, пов'язаних з авіацією, а також у авіаційній індустрії.

Дипломна робота, аванпроєкт літака, компонування, центрування, механізм завантаження, роликовий конвеєр

ABSTRACT

Bachelor degree thesis "Preliminary design of long range passenger aircraft with capacity up to 380 passengers"

50 pages, 2 figures, 10 tables, 10 references

The design of a long-range passenger aircraft with a seating capacity of up to 380 persons is the primary goal of this qualifying work. In the present investigation, engineering calculations were applied for identifying the meant aircraft's fundamental geometry and layout measures as well as the comparative examination of prototype aircraft to determine which design parameters were the most suitable and rational.

A brand-new system for loading passenger luggage is presented by the special part. The purpose of the work is to make managing luggage easier for employees, speed up loading and unloading, and improve productivity in the baggage area.

The work's results were made obtainable for use in the aviation industry and in specific aviation education programs.

Bachelor thesis, preliminary design, cabin layout, center of gravity calculation, loading device, roller conveyor

Format	№	Designation	Name	Quantity	Notes
			<u>General documents</u>		
A4	1	NAU 23.03K.00.00.00.71 EN	Task for work	1	
	2	NAU 23.03K.00.00.00.71	Long-range passenger aircraft	2	
A1		Sheet 1	General view		
A1		Sheet 2	Fuselage layout		
A4	3	NAU 23.03K.00.00.00.71 EN	Long-range passenger aircraft	49	
			Explanatory note		
			<u>Documentation for assembly units</u>		
A1	4	NAU 23.03K.00.00.00.71	Design of roller conveyor	1	

NAU 23.03K.00.00.00.71 EN

	Sh.	№ doc.	Sign	Date
Done by		Karpovich I.O.		
Supervisor		Krasnopolskyi V.S.		
St.control.		Krasnopolskyi V.S.		
Head of dep.		Ignatovich S.R.		

Preliminary design of mid-range passenger aircraft with 380 passenger capacity
(List of diploma work)

list	sheet	sheets
Q	9	50

402 ASF 134

CONTENT

INTRODUCTION

The demand for large, long-range aircraft has witnessed a significant surge in recent years due to the growing passenger capacity, especially on longer routes. Consequently, there has been an increased necessity for airplanes, given their ability to cover greater distances at higher speeds compared to other modes of transportation, all while being more cost-effective. The development of new civil aviation aircraft is essential to meet the requirements set by international air transport organizations, which encompass aspects such as flight safety, enhanced passenger comfort, reduced emissions of harmful gases, and other factors that ensure cost-effective operations, high reliability, and consistent flight schedules within the highly competitive global aviation market.

The objective of this bachelor's degree thesis is to design an aircraft capable of long-distance travel, accommodating 380 individuals of various classes and their corresponding luggage.

1. PRELIMINARY DESIGN OF LONG-RANGE AIRCRAFT

1.1 Analysis of prototype

The proposed aircraft is a wide-body twin-engine turbojet passenger liner. The cabin has a seating capacity of 380 individuals, varying depending on the specific configuration. It boasts a maximum range of 12,000 km when operating at maximum commercial load. The notable features of this aircraft lie in its fuel efficiency and environmental friendliness, achieved through the implementation of advanced turbojet engines. These exceptional performance parameters are attained by enhancing the aerodynamic qualities of the aircraft.

The fuselage design of the new aircraft exhibits improved airflow characteristics, achieved by employing a streamlined and uniformly narrowed nose section devoid of any protrusions or concavities. The utilization of composite materials has resulted in a reduction of cabin pressure, providing more comfortable conditions similar to those experienced at an altitude of 2400 m. The aircraft is designed following the configuration of an all-metal, cantilevered twin-engine wide-body with a low-mounted swept wing and a vertical tail.

Significant modifications have been made to the fuselage design to enhance reliability, ensure safety in the event of damage, reduce crack growth rates, achieve predetermined lifespan, minimize weight, and improve the quality of the external surface. The passenger cabin layout has been carefully arranged to accommodate 380 individuals, while the cabin itself is equipped with a ventilation system for heating. The risk of aileron reversal, commonly experienced by highly swept wings, has been mitigated. Additionally, the landing distance has been reduced from 3.3 km to 2.2 km, enabling the aircraft to safely land on airfields with runways categorized as Class A.

The aircraft is designed using the classical aerodynamic layout type, with a low-wing layout and a semi-monocoque fuselage structure. Aircraft has a modern navigation system and can travel long distances. The aircraft is structurally made up of the following parts: the torsion type wing (double spar); the tail unit; the power plant; the undercarriage; and the fuselage, which contains a pressurized cabin for crew and passengers. Statistical data for the prototype are presented in table 1.1.

Table 1.1

Statistic data of prototype

Name and size	A350	787-9	IL-96	ZiA1
Max. paid load, kg	50900	51000	37050	43320
Crew, men	10+3	12	10	10+2
Passenger seats	380	290	300	380
Load on wing, kN/m2	6	6.3	6	5,354
Average cruising quality	19.8	15	15	19.8
Flight range with mkn max, km	12000	14140	5800	12000
Cruise altitude range, km	12.6	11.7	10.7	12.6
Vkr max/N, km/h/km	880	905	865	865
Vkr econ/N, km/h/km	840	870	845	835
Weight capacity, kN/kg	2.6	2.52	2.6	2.8
Productivity, tkm/h				
Specific fuel consumption, g/t.km				
Power plant data				
Number and type of engines	2	2	2	2
Take-off thrust, kN	170	329.61	160	175
Cruising traction. kN	110	250	100	100
Specific take-off fuel consumption, kg/kN (kW)	35	28.8	40	34.6448
Cruising specific fuel consumption, kg/kN (kW)	58	52.82	55	57.4278
Degree of pressure increase	30	55.4	30	31.2
The degree of double-circuit	6	9.1	4.5	6
Takeoff and landing characteristics				
Base airfield class	SA	SA	SA	SA
Approach speed, km/h	235.1	255	271.7	235.1
Landing speed, km/h	220.1	240	256.7	220.1
Breakaway speed, km/h	281.95	290.74	299.6	281.95
Acceleration length, m	1790	1523	2108	1790
Mileage length, m	670	770	890	670

Ending of the table 1.1

1	2	3	4	5
Takeoff distance, m	2280	2100	2600	2280
Landing distance, m	1180	2150	2370	1180
Basic geometric parameters	A350	787-9	IL-96	ZiA1
Wing span, m	60.3	60.17	57,66	59.47
Arrowness by 1/4 chords, degrees	31	32.2	32.2	31
Mean geometric chord, m	9,437	5.4	6	9,437
Wing extension	6,7	11,13	10.3	6,7
Narrowing of the wing	3.5	2	4.7	3.5
Fuselage length, m	63.6192	63	55,345	63.6192
Diameter of the fuselage, m	5.64	5.87	6.08	5.64
Extending the fuselage	11,28	10.8	9	11,28
Width of the passenger cabin, m	5.45	5.70	5.85	5.45
Passenger cabin length, m	60	40	38	60
Cabin height, m	2.4	2.1	2	2.4
Cabin volume, m^3	1200	970	910	1200
Cargo space volume, m^3	200	174.5	140	200
Step of chairs, mm	870(800)	840	860	870(800)
Passage width, m	0.4	0.37	0.45	0.4
The scope of GO, m	20	10	19.82	20
Sagittality of GO by 1/4 chord, degree	33	37	37	33
Extension of GO	3,247	5.73	5.31	3,247
Narrowing of GO	3	3	3	3
Height of VO, m	8.32	9	7.81	8.32
Arrowness of VO by 1/4 chord, degree.	56	42	42	56
Extension of VO	1.04	1.56	1.68	1.04
Undercarriage base, m	25.1255	25.6	25.6	25.1255
Undercarriage track, m	9,094	9,768	9,768	9,094

1.2 Brief description of the main parts of the aircraft

1.2.1 Wing

For modern airplanes operating at speeds close to the speed of sound, wing profiles with near-symmetric characteristics and sharper leading edges are utilized. These profiles typically have a relatively rearward position of maximum thickness, ranging from 35% to 45%. Such wing profiles exhibit smoother pressure distribution along the wing's chords, resulting in reduced local airflow velocity over the upper surface of the wing.

