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 вантажного ближньомагістрального літака вантажепід'ємністю до 8 тонн»

Виконав: __________ **Данило КУЛЕШОВ**

Керівник: Ст. Викладач __________ **Олександр ЯКОБЧУК**

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

Київ 2023

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
National Aviation University
Department of Aircraft Design

PERMISSION TO DEFEND
Head of the department,
Professor, Dr. of Sc.
_________ Sergiy IGNATOVYCH
"___" ____________ 2023

BACHELOR DEGREE THESIS

Topic: "Preliminary design of the short range cargo aircraft with payload up to 8 tons"

Fulfilled by: ____________ **Danylo KULESHOV**

Supervisor:
Senior Teacher ____________ **Oleksandr YAKOBCHUK**

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

КУЛЕШОВА ДАНИЛА ОЛЕКСАНДРОВИЧА

1. Тема роботи: «Аванпроект вантажного ближньомагістрального літака вантажепід’ємністю до 8 тонн», 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: маса комерційного навантаження 8000 кг, дальність польоту з максимальним комерційним навантаженням 1150 км, крейсерська швидкість польоту 545 км/год, висота польоту 9,5 км, габаритні розміри вантажної кабіни.

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, спеціальна частина, яка містить аналіз блоку силового приводу в грузовій кабіні і можливі модернізації.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: загальний вигляд літака (А1×1), компонувальне креслення фюзеляжу (А1×1), загальне креслення блоку силового приводу (А1×1).

6. Календарний план-графік:

№	Завдання	Термін виконання	Відмітка про виконання
1	Вибір вихідних даних та аналіз льотно-технічних характеристик літаків-прототипів.	29.05.2023 – 31.05.2023	
2	Вибір і розрахунок параметрів проектованого 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 блоку силового приводу.	08.06.2023 – 09.06.2023	
6	Розрахунок параметрів блоку силового приводу. Розробка креслень блоку силового приводу.	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 ____________ Олександр ЯКОБЧУК

Завдання прийняв до виконання _____________ Данило КУЛЕШОВ

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

Danylo KULESHOV

1. Topic: "Preliminary design of the short range cargo aircraft with payload up to 8 tons", 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: payload 16 tons, flight range with maximum capacity 1150 km, cruise speed 545 km/h, flight altitude 9.5 km, cargo cabin dimensions.

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: analyze of the power drive unit of the cargo cabin and possible upgrades.

5. Required material: general view of the airplane (A1×1), layout of the airplane (A1×1), general drawing of the power drive unit (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 the power drive unit.	08.06.2023 – 09.06.2023	
6	Calculation of parameters of the power drive unit. Development of drawings of the power drive unit..	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: ____________ Oleksandr YAKOBCHUK

Student: ____________ Danylo KULESHOV

РЕФЕРАТ

Пояснювальна записка кваліфікаційної роботи бакалавра «Аванпроект вантажного ближньомагістрального літака вантажепід'ємністю до 8 тонн»:

53 с., 11 рис., 1 табл., 18 джерел

Дана кваліфікаційна робота присвячена розробці аванпроекту вантажного літака для ближньомагістральних авіаліній, що відповідає міжнародним стандартам польотів, нормам безпеки, економічності та надійності, а також проектування привід переміщення вантажу.

В роботі було використано методи аналітичного розрахунку, компьютерного проєктування за допомогою CAD/CAM/CAE систем, ескізного проєктування механізму завантаження з використанням технічних даних подібних пристроїв.

Практичне значення результату кваліфікаційної роботи полягає в покращенні умов для завантаження та розвантаження вантажу, що сприяє більш швидкому процесу перевезення вантажів в цілому та ефективності вантажних повітряних перевезень.

Матеріали кваліфікаційної роботи можуть бути використані в навчальному процесі та в практичній діяльності конструкторів спеціалізованих проектних установ.

Дипломна робота, аванпроект літака, компонування, механізм завантаження, привід переміщення вантажу, хвильовий редуктор

ABSTRACT

Bachelor degree thesis "Preliminary design of the short range cargo aircraft with payload up to 8 tons"

53 pages, 11 figures, 1 tables, 18 references

This qualification work is devoted to the development of a preliminary design of a cargo plane for short-haul airlines, which meets international flight standards, safety, economy and reliability standards, as well as the design of a mechanism for loading cargo into the aircraft cabin.