This, in turn, contributes to an increase in the critical flight Mach number (M_{cr}).

In line with this understanding, the relative thickness of wings for aircraft operating at speeds close to the speed of sound (M_{cr} = 0.8 to 0.9) is typically reduced. The relative thickness values range from 12% to 14% at the wing root and decrease to 8% to 9% at the wing tip.

The airplane's wing is cantilever in design, with a supercritical rear-loaded airfoil. The design cruising speed has been reduced to M 0.76-0.78 in order to respond to the characteristics of short and average flight distances. It is essential since wing properties change little with cruising speed and aerodynamic drag is minimal across the whole range of operation. The thickness of the airfoil's rear beam has been increased by 30% in order to accommodate the flaps and their control systemhe wing design incorporates several features to optimize aerodynamic performance. While "wingtip sails" are utilized, the leading edge employs a circular shape, transitioning to a wedge-shaped trailing edge. A "spindle" is integrated along the wing chord to minimize drag. In comparison to traditional "winglets," this configuration exhibits superior drag reduction characteristics, even in non-optimal conditions. The "wingtip sail" remains effective and resistant to stalling when encountering crosswinds.

The leading edge slat, spanning the entire wingspan, is divided into five sections. To enhance the deployment of the leading edge slats without compromising high-speed cruising capabilities, modifications have been made to the engine pendant, considering the close proximity of the engine nacelle to the lower wing surface. Both the inner and outer trailing edge feature large single-slot Fowler flaps. Each side of the wing is equipped with five spoilers on the upper surface. Two inner spoilers function as speed brakes, while three outer spoilers serve roll control. During landing, all five spoilers contribute to reducing lift force.

To improve the spanwise length of the trailing edge flaps during take-off and landing, the inboard ailerons have been eliminated, effectively increasing the lift generated. The front and rear edges of each wing consist of fixed panels, while the trailing edge flaps, flap fairings, spoilers, ailerons, and wing root fairings are constructed using composite materials for optimal performance and weight reduction.

1.2.2 Fuselage

The fuselage of the aircraft features a semi-monocoque structure. The longest section of the fuselage is the equal-diameter section, which houses the passenger cabin. To minimize aerodynamic resistance, a waist-shaped rear section is implemented in the fuselage design. The structure of the fuselage comprises frames, stringers, beams, and a load-bearing skin.

The aerodynamic and weight characteristics of the fuselage are greatly influenced by its shape and dimensions, which are determined by geometric parameters such as the cross-sectional shape, fuselage elongation (λf), and fuselage diameter (Df).

It is important to note that the elongation and length of the fuselage are carefully determined during the aircraft layout process to ensure adequate space for the crew, passengers, and cargo, as well as to maintain the appropriate clearances for the horizontal and vertical wings of the aircraft on both the left and right sides.

1.2.3 Tail unit

The tail unit of the aircraft consists of the horizontal and vertical stabilizers, elevators, and rudder. Among the crucial aspects of the aerodynamic configuration is the selection of the horizontal tail's positioning. In order to achieve longitudinal static stability and counteract overloading, the center of mass must be positioned ahead of the aircraft's aerodynamic center. The distance between these points, in relation to the average aerodynamic chord of the wing, determines the degree of longitudinal stability.

The horizontal tail is designed with a reverse camber profile to enhance flight stability. The elevator is controlled using a fly-by-wire control system, while the rudder is operated through a hydromechanical flight control system. Both the horizontal and vertical stabilizers are constructed entirely from composite materials.

1.2.4 Undercarriage

The aircraft's landing gear or undercarriage is composed of two retractable primary landing gears and one retractable nose landing gear. All landing gear struts and hatches can be controlled hydraulically and electrically. The landing gear mechanically operates the hatch associated to the landing gear struts: when the landing gear is fully retracted, the hatch closes. All landing gear hatches are opened when retraction and extending of the landing gear. Hydraulically retracting the landing gear. Two-wheeled struts with oil-gas shock absorbers are responsible for each landing gear. All of the main landing gear is housed in the wing-fuselage fairing. It is possible to turn the nose gear and move forward it into the fuselage. Composite materials were implemented to make the main landing gear hatch.

1.2.5 Control system

The fly-by-wire control system manages the entire flight process, from take-off to landing. The main control system consists of two independent systems with a total of five computers. Two computers control the elevators and ailerons, while three computers are responsible for the spoilers. The rudder trim is handled by two flight stabilization computers, and two special computers oversee the control of the slats and flaps. The implementation of fly-by-wire control enhances flight safety and significantly reduces pilot workload.

To enhance the reliability of the fly-by-wire control system, two measures have been implemented. First, the signal transmission cables leading to each control surface are separated from one another. For example, the aileron and spoiler cables are respectively routed before and after the wing front beam. Second, to protect against lightning strikes, all telex control cables are enclosed in metal shielding sleeves, with exposed sections housed in cable ducts.

The flight control system utilizes side sticks instead of conventional steering sticks and handwheels, which contributes to a reduction in system weight. The side stick control system consists of an inward and forward tilting joystick, a roll and pitch sensor box, and an artificial sensor system. When the autopilot is engaged, an electromagnetic coil-driven bayonet locks the control system in a neutral position. An electronic circuit connects the two fly-by-wire control devices. Under normal circumstances, two pilots cannot simultaneously operate the aircraft. To address conflicting control inputs from the pilots, a comparison device is installed in the electronic circuit. The fly-by-wire control system can merge the two input signals. If one pilot wishes to cancel the input from the other, they can press and hold the "takeover button" to release the other pilot's control input.

The hydraulic systems are color-coded into three groups: green, yellow, and blue. The green and yellow systems are interconnected, with each engine driving one of them. The blue hydraulic system, powered by air ram wheels, is equipped with three engines. Two engines are driven by the main engines for normal power supply, while the third engine is driven by an auxiliary power unit. The blue hydraulic system can also serve as an emergency backup power supply in the air, in addition to its ground use. In the event of a failure of all three engines, there is a 5,000 AC emergency engine driven by the blue hydraulic system. A converter is installed to provide DC power, and a battery is also available for backup power.

1.2.6 Power plant

The designed aircraft incorporates two Rolls-Royce Trent XWB engines, which are high bypass turbofan engines with axial flow. These engines are renowned for their reliability and impressive power output. The key performance characteristics of these engines are comparable, making them suitable for the designed aircraft. Specifically, the Trent-97 XWB engine was selected for this project based on its calculated take-off thrust. Detailed information about these engines can be found in Table 1.2.

Table 1.2

Engines performances

Model	Thrust	Bypass ratio	Dry weight	Pressurized ratio	Specific fuel consumption	Working temperature
Trent-97 XWB	97,000 lbf (431 kN)	9.6	7,550 kg (16,640 lb)	50	2.74 t	920°of Celsius

Conclusion to the analytical part

After conducting a thorough comparison with similar aircraft models such as the Boeing 787-9, A350 and IL-96, it can be concluded that the long-range civil passenger aircraft designed in this project, with a seating capacity of 380, not only meets but also exceeds the essential specifications within the project's scope. The investigation also determined a range of permissible center of gravity positions that satisfy the aircraft's criteria for longitudinal stability and controllability.