The work used methods of analytical calculation, computer design using CAD/CAM/CAE systems, sketch design of the loading mechanism using technical data of similar devices.

The practical significance of the result of the qualification work is to improve the conditions for loading and unloading cargo, which contributes to a faster process of cargo transportation in general and the efficiency of cargo air transportation.

The materials of the qualification work can be used in the educational process and in the practical activity of designers of specialized design institutions.

Bachelor thesis, preliminary design, cabin layout, loading device, power drive unit harmonic drive

Format	№	Designation	Name	Quantity	Notes
			<u>General documents</u>		
A4	1	NAU 23 05K 00 00 00 48 EN	Task for work	1	
	2	NAU 23 05K 00 00 00 48 EN	Short range cargo aircraft	2	
A1		Sheet 1	General view		
A1		Sheet 2	Fuselage layout		
A4	3	NAU 23 05K 00 00 00 48 EN	Short range cargo aircraft	54	
			Explanatory note		
			<u>Documentation for assembly units</u>		
A1	4	NAU 23 05K 00 00 00 48 EN	Design of power drive unit	1	

NAU 23 05K 00 00 00 48 EN

	Sh.	№ doc.	Sign	Date
Done by		Kuleshov D.O		
Supervisor		Yakobchuk O. Ye		
St.control.		Krasnopolsky V.S.		
Head of dep.		Ignatovich S.R.		

Preliminary design of the short range cargo aircraft with payload up to 8 tons (List of diploma work)

list	sheet	sheets
Q	9	54

402 ASF 134

CONTENT

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Done by	Kuleshov D.O				CONTENT	Let	Page	Pages
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St.control	Krasnopolsky V.S							
Head of dep.	Ignatovich S.R.							

INTRODUCTION

In recent years, the aviation industry has been actively exploring ways to address these challenges and find innovative solutions. One approach is the development of more fuel-efficient aircraft. Manufacturers are investing in research and development to design airplanes that consume less fuel per mile traveled, thereby reducing operational costs. This includes advancements in aerodynamics, engine technology, and the use of lightweight materials.

Another area of focus is the optimization of cargo loading and unloading processes. Efficient cargo handling can significantly impact turnaround times and overall operational efficiency. Technologies such as automated cargo handling systems, improved packaging, and streamlined logistics have been introduced to expedite the loading and unloading processes.

In terms of manufacturing expenses, advancements in technology and production processes have allowed for more efficient and cost-effective aircraft production. Advanced computer-aided design (CAD) software, additive manufacturing (3D printing), and robotic automation are being utilized to streamline manufacturing operations, reduce waste, and improve overall productivity. These advancements not only contribute to cost savings but also enable faster production cycles, allowing airlines to introduce new aircraft models more quickly.

In summary, while the aviation industry plays a crucial role in enabling rapid and reliable cargo transport, it faces challenges related to cost. However, through continuous research, development, and innovation, the industry is actively working on reducing operational costs, optimizing cargo processes and leveraging advanced manufacturing techniques. These efforts aim to create a more sustainable and cost-effective aviation industry, ensuring timely cargo delivery while minimizing expenses.

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						402 ASF 134		
St.control		Krasnopolsky V.S						
Head of dep.		Ignatovich S.R.						

1. ANALYSIS OF PROTOTYPES

1.1 Importance of analyzing successful prototypes in aircraft design

Statistic data of prototypes among the numerous procedures of the preliminary design stage, the accumulation and analysis of data related to the previous successful machines play an important role. The analysis of the aircraft can be divided into these types of parameters, which in the future will represent the achievement of high economic efficiency of the plane: aerodynamics, bulk cargo, structural strength and fuel consumption. For the plane designed in the frame of presented work, the prototypes have been selected on the base of similar take-offweight, cruising speed, cruising altitude, cargo capacity, fuel consumption, etc. The primary role in this selection plays, of course, the question "How much the former planes are successful?"

1.2 Key Parameters and Considerations in Aircraft Design

When choosing the design parameters of the aircraft, it is necessary to be guided by the already achieved level of technical excellence of flying machines, it is meant to use the main characteristics of the plane (prototype aircraft), the purpose and parameters of which are most similar to those most like incorporated in the project.