2. GEOMETRY CALCULATIONS OF THE MAIN PART OF AIRCRAFT

2.1 Determination of geometric parameters of the wing

The aircraft layout calculation involves determining the main dimensions and operational requirements of the designed aircraft, as well as selecting its purpose. It encompasses the geometric calculation of key structural components such as the wing, fuselage, tail unit, and landing gear. Additionally, this analytical process entails choosing the appropriate power plant and interior scheme. The interior scheme estimation involves dimensional calculations to meet the capacity requirements of the aircraft.

It is worth noting that this layout adheres to both contemporary standards and established calculation methods.

2.1.1 Wing geometry calculation

Full wing area is:

$$S_w = \frac{m_0 \cdot g}{P_0} = \frac{331080 \cdot 9.81}{6.5} = 499.16 \text{ m}^2$$

where m_0 – take-off weight; g – gravity acceleration; P_0 – specific wing load.

Wing span is:

$$l_w = \sqrt{S_w \cdot \lambda_w} = \sqrt{499.16 \cdot 7} = 59.16 \text{ m}$$

where λ_w – wing aspect ratio.

Root chord is:

$$b_0 = \frac{2S_w \cdot \eta_w}{(1+\eta_w) \cdot l_w} = \frac{2 \cdot 499.16 \cdot 3.22}{(1+3.22) \cdot 59.16} = 12.87 \text{ m}$$

where η_w – wing taper ratio.

Tip chord is:

$$b = \frac{b}{\eta} = \frac{12.87}{3.22} = 3.99\,\text{m}$$

Maximum wing thickness is:

$$c_{\max} = c_w \cdot b_t = 0.11 \cdot 3.99 = 0.438\,\text{m}$$

The mean aerodynamic chord of the aircraft was determined using the geometrical method, as illustrated in figure 1.1. This method involves measuring a line parallel to the chords, which intersects the sections connecting the midpoint of the tip chord with the midpoint of the root chord, as well as the upper end of the tip chord extension (equal to the length of the root chord) with the lower end of the root chord extension (equal to the length of the tip chord). The geometrical method was selected for its accuracy and straightforwardness in execution.

Mean aerodynamic chord is equal: $b_{mac} = 9.11\,\text{m}$

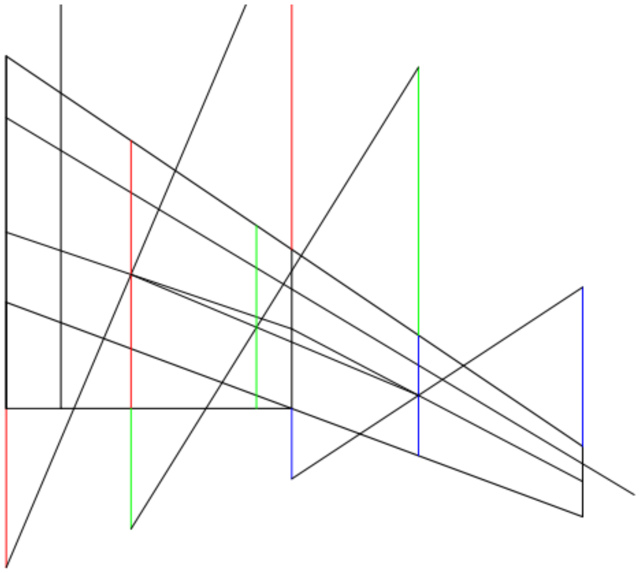

Figure 1.1 – Mean aerodynamic chord.

Once the geometric characteristics of the wing have been established, the next step is to evaluate the dimensions of the ailerons and high-lift devices. The determination of the ailerons' geometric parameters follows the following sequence:

Ailerons’ span:

$$l_{ai} = 0.375 * \frac{l_w}{2} = 0.375 * \frac{59.160}{2} = 9.35m$$

Aileron area:

$$S_{ai} = 0.065 * \frac{S_w}{2} = 0.065 * \frac{499.16}{2} = 16.22m^2$$

The values calculated earlier are considered optimal. It is not recommended to increase the span and chord of the ailerons beyond these values, as it would result in a decrease in the aileron's coefficient and a reduction in the span of the high-lift devices. Similarly, increasing the chord of the ailerons would result in a decrease in the width of the wing box.

Aerodynamic compensation of the aileron:

$$\text{Axial } S_{ax.ail} \le (0.25...0.28) \cdot S_{ail}$$

$$S_{ax.ail} = 0.26 \cdot 16.22 = 4.26\,\mathrm{m}^2$$

Area of ailerons trim tab. For two engine airplane:

$$S_{tt} = (0.07...0.08) \cdot S_{ail} = 0.08 \cdot 16,22 = 1.29\,\mathrm{m}^2$$

The recommended range of aileron deflection is 25 degrees upward direction and 15 degrees downward direction.

2.2 Fuselage layout

The estimation of the fuselage layout involves calculating the main geometrical dimensions and creating the interior scheme. In the geometrical calculation, the anticipated aerodynamic characteristics of the designed aircraft and the expected resistances during normal and extreme flight conditions are taken into consideration, aligning with the intended purpose. The fuselage geometry should minimize parasitic, skin friction, and wave drags, while being able to withstand aerodynamic loads and ensuring a sufficient safety factor. To minimize form and wave drag and achieve the required strength characteristics without stress concentrators in the fuselage cross-section, a round shape has been selected.

The interior scheme creation, which is another aspect of the fuselage calculation, is based on the desired capacity of the designed aircraft. Additionally, the requirements of ergonomics and sanitary standards for passenger aircraft must be met. The subsequent steps involve calculating the main geometrical characteristics of the fuselage and determining its outline.Nose part length is:

$$l_{np} = (2...3) \cdot D_f = 2.1 \cdot 7.35 = 15.43 \text{ m}$$

Fuselage length is:

$$l_f = \lambda_f \cdot D_f = 11.28 \cdot 7.35 = 82.9 \text{ m}$$

where λ_f – fuselage fineness ratio.

Fuselage nose part fineness ratio is:

$$\lambda_{np} = \frac{l_{np}}{D_f} = \frac{16.35}{7.35} = 2.2$$

Length of the fuselage rear part is:

$$l_{rp} = \lambda_{rp} \cdot D_f = 2.8 \cdot 7.35 = 60.58 \text{ m}$$

where λ_{rp} – fuselage rear part fineness ratio.

Cabin height is:

$$H_{cab} = 1.54 + 0.19 B_{cab} = 1.54 + 0.19 \cdot 2.56 = 2.02 \text{ m}$$

where B_{cab} – width of the cabin.

For the economy class passenger cabin, the arrangement of seats in a single row (3 + 3 + 3) determines the following parameter:

$$B_{cab} = n_{3chblock} \cdot b_{3chblock} + b_{aisle} + 2 \cdot \delta = 3 \cdot 1100 + 600 + 2 \cdot 30 = 3.42 \text{ m}$$

where $n_{3chblock}$ – width of 3 chairs; $b_{3chblock}$ – number of 3 chair block; b_{aisle} – width of aisle.

The length of passenger cabin is:

$$L_{cab} = L_1 + (n_{raws} - 1) \cdot L_{seatpitch} + L_2 = 1500 + (40 - 1) \cdot 800 + 300 = 33 \text{ m}$$

where L_1 – distance between the wall and the back of first seat;

n_{rows} – number of rows;

$L_{seatpitch}$ – seat pitch;

L_1 – distance between the back of last seat and the wall.

2.3 Luggage compartment

Cargo compartments can be positioned either on the main deck of the passenger cabin or in the lower deck within the sealed section of the fuselage. When located on the main deck, the cargo compartments are typically situated in front and rear of the passenger cabin. This arrangement allows for proper centering of the aircraft by adjusting the cargo weight based on the number of passengers. The specific placement of the cargo bays is determined during the assessment of the fuselage length, and it is advisable to refer to data from prototype aircraft.