Aerodynamics: The aerodynamic design of an aircraft plays a crucial role in its performance and efficiency. Factors such as wing design, airfoil shape, and drag reduction techniques are taken into account during the design process. Aerodynamic improvements can lead to reduced fuel consumption and improved overall performance.

Bulk cargo: The ability to transport bulk cargo efficiently is essential in the aviation industry. Cargo capacity and loading/unloading processes are optimized to ensure efficient and secure transport of goods.

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St.control	Krasnopolsky V.S						
Head of dep.	Ignatovich S.R.						

Specialized cargo handling systems and equipment may be incorporated into the aircraft design to facilitate smooth cargo operations.

Structural strength: The structural strength of an aircraft is of utmost importance to ensure safe and reliable operations. The materials used in construction, such as lightweight composites or advanced alloys, are carefully selected to provide adequate strength while minimizing weight. Structural integrity is crucial for withstanding aerodynamic forces, turbulence, and other external factors.

Fuel consumption: Fuel efficiency is a significant consideration in aircraft design. Manufacturers strive to reduce fuel consumption by employing lightweight materials, aerodynamic optimizations, and efficient engine technologies. Improved fuel efficiency not only reduces operational costs but also contributes to environmental sustainability by minimizing carbon emissions.

Take-offweight: The take-offweight of an aircraft influences its performance capabilities, including range, payload capacity, and operational flexibility. Designers aim to balance the weight of the aircraft, ensuring it can carry the desired payload while meeting performance and safety requirements.

Cruising speed: Cruising speed refers to the speed at which an aircraft maintains stable flight during long-distance travel. Optimal cruising speeds are determined based on factors such as fuel efficiency, range requirements, and safety considerations. Balancing speed with fuel economy is essential to achieve efficient operations.

Cruising altitude: The cruising altitude refers to the optimal height at which an aircraft flies during its journey. Factors such as air traffic control, weather conditions, and fuel efficiency are taken into account when determining the cruising altitude. Flying at higher altitudes can result in reduced fuel consumption and more efficient operations.

Payload capacity: The payload capacity of an aircraft determines its ability to carry passengers or cargo. Design considerations include the size and layout of the cabin or cargo hold, as well as the weight-bearing capabilities of the aircraft's structure. Optimizing payload capacity allows for efficient transport of goods or passengers.

Range: The range of an aircraft refers to the maximum distance it can travel without refueling. Longer range capabilities are desirable for airlines and operators, as they allow for more direct routes, reduced stopovers, and increased operational flexibility.

Purpose and parameters: The purpose and parameters of an aircraft define its intended use and operational characteristics. Design choices are made based on the specific requirements of the aircraft's target market, whether it be military, commercial, regional, or specialized operations.

These factors contribute to the overall design and performance of the aircraft, ensuring its efficiency, reliability, and operational success in meeting the specific needs of its intended use.

1.3 Comparative Analysis of C-27J Spartan, Bombardier Q400, and Antonov An-140

C-27J Spartan:

Wingspan: 28.70 m

Length: 22.70 m

Height: 9.64 m

Wing area: 82.60 m²

Empty weight: 16,000 kg

Maximum take-offweight: 30,500 kg

Payload capacity: 11,500 kg

Range: 1,852 km

Bombardier Q400:

Wingspan: 28.42 m

Length: 32.81 m

Height: 8.35 m

Wing area: 84.7 m²

Empty weight: approximately 19,200 kg

Maximum take-offweight: 29,257 kg

Payload capacity: approximately 8,400 kg

Range: approximately 2,518 km

Antonov An-140:

Wingspan: 24.50 m

Length: 22.60 m

Height: 8.23 m

Wing area: 51.81 m²

Empty weight: 11,800 kg

Maximum take-offweight: 18,480 kg

Payload capacity: 6,000 kg

Range: approximately 3,700 km

The C-27J Spartan, built by Leonardo's Aircraft Division, is the epitome of a modern military transport aircraft. As an updated variant of the G.222, it incorporates state-of-the-art technology, borrowing elements from the Lockheed Martin C-130J Super Hercules, including advanced engines and integrated avionics systems. This fusion of technology results in an aircraft with a unique operational versatility, able to handle diverse missions from cargo transport to disaster relief, making it a vital asset in global humanitarian efforts. The C-27J can land on short and even unprepared airstrips, a feature that highlights its agility and adaptability, especially in hostile or remote environments. With its impressive maximum speed exceeding 600 km/h and an exceptional power-to-weight ratio, the C-27J can reach high altitudes rapidly, crucial for escaping ground-based threats in military scenarios.

In contrast, the Bombardier Q400, now produced under the stewardship of De Havilland Aircraft of Canada Limited, stands as a paragon of commercial aviation. This medium-range, twin-engine turboprop airliner is specifically tailored for short-haul flights and has the capacity to accommodate up to 90 passengers comfortably. In terms of speed, the Q400 outclasses many turboprop aircraft, boasting a maximum cruise speed of 667 km/h, allowing it to operate efficiently within a bustling commercial aviation network. Furthermore, its ability to operate at high altitudes up to 27,000 feet, and excellent fuel efficiency, reflect the meticulous engineering dedicated to reducing operating costs and environmental impact, making it an increasingly popular choice for regional airlines.

Meanwhile, the Antonov An-140, a product of the Ukrainian Antonov ASTC bureau, serves as a testament to rugged and dependable engineering. This turboprop regional airliner, primarily used in passenger, cargo, and mixed configurations, can ferry up to 52 passengers while maintaining a maximum speed of around 575 km/h. However, its standout feature is its resilience under duress. The Antonov An-140 can operate under extreme weather conditions, and its robust design allows it to take-offand land on unprepared or artificially prepared airfields. Such ruggedness endears it to operators who have to maintain regular service in challenging environments.

In aircraft like the C-27J Spartan, high wing configuration is often used to improve aerodynamic efficiency and provide greater ground clearance for engines and other equipment. The swept wings design of the Spartan, combined with its forward-mounted engines, boosts lift and improves performance during take-offand landing. The Coanda effect comes into play here as well; the airflow from the engines sticks to the wing, helping the aircraft to lift off the ground at low speeds.

Likewise, the Bombardier Q400 and the Antonov An-140 have design features that enable them to operate from shorter runways and less prepared surfaces. The Q400, with its advanced turboprop engines and high wing design, is able to achieve high lift at low speeds. The An-140, known for its ruggedness, can operate in extreme weather conditions and from less prepared airfields, in part thanks to its high wing configuration and robust landing gear.

Engine choice is another critical factor in aircraft performance. The C-27J Spartan uses the Rolls-Royce AE 2100-D2A engine, a turboprop engine that provides the power needed for the aircraft's wide range of operations. The Bombardier Q400, on the other hand, uses the Pratt & Whitney Canada PW150A, which delivers excellent fuel efficiency. The Antonov An-140 is powered by two

Progress D-436 engines, which contribute to its ability to operate in challenging conditions.

As for the tail assembly, this contributes to the stability and control of the aircraft. A powerful vertical stabilizer helps to ensure directional stability. Many modern aircraft, employ a two-hinged rudder design, which increases efficiency at low speeds.

The landing gear design also plays a significant role in an aircraft's ability to handle short and unprepared runways. In summary, the C-27J Spartan, Bombardier Q400, and Antonov An-140 represent the wide range of purposes and environments in which modern aircraft operate. Whether it's the versatility and combat-readiness of the Spartan, the speed and efficiency of the Q400, or the all-weather robustness of the An-140, each aircraft demonstrates excellence in its unique operational context.

Conclusion to analytical part

Indeed, studying and analyzing these successful prototypes provides valuable insights and data for future aircraft design. The C-27J Spartan's versatility and readiness for combat environments offer lessons in building flexible and robust aircraft that can operate in various challenging conditions. The Bombardier Q400's speed, efficiency, and suitability for short-haul flights highlight the importance of creating aircraft that can adapt to the evolving commercial aviation landscape, balancing performance and cost-effectiveness. Lastly, the Antonov An-140's resilience under harsh weather and its ability to handle unprepared or artificially prepared airfields show the significance of robust and durable designs.