Cargo compartment volume is:

$$V_{c\arg o} = \nu \cdot n_{pass} = 0.2 \cdot 380 = 76\ \text{m}^3$$

where ν – relative mass of baggage (0.2…0.4 for $D_f \le 4\ \text{m}$ and 0.36…0.38 for $D_f > 4\ \text{m}$); n_{pass} – number of passengers.

Luggage compartment design is similar to the prototype.

2.4 Galleys and buffets

Volume of buffets (galleys) is:

$$V_{galley} = \left(0.1...0.12\right) \cdot n_{pass} = 0.11 \cdot 380 = 41.8\ \text{m}^3$$

where V – volume of buffets; n_{pass} – number of passengers.

Area of buffets (galleys) is:

$$S_{galley} = \frac{V_{galley}}{H_{cab}} = \frac{41.8}{2.3} = 18.17\ \text{m}^2$$

The amount of food provided per passenger consists of 0.9 kg for breakfast, lunch, and dinner, while 0.6 kg is allocated for tea and water. The design of the buffet area closely resembles that of the prototype. An example of the composition of the buffet is shown in fig. 2.4.

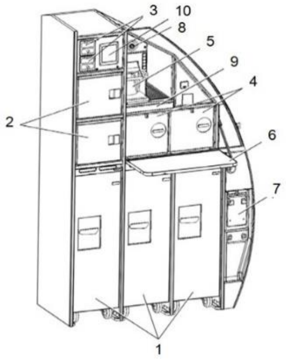

Fig. 2.4. Arrangement of buffet elements

1 - service carts; 2 - convection ovens; 3 - stove control panels; 4 - flight attendant's containers; 5 - coffee maker; 6 - table; 7 - garbage container; 8 - nozzles of individual ventilation; 9 - tray for water; 10 - a mirror.

2.5 Undercarriage design

In order to determine the undercarriage configuration for this project, it is essential to analyze the positioning of each strut in relation to one another, calculate the loads imposed on the landing gear system, and consider the aircraft's center of gravity. The layout of the landing gear in this design closely follows the established data from the prototype. Similar to the tail unit, it is crucial to ensure a stable and controllable foundation for the aircraft during ground operations, including takeoff and landing. Main wheel axes offset is:

$$e = k_e \cdot b_{MAC} = 0.3 \cdot 9.11 = 2.73 \text{ m}$$

where k_e – coefficient of axes offset ($k_e = 0.15\ldots0.3$); b_{MAC} – mean aerodynamic chord.

Landing gear wheel base is:

$$B = k_b \cdot L_f = 0.39 \cdot 82.9 = 32.33 \text{ m}$$

where k_b – wheel base calculation coefficient ($k_b = 0.3\ldots0.4$).

That means that the nose strut holds 5...11% of airplane weight.

Front wheel axial offset is:

$$d_n = B - e = 32.33 - 2.47 = 29.86 \text{ m}$$

Wheel track is:

$$T = k_T \cdot B = 0.9 \cdot 32.33 = 29.09 \text{ m}$$

where k_T – wheel track calculation coefficient ($k_T = 0.7\ldots1.2$).

Nose wheel load is:

$$P_n = \frac{9.81 \cdot e \cdot k_d \cdot m_0}{B \cdot i} = \frac{9.81 \cdot 2.47 \cdot 1.9 \cdot 331080}{32.33 \cdot 2} = 235731.05 \text{ N}$$

where k_d – dynamics coefficient (k_d = 1.5…2.0); i – number of wheels.

Main wheel load is equal to:

$$P_m = \frac{9.81 \cdot (B-e) \cdot m_0}{B \cdot n \cdot i} = \frac{9.81 \cdot (32.33 - 2.47) \cdot 331080}{32.33 \cdot 16 \cdot 4} = 46871.2 \text{ N}$$

where n – number of main landing gear struts.

Based on the calculated wheel loading and take-off speed, we can select the appropriate tires for the landing gear. Referring to the catalog, we obtained the following options:

for nose landing gear

Flight Eagle DDT 277K08-1 with parameters $P_{rated} = 4000$ lbf ; $V_{rated} = 160$ MPH ; size 19.5×.75-10.

for main landing gear

Aircraft Rib 277K28-1 with parameters $P_{rated} = 6700$ lbf ; $V_{rated} = 190$ MPH ; size 22×7.75-10.

The rate of wheel loading is:

for nose wheel $\frac{4000-3957}{4000} \cdot 100\% = 1.07\%$

for main wheel $\frac{6700-6595}{6700} \cdot 100\% = 1.56\%$

The values are less than 10% so choosed tires can be used for this airplane.

2.6 Layout and calculation of basic parameters of tail unit

The selected configuration for the tail unit is conventional, which was determined based on the analysis of three prototype empennage schemes. In order to determine the overall outline of the tail unit, it is necessary to calculate the geometric dimensions of the vertical and horizontal stabilizers, as well as the dimensions of the control surfaces. The primary objective of the tail unit is to meet the requirements for aircraft stability and controllability.

Area of vertical tail unit is:

$$S_{VTU} = \frac{l_{wx} \cdot S_w}{L_{VTU}} \cdot A_{VTU} = \frac{59.47 \cdot 485.70}{30} \cdot 0.12 = 103.98 \text{ m}^2$$

where L_{VTU} – length of vertical tail unit; A_{VTU} – coefficient of static momentum of vertical tail unit (see the table in methodical guide).

Area o horizontal tail unit is:

$$S_{HTU} = \frac{b_{MAC} \cdot S_w}{L_{HTU}} \cdot A_{HTU} = \frac{9.11 \cdot 485.70}{32.5} \cdot 0.9 = 122.53 \text{ m}^2$$

where L_{HTU} – length of horizontal tail unit; A_{HTU} – coefficient of static momentum of horizontal tail unit (see the table in methodical guide).

Determination of the elevator area and direction:

Altitude elevator area is:

$$S_{el} = k_{el} \cdot S_{HTU} = 0.3 \cdot 122.53 = 36.759 \text{ m}^2$$

where k_{el} – relative elevator area coefficient (k_{el} = 0.3…0.4).

Rudder area is:

$$S_{rud} = k_r \cdot S_{VTU} = 0.4 \cdot 103.98 = 41.592 \text{ m}^2$$

where k_r – relative rudder area coefficient (k_r = 0.35…0.45).

Choose the area of aerodynamic balance:

$$0.3 \le M \le 0.6$$

$$S_{eb} = (0.22...0.25) \cdot S_{el} = 0.22 \cdot 36.759 = 8.09 \text{ m}^2$$

$$S_{rb} = (0.2...0.22) \cdot S_{rud} = 0.2 \cdot 41.592 = 8.32 \text{ m}^2$$

where k_{eb} – relative elevator balance area coefficient;

k_{rb} – relative rudder balance area coefficient.

The area of altitude elevator trim tab is:

$$S_{te} = k_{te} \cdot S_{el} = 0.08 \cdot 36.759 = 2.94 \text{ m}^2$$

where k_{te} – relative elevator trim tab area coefficient (k_{te} = 0.08…0.12).

Area of rudder trim tab is:

$$S_{tr} = k_{tr} \cdot S_{rud} = 0.06 \cdot 41.592 = 2.49 \text{ m}^2$$

where k_{tr} – relative trim tab area coefficient (k_{tr} = 0.04…0.06 for airplanes with 2 engines and k_{tr} = 0.06…0.1 for airplanes with 4 engines).

Root chord of horizontal stabilizer is:

$$b_{0HTU} = \frac{2\cdot S_{HTU}\cdot\eta_{HTU}}{\left(1+\eta_{HTU}\right)\cdot L_{HTU}} = \frac{2\cdot 122.53\cdot 2.2}{\left(1+2.2\right)\cdot 32.5} = 5.25 \text{ m}$$

where η_{HTU} – horizontal tail unit taper ratio; L_{HTU} – horizontal tail unit span.