Collectively, these cases underline the need to ensure high economic efficiency and technical excellence in the design of future aircraft. They emphasize the importance of considering multiple factors like aerodynamics, cargo capacity, structural strength, and fuel consumption in the design process. By learning from these successful designs, future aircraft can be engineered to meet or even exceed existing levels of technical excellence while also optimizing economic performance.

2. PRELIMINARY DESIGN OF THE SHORT RANGE CARGO AIRCRAFT

2.1 Geometry calculations for the main parts of the aircraft

During the initial stages of aircraft design, it's crucial to consider the primary geometric parameters of all components of the aircraft under development.

The wing's design, inclusive of the calculations for high-lift devices, forms an integral part of this process. High-lift devices, such as flaps and slats, can greatly affect an aircraft's performance, particularly during take-offand landing.

The geometry of the fuselage and the layout of the cabin also require careful consideration. The fuselage's shape and size can influence the aircraft's aerodynamics and capacity.

Designing the landing gear is another key element of this phase. The landing gear must be robust enough to withstand the stresses of landing, while being light enough to not drastically impact the aircraft's overall weight and performance.

The tail unit design, which includes the horizontal and vertical stabilizers, is vital for maintaining the aircraft's stability and control in flight.

All these elements are intricately interconnected, and alterations in one area can significantly impact others, emphasizing the need for a comprehensive and meticulous approach during the preliminary design phase.

2.2 Wing geometry calculation

The Aircraft Design Department of NAU has developed a specialized software program that was used to compute the initial data for the aircraft under design.

This data, provided in Appendix A titled "Initial Aircraft Data," includes important parameters such as wing loading, gross weight, and other geometric and aerodynamic characteristics.

During the preliminary phase of design, an airfoil is selected from a wide range of options available in aeronautical literature. These options have well-documented geometric and aerodynamic characteristics.

The wing area, which represents the total surface area of the aircraft's wings when viewed from above, is determined based on the established wing loading and gross weight values provided in Appendix A. The wing area is typically measured in square units such as square feet or square meters.

In the case of a simple rectangular wing, the wing area can be calculated by multiplying the wingspan (the distance between the wingtips) by the average chord length (the distance from the leading edge to the trailing edge along the wing's span).

The wing area plays a crucial role in determining the aircraft's performance characteristics. It directly affects lift production, with a larger wing area generally resulting in greater lift, especially during take-offand landing. The wing area also impacts the aircraft's stall speed, as a larger wing area allows for slower flight speeds before stalling occurs.

Moreover, the wing area influences drag characteristics. A larger wing area tends to create more drag, which can affect the overall efficiency and fuel consumption of the aircraft. However, it can also provide advantages in terms of maneuverability and stability.

$$S_{wing} = \frac{m_0 \cdot g}{P_0} = \frac{30685 \cdot 9.8}{3076} = 97.666\,\text{m}^2,$$

where m_0 – take-offmass of the aircraft, m;

g – gravitational acceleration, m/s^2;

P_0 – wing loading at cruise regime of flight, kg/m^2;

S_{wing} – wing area, m^2.

Wing span is:

$$l_w = \sqrt{S_{wing} \cdot \lambda_w} = \sqrt{97.666 \cdot 11} = 32.78 \text{ m},$$

where λ_w – wing aspect ratio, m.

Root chord is:

$$C_{root} = \frac{2S_w \eta_w}{(1+\eta_w)\cdot 1} = \frac{2 \cdot 97.666 \cdot 3}{(1+3)32.777} = 4.47 \text{ m},$$

where η_w – wing taper ratio.

Tip chord is:

$$C_{tip} = \frac{C_{root}}{\eta_w} = \frac{4.47}{3} = 1.48 \text{ m},$$

on board chord for trapezoidal shaped wing is:

$$C_{board} = C_{root} \cdot \left(1 - \frac{(\eta_w - 1) D_f}{\eta_w \cdot l_w}\right) = 4.47 \cdot \left(1 - \frac{(3-1)\cdot 2.64}{3 \cdot 32.777}\right) = 4.229 \text{ m}.$$

Wing construction and spars position.

To choose the structure scheme of the wing it is necessary to determine the type of its internal design. The torsion box type with two spars was chosen to meet the requirements of strength and at the same time to make the structure comparatively light.