Tip chord of horizontal stabilizer is:

$$b_{tHTU} = \frac{b_{0HTU}}{\eta_{HTU}} = \frac{5.25}{2.2} = 2.38 \text{ m}$$

Root chord of vertical stabilizer is:

$$b_{0VTU} = \frac{2\cdot S_{VTU}\cdot\eta_{VTU}}{\left(1+\eta_{VTU}\right)\cdot L_{VTU}} = \frac{2\cdot 103.98\cdot 2.7}{\left(1+2.7\right)\cdot 30} = 5.05 \text{ m}$$

where η_{VTU} – vertical tail unit taper ratio; L_{VTU} – vertical tail unit span.

Tip chord of vertical stabilizer is:

$$b_{tVTU} = \frac{b_{0VTU}}{\eta_{VTU}} = \frac{5.05}{2.7} = 1.87 \text{ m}.$$

2.7 Determination of the aircraft center of gravity position

During the volume-mass layout process, calculations are conducted to determine the centering of the aircraft. This involves finding the position of the center of mass (CM) relative to the average geometric chord of the wing (CAH), which satisfies specific requirements. In the case of the rearward position of the CM, it ensures the minimum allowable margin of static stability for the aircraft. On the other hand, the forward position of the CM allows for sufficient control deflection of the pitch rudder or stabilizer to achieve longitudinal balance in all flight modes. These considerations are essential for achieving the desired stability and control characteristics of the aircraft.

2.8 Determination of centering of the equipped wing

The centering of an aircraft refers to the distance between the main aerodynamic chord and the center of gravity. It is a critical parameter that is influenced by variations in aircraft loading and weight changes during flight. The movement of cargo within the aircraft can also affect the position of the aircraft’s center of gravity. Maintaining proper centering is crucial as it directly impacts the aircraft's balance. To calculate the centering, the masses of the main structural units and devices must be determined. The table 2.1 provides a list of the masses of these units for the aircraft.

Table 2.1

Centering information of the masses of the equipped wing

No	Name object	Mass, m		Coordinate of the center of mass, m	Static mass moment $m X_i$, kgm
		relative, kg	absolute, kg		
1	2	3	4	5	6
1.	Wing (structure)	0.0910	26162.0	4.24	111103.00
2.	Fuel system	0.00810	2335.79	4.24	9919.45
3.	Management system by plane (30%)	0.00230	328.45	5.70	1860.0
4.	Electrical equipment (10%)	0.00230	651.10	0.91	614.47
5.	System of protection against icing (70%)	0.008920	2569.57	0.93	2423.91
6.	Hydraulic system (70%)	0.0079	2420.19	6.57	15988.40
7.	Main engines	0.04250	12231.08	-2.97	-36693.30
8.	Engine equipment, fastening units	0.022078	6360.09	0.019	135.90
9.	Fire protection system	0.014433	4158.52	0.021	88,80
Equipped wing (without fuel and chassis)			57216.79	1.82	105442
10.	The main supports of the chassis	0.029487	8498.80	3.047	25921.04
11.	Fuel (including aero-navigation stock):	0.40537	116791.11	4.24	495974.74
In total			182506.7	3.47	627337.02

2.9 Determination of the centering of the equipped fuselage

The coordinate system used for the calculations is based on the projection of the nose section of the fuselage onto the horizontal axis, as indicated in the appendices. Table 2.2 provides an approximate list of objects and their corresponding masses, along with recommendations for determining the coordinates of their centers of mass.

Table 2.2

Centering information of the mass of the equipped fuselage

No	Name object	Mass mi		Coordinate of the center of mass, m	Static mass moment , kgm
		relative, kg	absolute kg		
1	2	3	4	5	6
GLIDER					
1.	Fuselage (construction)	0.08500	24480.1	30.52	747536.5
2.	Horizontal plumage	0.00942	2714.18	56.96	154603.55
3.	Vertical plumage	0.01100	3186.8	57.01	181520.1
EQUIPMENT AND CONTROLS					
4.	Height equipment	0.00550	1573.2	29.23	46039.18
5.	Anti-icing system (30%)	0.003810	1101.2	30.52	33628.62
6.	Passenger equipment	0.0102	3054.21	31.20	95209.19
7.	Decorative paneling and TZS	0.004	1440.7	31.20	44910.01
8.	Household goods:	0.0146	4178.1	31.88	132896.91
9.	Hydraulic system (30%)	0.0046	1037.21	31.88	32995.18
10.	Electrical equipment (90%)	0.02041	5860.49	25.49	149137.81
11.	Location equipment	0.0017	547.54	0.68	348.19
12.	Navigation equipment	0.0028	835.61	3.21	2657.98
13.	Equipment for radio communication	0.0013	432.27	3.21	1375.01
14.	Instrument equipment	0.0038	979.79	2.57	2492.99
15.	Aircraft control systems (70%)	0.00269	766.39	31.89	24380.01
16.	Auxiliary power plant	0.005943	1712.41	62.39	106760.24

Ending of the table 2.2

1	2	3	4	5	6
Empty fuselage			53909.2	32.59	1756491.47
EQUIPMENT					
17.	Crew		191.00	3.20	605.02
18.	Flight attendants		748.00	31.89	23857.70
19.	Documentation and tools	0.0029	432.13	4.47	1924.8
20.	Water (chemical species)		782.00	30.52	23941.28
21.	Additional equipment	0.0060	1525.99	25.39	38861.07
Empty equipped fuselage			57588.32	32.09	1845681.34
22.	Front chassis support	0.007371	2125.09	8.24	17422.40
In total			59713.41	31.28	1863103.74
COMMERCIAL CARGO					
23.	Passengers		28550.00	32.49	924704.97
24.	Baggage		15000.00	30.05	443133.27
25.	Products food		1415.50	33.11	46717.99
In total			104678.91	31.42	3277659.97

The coordinate of the center of mass of the equipped fuselage is determined by the formula:

$$x_{ф} = \frac{\sum m_i x_i}{\sum m_i}$$

After identifying the centers of mass for the equipped wings and fuselage, the equation of moment equilibrium with respect to the nose section of the fuselage is formulated:

$$m_f x_f + m_{cr}(x_a + x_{cr}) = m_0(x_a + x_c)$$

where x_a is the position of the beginning of the CA of the wing relative to the nose of the fuselage; c is the distance from the beginning of the SAH to the center of mass of the aircraft. As previously mentioned, the centroid of the aircraft refers to the coordinate representing the location of its center of mass projected onto the wing's SAH. It can be calculated using the formula mentioned earlier as follows:

$$\bar{x}_{\text{т}} = \frac{m_{\text{ф}} x_{\text{ф}} + m_{\text{кр}}\left(x_{\text{а}} + x_{\text{кр}}\right)}{m_0}$$

In practical applications, the centering of the aircraft is typically determined using relative coordinates. This means that the position of the aircraft's center of mass is expressed as a percentage or fraction of the average aerodynamic chord (SAH) length from its starting point $\bar{x}_{\text{т}}$:

$$\bar{x}_T = \frac{x_T - x_{\text{А}}}{b_{\text{А}}} 100\%$$

To determine the centroid of the aircraft, it is important to have knowledge of the wing's chord average (CA) and its starting position relative to the nose of the fuselage, denoted as xa. The initial value of xa can be obtained by referencing the scale on the prototype aircraft diagram, after determining the value of the average aerodynamic chord (SAH) and plotting it on the wing $\bar{x}_{\text{т}}$.

By performing the necessary calculations, the centroid coordinates of the aircraft should be obtained, as indicated in Table 2.3.