The geometrical method of mean aerodynamic chord determination has been taken, which is presented at the figure 2.1

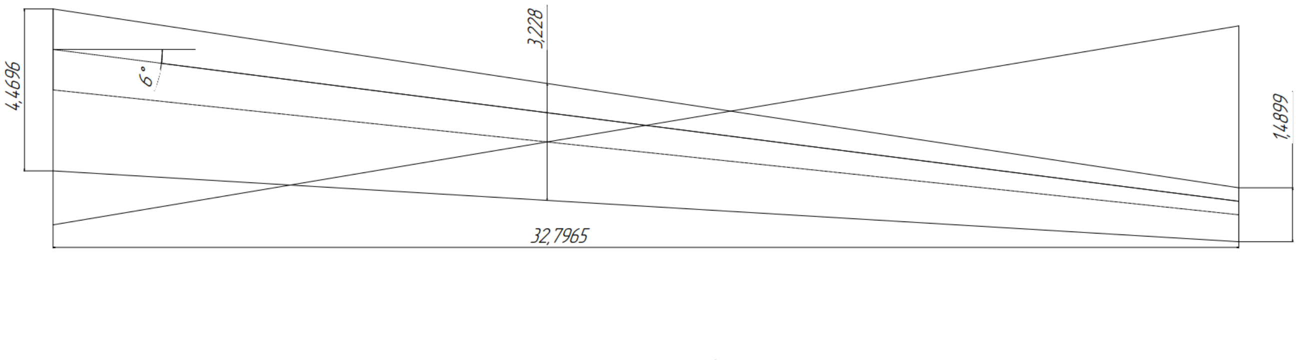


Figure 2.1 – Determination of mean aerodynamic chord.

Mean aerodynamic chord is equal $b_{MAC} = 3.228$ m.

Also we could calculate the MAC by the approximately formulas for trapezoidal wing shape:

$$b_{MAC} = \frac{2}{3} \cdot \frac{C_{root}^2 + C_{root} \cdot C_{tip} + C_{tip}^2}{C_{root} + C_{tip}} = \frac{2}{3} \cdot \frac{4.47^2 + 4.47 \cdot 1.49 + 1.49^2}{4.47 + 1.49} = 3.228 \text{ m.}$$

Once the geometrical characteristics of the wing have been determined, we proceed to assess the aileron’s geometry and high-lift devices. Ailerons geometrical parameters are determined in next consequence:

ailerons span:

$$l_{aileron} = 0.31 \frac{l_w}{2} = \frac{0.31 \cdot 32777}{2} = 5.080 \text{ m,}$$

aileron area:

$$S_{aileron} = 0.06 \frac{S_w}{2} = \frac{0.06 \cdot 97.666}{2} = 2.93 \text{ m.}$$

The aileron deflection range will be 25 degrees in the upward direction and 15 degrees in the downward direction.

For the design of the aircraft, it is possible to incorporate simple slotted flaps without slats. Based on the prototypes, the relative chords of the wing's high-lift devices are as follows:

For a single slotted flap, the relative chord (bf) ranges from 0.28 to 0.3.

Starting from a short distance from the root cross-section of the wing (bwing=4.35 m), the flaps are positioned. Therefore, the chord of the flap at this cross-section can be calculated as:

$$b_f = 0.28 \cdot 4.35 = 1.3 \text{ m.}$$

2.3 Fuselage layout

The fuselage layout is an essential aspect of aircraft design, ensuring comfortable passenger accommodation in the cabin for passenger aircraft or proper positioning of cargo on pallets or in unit load devices for cargo aircraft.

During the preliminary design of the fuselage structure, typically follow the typical semi-monocoque design. The fuselage structure comprises bulkheads (formers and frames), stringers, longerons, and skin. Formers provide the shape for the fuselage and support the stringers and skin. They are installed parallel to each other and connected with stringers. Frames bear the main loads and distribute concentrated loads from other components such as the wing, tail, landing gear attachment, entrance doors, emergency exits, and cargo doors. The first frame at the front of the fuselage is the pressurized bulkhead, which ensures cabin sealing. At the rear of the fuselage, the aft pressure bulkhead is located before the auxiliary power unit, sealing off the pressurized cabin.

Technologically, the fuselage is divided into three parts: the front (cockpit compartment), middle (passenger compartment or cargo cabin), and rear (tail unit). The cockpit is situated in the front part, with the space beneath accommodating electrical instruments, devices, and the landing gear nose wheel. The central part houses the passenger compartment (or cargo compartment), a baggage compartment below the floor, the center wing box with fuel tanks, and the main landing gear wheel well. The rear part comprises the equipment compartment, smaller forms, spars, and stringers. The smaller formers, due to their constant thickness, are more rigid and capable of supporting both the horizontal and vertical stabilizers. The auxiliary power unit (APU) is typically located at the tail.

When selecting fuselage parameters, aerodynamic requirements related to streamline and cross-section play a crucial role. The circular cross-section is preferred due to its efficiency in providing minimum weight and maximum strength. Meeting strength requirements while reducing weight is essential in aircraft design.

Geometrical parameters, such as fuselage diameter, length, fineness ratio, nose part, and tail unit geometry, are carefully considered at the figure 2.2.

The length of the aircraft fuselage is designed based on factors such as the aircraft's purpose, passenger capacity, cabin layout, center of gravity position, and landing angle of attack.

Length of the aircraft fuselage:

$$FR_f = \frac{L_{fus}}{D_{fus}}; \quad L_{fus} = FR_f \cdot D_{fus} = 9 \cdot 2.64 = 23.76\,\text{m},$$

where: FR – fineness ratio of the fuselage (from initial data),

D_{fus} – diameter of the fuselage (from initial data).

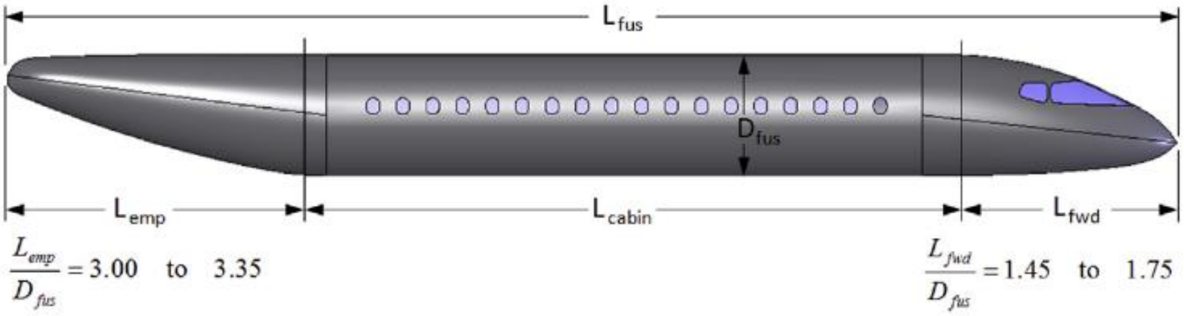


Figure 2.2 – Fuselage geometry.

Length of aircraft fuselage forward part:

$$L_{fwd} = FR_{np} \cdot D_{fus} = 1.45 \cdot 2.64 = 3.83\,\text{m};$$

Length of the fuselage tail part:

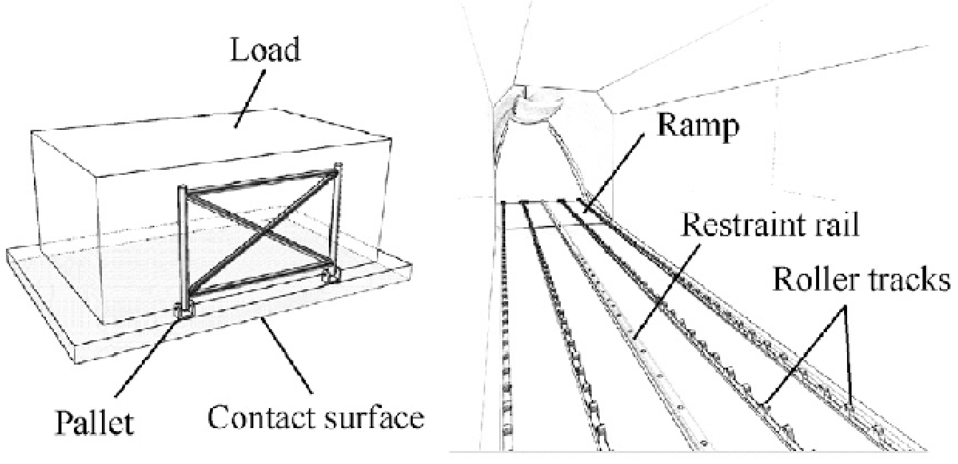
$$L_{tailpart} = FR_{tu} \cdot D_{fus} = 3 \cdot 7.92\ \text{m};$$