Table 2.3

The value of aircraft centers according to statistics

Straight wing		Arrow-shaped wing	
Low-level	High-rise	Low-level	High-rise
13...32	15...33	18...38	20...42

If it is not possible to achieve the desired values, it is advised to employ the following methods to correct the centering: adjust the positioning of the heaviest loads within the fuselage; shift the wing along the fuselage. However, it is important to note that moving the wing will not only change the center of mass of the aircraft but also alter the wing's average aerodynamic chord (SAH).

To determine the required displacement distance (l) for the wing, which is typically the largest component in terms of mass, the magnitude of the required centering change must be established to achieve the recommended values.

This magnitude is determined by calculating the difference between the calculated centering and the recommended centering. The distance l can then be calculated using the following formula:

$$\overline{\Delta \mathrm{x}_{\mathrm{T}}}\overline{\mathrm{x}_{\mathrm{T}}}\overline{\Delta \mathrm{x}_{\mathrm{T}}}\ \overline{\mathrm{x}_{\mathrm{T}}}\, l = \frac{\Delta \bar{x}_T b_a m_0}{m_{кр}}$$

2.10 Calculation of center of gravity

To simplify the calculation of centering options, it is advisable to consolidate the masses and their corresponding mass coordinates in Table 2.2.

Table 2.4 provides essential calculations for aircraft centering, covering the most common operational scenarios. For the landing configuration, the fuel mass can be estimated as approximately 15% to 20% (depending on the aircraft type) of the take-off fuel mass. For refueling, the fuel mass should be maximized (considering the absence of commercial load) and is determined by the aircraft's fuel tank capacity.

Aircraft centering options

Table 2.4

No n/p	Name option	Mass m_i, kg	Static mass moment M_i X, kgm	Center of mass of the plane , m	Centering $\bar{X}$
1	2	3	4	5	6
1.	Takeoff mass (chassis released)	286945.85	3904994.05	31.70	32.3
2.	Takeoff mass (chassis removed)	286945.85	3903931.71	31.70	32.25
3.	Landing mass	179352.3	3443047.86	30.97	24.61
4.	Distillatory	242213.7	2489375,25	2489375.25	31.87
5.	Equipped wing (without fuel and chassis)	57216.79	105441.50	1.82	105442

Ending of the Table 2.4

1	2	3	4	5	6
6.	Front landing gear support (released)	2125.09	17422/30	8.24	17422.40
7.	The main supports of the chassis (released)	8498.80	25920.98	3.047	25921.04
8.	Fuel	116791.11	495974.54	4.24	495974.74
9.	Empty equipped fuselage	57588332	1845678.27	32.09	1845681.34
10.	Passengers	28550.00	924705.07	32.49	924705.07
11.	Baggage	15000.00	443133.18	30.05	443133.18
12.	Food	1415.50	46718.21	33.11	46718.21
13.	Front landing gear support (cleaned up)	2125.09	16359.96	8.24	17422.20
14.	The main supports of the landing gear (cleaned up)	8498.68	25920.98	3.05	25920.98

Conclusion of project part

In this project phase, we thoroughly analyzed and developed the primary geometric parameters for the structural design of the aircraft. This included detailed considerations and designs for the wing characteristics, fuselage structure, tail components, and landing gear parameters. Once the wing and fuselage layouts were finalized, we proceeded to calculate the center of gravity of the aircraft, taking into account the masses of the wings, fuselage, and other aircraft components.

3. SPECIAL PART. ROLLER MECHANISM FOR LUGAGGE

3.1 Introduction

A conveyor system is a widely used mechanical handling equipment designed to transport materials from one location to another. It is particularly beneficial for moving heavy or bulky items efficiently. Conveyors play a vital role in various industries, especially in material handling and packaging, due to their ability to facilitate quick and effective transportation of diverse materials.

Conveyor systems offer several advantages over other methods of material movement, such as forklifts. They provide enhanced safety, ensuring a smoother and controlled transportation process. Conveyors find applications across multiple industries, including agriculture, automotive, computer, electronics, aerospace, chemical, and more.

Conveyors can be operated using different mechanisms, such as hydraulic, pneumatic, mechanical, electric, or fully automated systems. Gravity roller conveyors, which do not require power, are commonly used for moving unit loads. Continuous conveyors are employed for uninterrupted movement of bulk or unit loads along a predetermined path, eliminating the need for frequent loading or unloading. They are capable of simultaneously transferring items between various stages of a technical operation, distributing loads to multiple destinations, transporting goods to retailers, and maintaining the desired manufacturing process speed.

There are various types of conveyors available, including screw conveyors, driven and non-driven roller conveyors (operating on gravity), ribbon conveyors, belt-rope conveyors, tape-chain conveyors, scraper conveyors, vibrating conveyors, and lamellar conveyors. Roller conveyors are widely utilized in the aviation industry, such as airport baggage handling systems, where they efficiently transport passengers' luggage from the cargo compartment to their hands. Additionally, specialized vehicles equipped with roller conveyors are employed for specific purposes.

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Done by	Karpovich I.O.
Supervisor	Krasnopolskii V.S.
St.control.	Krasnopolskii V.S.
Head of dep.	Ignatovich S.R.

Special part

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3.2 Calculations of the roller conveyor

The typical dimensions of passenger luggage are considered medium-sized, measuring approximately 67 cm × 45 cm × 25 cm. According to aircraft regulations, the baggage should adhere to the specified dimensions of 670 mm × 450 mm × 250 mm. Based on this, the width of the load is determined to be 600 mm.

The length of the rollers used in conveyor systems depends on the width of the load and the desired consistent width throughout the conveyor.

$$L = W + \Delta \mathrm{B} = 450 + 550 = 1000\ (mm);$$

where W - width of the load; ΔB width desire.

To determine the diameter of the rollers, certain initial parameters of the equipment need to be considered. These parameters include the length of the conveyor (4 m), the payload it can carry (300 kg), the transmission mode (chain transmission), and the desired roller speed (0.5 m/s). Additionally, the dynamic friction coefficient between the surface and the roller is given as 0.4.

Sliding friction of the rollers and baggage:

$$F_s = \mu \mathrm{G} = 0.4 \cdot 300 \cdot 10 = 1200\ N,$$

where, μ – dynamic friction, G – payload of conveyor.

Required transmission power:

$$\mathrm{P_r} = F_s V = 1200 \cdot 0.5 = 600\ W.$$

For the material of the rollers, Aluminum Wrought Alloy 2015-T6 could satisfy the reuqirements well. And the ultimated shear stress $\tau = 184 MPa$. Based on the safty consideration, we take the allowable shear stress $[\tau] = 160 MPa$.

Table 3.1

material	Yield strength(ksi)			Ultimate strength(ksi)		
	Tens.	Comp.	shear	Tens.	Comp.	shear
Aluminum Wrought Alloy 2015-T6	60	60	25	686	68	42
Aluminum Wrought Alloy 6062-T6	37	37	19	42	42	27
Steel alloy structure A34	36	36	-	58	58	-

Overall, the diameter calculated by following formula:

$$d \geq \sqrt{\frac{9.55*10^{6}}{0.2[\tau]}}\sqrt{\frac{p}{n_{roller}}} = \sqrt{\frac{9.55*10^{6}}{0.2*160}}\sqrt{\frac{600*10^{-3}}{13}} = 134.75$$

where: P – power transmitted by the rollers;

n_{roller} – rotating speed of the rollers.

To simplify the calculation and utilize a standard bar, we have chosen a diameter of 140 mm for the rollers. During the rotation process, the rollers primarily experience radial forces. Based on the previous calculations, with a roller length of 1000 mm and an outer diameter of 140 mm, the luggage will be supported by a minimum of three rollers. Therefore, we can focus on calculating the radial force (Fr) acting on each bearing and disregard the axial force (Fa).

$$F_r = \frac{G}{6} = \frac{470}{6} = 78N$$

$$F_a = 0N$$

Dynamic load can be calculated by formula:

$$P = X * F_r + Y * F_a = 1*78+0*0=78,$$

where:

Fr - the radial force of the bearing;

Fa - the axial force of the bearingX - radial load factor;

Y - axial load factor.

Table 3.2

Bearing types	Relative axial load		Single row bearing			
			$F_a/F_r \le e$		$F_a/F_r > e$	
	F_a/C_{or}	F_a/zD_w^2	X	Y	X	Y
Deep groove ball bearing	0.014	0.172	1	0	0.56	2.30
	0.028	0.345				1.99
	0.056	0.689				1.71
	0.084	1.03				1.55
	0.11	1.38				1.45
	0.17	2.07				1.31
	0.28	3.45				1.15
	0.42	5.17				1.04
	0.56	6.89				1.00

The velocity of rotating of the bearing:

$$n_m \approx n = 120(\frac{r}{\min})$$

The next is that the required axial basic dynamic load rating calculation:

$$C_r = \frac{f_{p*p}}{f_t}(\frac{60n_m}{10^6}L_h)^{\frac{1}{\varepsilon}} = \frac{1.0*78}{1.0}\times(\frac{60*100}{10^6}\times 50000)^{\frac{3}{10}} = 401.7N$$

where: n_m - the rotating speed of the bearing;

P - the dynamic load;

f_p - load factor (take it as 1.0);

f_t - temperature coefficient (take it as 1.0);

Lh - bearing life expectancy (from table 3.3);

ε - life factor (for ball bearing is 10/3).

Table 3.3

Working condition	L_h/h, hours
Infrequently used instruments and equipment	500
Short-term or intermittent used, no serious consequences will be caused when interrupted	4000~8000
Intermittent used, interruption will cause serious consequences	8000~12000
Machinery that works 8 hours a day	12000~20000
24-hour continuous working machinery	40000~60000

The 61858 bearing $C_r = 2.1kN \geq 0.525kN$; the bearing has an inner diameter of 15 mm and an outer diameter of 24 mm, with a thickness of 5 mm.

Form the machanical design manual, we can get the basic dynamic load rating of bearing 61858 is 2.1 kN. So:

$$L_h = \frac{10^6}{60n_m} * \left(\frac{f_t C_r}{f_p P}\right)^{\frac{1}{\varepsilon}} = \frac{10^6}{60*100} * \left(\frac{1.0*2100}{1.0*95}\right)^{\frac{10}{3}} = 4851849 > 50000 \text{ (h)}$$

The selected bearing life meets the requirements.

The motor power could be calculated by following formula:

$$N = N_1 + N_2;$$

where:

N_1 – the power required to overcome the friction of the roller;

N_2 – the power required to overcome the interial resistance of the baggage.

It’s significant to know the resistance moment of the bearing at the roller journal (W_1) and the resistance of the baggage along the roller (W_2).

$$W_1 = g(m_{luggage} + z*q)\mu\frac{d}{2} = 9.8*(270+39*10)*0.015*\frac{0.05}{2} = 2.4255\ W$$

where:

$m_{luggage}$ - the maximum load of the conveyor;

z - the number of the rollers;

q - the mass of each roller;

g - gravity coefficient;

μ - rolling friction coefficient (from table , it’s 0.015); d - outer diameter of the bearing

$$W_2 = g*m_{luggage} + \frac{k}{100} = 9.8*270*\frac{0.05}{100} = 1.25\,(W)$$

where: g - gravity coefficient;

$m_{baggages}$ - the maximum load of the conveyor;

k - rolling friction coefficient between baggages and rollers (from table 3.3, it’s 0.05).

Table 3.3

Working condition	Enviroment	Sliding bearing	Rolling bearing
Good	clean and dry indoor work without abrasive dust	0.1~0.15	0.01~0.015
Medium	Normal temperature with small of dust	0.15~0.20	0.01~0.02
Bad	Work outdoor where there is a possibilityof losing friction surface	0.20~0.25	-

The power required to overcome the friction of the roller:

$$N_1 = (W_1 + W_2)\varpi = (2.4255+1.25)*160 = 588.08\,(W)$$

where: ω - the rotating speed of the bearing.

$$N_2 = \frac{m_{luggage} V^2}{t_s} = \frac{270 * 0.4^2}{1} = 43.2$$

where:

t_s - strating time of the motor(t_s = 1s);

V - the velocity of the roller.

That,

$$N = N_1 + N_2 = 588.08 + 43.2 = 631.28\,(W)$$

Overall, we can determine the motor power:

$$N_j = \frac{N}{\eta} = \frac{631.28}{0.5} = 1262.5\,(kW)$$

where:

η – machincial efficiency of the conveyor;

N_j – the rated power of the motor.

Based on the previous calculations, it is determined that the motor needs to have a certain rated power and speed. Consequently, the motor chosen for the system should possess a rated power and speed that exceed the values calculated earlier.

Table 3.4

model	Rated power/kw	Rated torque/Nm	Rated speed/rpm	Rated current/A	effectiveness	Power factor
W89G-6	0.8	2	900	2.3	72.5	0.71
W92	1.3	2	900	3.2	73.5	0.74
W99L-6	1.7	2	950	4.0	77.5	0.75
W108K-6	2.4	2	950	5.6	80.5	0.75
W133G-6	3	2	970	7.2	83.0	0.77

From the table , we find that the rated power of the motor W99L-6 N_J 1.7 $kW \geq$ 1.262 kW. The rated speed of the motor W99L-6 is 950 rpm which is bigger that the 120 r/min. So, motor W99L-6 could satisfied the requirements well.

Conclusion to the special part

The dimensions of the conveyor roller overall, the bearing's strength, and the motor's power are the three most important variables taken into consideration while designing the roller conveyor's parameters. The size of the luggage and the strength of the material are fully taken into account while designing the conveyor's overall size.

Be sure to account for the longest possible working life when calculating bearing strength. Finally, a 1.7kW motor was chosen to enable the smooth operation of the machine throughout determination and motor selection according to safety and practicability.

GENERAL CONCLUSIONS

This paper presents the preliminary design of an aircraft and a conveyor system. Drawing inspiration from popular jets in the current market, we have developed a long-range civil airliner with a seating capacity of 380 passengers. Various parameters of the aircraft wing, including length, sweep angle, and aileron configuration, have been carefully chosen and calculated. Our design incorporates a low-level wing design with a sweep angle to optimize aerodynamic performance, complemented by the adoption of slotted flaps and advanced airfoils.

The fuselage layout is divided into economy class and business class sections. The width of the corridor, as well as the arrangement and spacing of seats, have been determined through detailed calculations. To ensure safe takeoff and landing, we have implemented the classic first three-point landing gear system and performed center of gravity calculations under different conditions such as full-load takeoff and landing.

In the conveyor parameter design, we have primarily focused on the overall size of the conveyor roller, the strength of the bearings, the dimensions of the connections, and the power requirements of the motor. The dimensions of the drum have been designed based on the specifications of the checked baggage. Safety and bearing service life considerations have been integral to the bearing selection and strength design process.

Additionally, the design of connections has been optimized to fulfill the functional requirements as effectively as possible. Finally, to ensure smooth transportation, a 1.7 kW motor has been selected, taking into account the principle of redundancy.

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				NAU 23.03K.00.00.00.71 EN			
Done by	Karpovich I.O.			References	list	sheet	sheets
Supervisor	Krasnopolskii V.S.				Q	46	50
St.control.	Krasnopolskii V.S.				ASF 402		
Head of dep.	Ignatovich S.R.						

Appendix A

Performed by: Karpovich Illya

Supervisor:

PRELIMINARY DESIGN OF THE AIRCRAFT

The main prototype is …

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          ИСХОДНЫЕ ДАННЫЕ И ВЫБРАННЫЕ ПАРАМЕТРЫ
  Количество пассажиров                                        380.
  Количество членов экипажа                                      2.
  Количество бортпроводников или сопровождающих                  10.
  Масса снаряжения и служебного груза                         3398.57 кг.
  Масса коммерческой нагрузки                                43320.00 кг.

  Крейсерская скорость полета                                  845.  км/ч
  Число "М" полета при крейсерской скорости                      0.8390
  Расчетная высота начала реализации полетов с крейсерской
  экономической скоростью                                       12.60  км
  Дальность полета с максимальной коммерческой нагрузкой        12000.  км.
  Длина летной полосы аэродрома базирования                      3.30 км.

  Количество двигателей                                          2.
  Оценка по статистике тяговооруженности в н/кг                  2.5000
  Степень повышения давления                                     50.00
  Принятая степень двухконтурности двигателя                     9.6
  Оптимальная степень двухконтурности двигателя                  9.00
  Относительная масса топлива по статистике                      0.2200

  Удлинение крыла                                                6.70
  Сужение крыла                                                  3.52
  Средняя относительная толщина крыла                            0.102
  Стреловидность крыла по 0.25 хорд                              33.0  град.
  Степень механизированности крыла                               1.220
  Относительная площадь прикорневых наплывов                     0.000
  Профиль крыла - Суперкритический
  Шайбы УИТКОМБА - установлены
  Спойлеры - установлены
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Диаметр фюзеляжа                                               5.54 м.
Удлинение фюзеляжа                                             11.29
Стреловидность горизонтального оперения                        32. град.
Стреловидность вертикального оперения                          55.0  град.

 Значение  оптимального  коэффициента  подъемной силы в расчетной точке
 крейсерского режима полета     Су        0.43814

 Значение коэффициента          Сх.инд.   0.00882

     ОПРЕДЕЛЕНИЕ КОЭФФИЦИЕНТА  Dм = Мкрит - Мкрейс

 Число Маха крейсерское               Мкрейс  0.84565
 Число Маха волнового кризиса         Мкрит   0.85982
 Вычисленное значение                 Dм      0.01327

   Значения удельных нагрузок на крыло в кПА(по полной площади):
             при взлете                          6.457
             в середине крейсерского участка     5.257
             в начале крейсерского участка       6.254
   Значение коэффициента сопротивления фюзеляжа и гондол      0.01298
   Значение коэфф. профиль. сопротивления крыла и оперения    0.00864

   Значение коэффициента сопротивления самолета:
             в начале крейсерского режима                   0.03758
             в середине крейсерского режима                 0.03204
   Среднее значение Су при условном полете по потолкам      0.43795

   Среднее крейсерское качество самолета                   13.71325

 Значение коэффициента Су.пос.                                    1.590
 Значение коэффициента ( при скорости сваливания ) Су.пос.макс.  2.385
 Значение коэффициента ( при скорости сваливания ) Су.взл.макс.  1.931
 Значение коэффициента  Су.отр.                                   1.410
 Тяговооруженность в начале крейсерского режима                   0.624
 Стартовая тяговооруженность по условиям крейс. режима Ro.кр.    2.479
 Стартовая тяговооруж. по условиям безопасного взлета Ro.взл.    2.469

 Расчетная тяговооруженность самолета   Ro   2.602

 Отношение   Dr = Ro.кр / Ro.взл        Dr   1.004
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                      УДЕЛЬНЫЕ РАСХОДЫ ТОПЛИВА ( в кг/кН*ч ):
         взлетный                                             34.6448
         крейсерский (характеристика двигателя)               57.7856
         средний крейсерский при заданной дальности полета   57.0350

                        ОТНОСИТЕЛЬНЫЕ МАССЫ ТОПЛИВА:
                аэронавигационный запас        0.04399
                расходуемая масса топлива      0.39194


              ЗНАЧЕНИЯ ОТНОСИТЕЛЬНЫХ МАСС ОСНОВНЫХ ГРУПП:
                крыла                        0.09206
                горизонтального оперения     0.00799
                вертикального оперения       0.00810
                шасси                        0.03537
                силовой установки            0.09049
                фюзеляжа                     0.05980
                оборудования и управления    0.10137
                дополнительного оснащения    0.00344
                служебной нагрузки           0.01594
                топлива при  Lрасч.          0.43593
                коммерческой нагрузки        0.14948

             Взлетная масса самолета "M.o" =  213264. кГ.
      Потребная взлетная тяга одного двигателя 138.75 kH

 Относительная масса высотного оборудования и
 противообледенительной системы самолета                         0.0181
 Относительная масса пассажирского оборудования
 (или оборудования кабин грузового самолета)                     0.0105
 Относительная масса декоративной обшивки и ТЗИ                  0.0064
 Относительная масса бытового (или грузового) оборудования      0.0111
 Относительная масса управления                                  0.0041
 Относительная масса гидросистем                                 0.0124
 Относительная масса электрооборудования                         0.0262
 Относительная масса локационного оборудования                   0.0023
 Относительная масса навигационного оборудования                 0.0035
 Относительная масса радиосвязного оборудования                  0.0017
 Относительная масса приборного оборудования                     0.0041
 Относительная масса топливной системы (входит в массу "СУ")    0.0142
Дополнительное оснащение:
 Относительная масса контейнерного оборудования                  0.0000
 Относительная масса нетипичного оборудования                    0.0034
 [встроенные системы диагностики и контроля параметров,
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  дополнительное оснащение салонов и др.]
             ХАРАКТЕРИСТИКИ ВЗЛЕТНОЙ ДИСТАНЦИИ
Скорость отрыва самолета                                317.93 км/ч
Ускорение при разбеге                                     1.92 м/с*с
Длина разбега самолета                                 2025. м.
Дистанция набора безопасной высоты                      472. м.
Взлетная дистанция                                     2497. м.

             ХАРАКТЕРИСТИКИ ВЗЛЕТНОЙ ДИСТАНЦИИ
                ПРОДОЛЖЕННОГО ВЗЛЕТА
Скорость принятия решения                               286.14 км/ч
Среднее ускорение при продолженном взлете на мокрой ВПП   0.79 м/с*с
Длина разбега при продолженном взлете на мокрой ВПП    2524.05 м.
Взлетная дистанция продолженного взлета                2996.29 м.
Потребная длина летной полосы по условиям
прерванного взлета                                     3107.48 м.

             ХАРАКТЕРИСТИКИ ПОСАДОЧНОЙ ДИСТАНЦИИ
Максимальная посадочная масса самолета                     136450. кг.
Время снижения с высоты эшелона до высоты полета по кругу    20.2  мин.
Дистанция снижения                                           51.07 км.
Скорость захода на посадку                                  257.49 км/ч.
Средняя вертикальная скорость снижения                        2.04 м/с
Дистанция воздушного участка                                530.   м.
Посадочная скорость                                         244.59 км/ч.
Длина пробега                                               797.   м.
Посадочная дистанция                                       1310.   м.
Потребная длина летной полосы (ВПП + КПБ) для
основного аэродрома                                        2233.   м.
Потребная длина летной полосы для запасного аэродрома      1905.   м.

              ПОКАЗАТЕЛИ ЭФФЕКТИВНОСТИ САМОЛЕТА
Отношение массы снаряженного самолета к
массе коммерческой нагрузки                              2.6903
Масса пустого снаряженного с-та приход. на 1 пассажира  316.88 кг/пас.
Относительная производительность по полной нагрузке     526.87 км/ч
Производительность с-та при макс. коммерч. нагрузке    27806.9 кг*км/ч
Средний часовой расход топлива                        8568.809 кг/ч
Средний километровый расход топлива                       9.76 кг/км
Средний расход топлива на тоннокилометр                307.884 г/(т*км)
Средний расход топлива на пассажирокилометр             30.9079 г/(пас.*км)
Ориентировочная оценка приведен. затрат на тоннокилометр 0.3278 $/(т*км)
```