The equipment of an aircraft cargo cabin is designed to ensure the safety and protection of cargo during flight, as well as to facilitate efficiency and promptness of service. The requirements for the equipment of an aircraft cargo cabin affect the reliability of cargo transportation, their integrity, and timely delivery.

Cargo securing system: This is the first and main requirement for the equipment of the cargo cabin.

The securing system must be reliable and durable to withstand large loads during take-off, flight, and landing. It also needs to be flexible so that it can be adapted for cargo of various sizes and shapes. The cargo securing system in aircraft helps ensure that the cargo remains in place throughout the entire flight, including take-off, cruising, and landing. Cargo securing systems need to be structurally resilient, flexible, and easy to adjust. The main components of the cargo securing system may include:

Track-fitted floors: Track-fitted floors refer to the flooring of an aircraft's cargo hold that is fitted with tracks or rails. These tracks are often designed to accommodate various types of cargo securing devices, such as straps, locks, or pallets. They play an essential role in cargo transport as they allow for the secure and efficient loading, transport, and unloading of cargo. The tracks are designed to secure cargo in place, preventing it from moving during flight, which could otherwise lead to instability or potential damage. The design of these tracks varies depending on the type of aircraft and its intended cargo Figure 2.3. These floors can usually accommodate standardized cargo units, such as containers or pallets, making it easier to load and unload cargo and improving efficiency.



(a) Configuration of cargo (b) Aircraft roller-rail system

Figure 2.3 – Typical configuration of a cargo and an aircraft roller.

Straps: These are usually made of strong, durable materials such as polyester, nylon. Straps are used to bind cargo to the pallet or directly to the track system on the floor of the aircraft. They are often designed to handle heavy loads and can be tightened to hold the cargo firmly in place. Straps might come with ratchet mechanisms that allow for tensioning and secure fastening.

Belts: Belts, also known as cargo belts or lashing belts, serve a similar purpose to straps. They are typically made of textile materials and are used to tie down lighter or irregularly shaped cargo that might not be suited for strapping. Belts often come with buckle systems that allow them to be easily adjusted to fit the cargo they are securing.

Net securing devices: Net securing devices, also known as cargo nets. They serve to secure cargo and prevent it from moving during flight. Cargo nets are typically made from high-strength materials such as nylon or polyester and consist of a grid or mesh design figure 2.4.

This design allows the net to flex and adapt to various cargo shapes and sizes, while maintaining a strong hold on the cargo.

Figure 2.4 – Net securing devices.

The key features of net securing devices include:

Versatility: Cargo nets can accommodate different shapes and sizes of cargo, making them highly versatile for a range of goods. This adaptability makes them suitable for securing irregularly shaped or bulk items that cannot be efficiently secured with straps or belts.

Strength: Made from robust, high-tensile materials, cargo nets are designed to withstand significant loads and stresses during flight. This ensures that cargo remains secure even under turbulent conditions.

Safety: By preventing cargo movement during flight, cargo nets contribute significantly to flight safety. Unsecured cargo can shift during take-off, flight, or landing, potentially destabilizing the aircraft.

Efficiency: Cargo nets allow for quick and efficient loading and unloading processes. They can be easily deployed and adjusted to secure cargo, and just as easily removed when the cargo arrives at its destination.

In summary, net securing devices provide an effective solution for securing cargo during flight, particularly for cargo that is irregularly shaped or too bulky for other securing methods.

Seals and latches: These are used for additional cargo security, integrity check of the cargo, and prevention of unauthorized access to the cargo. Proper securing of cargo is critically important for safe flight. Improperly secured cargo can shift during flight, creating potential danger for the aircraft and its crew. In addition, cargo that is out of place can be damaged or can damage other cargos in the cabin.

Temperature Control and Storage Equipment: Certain cargo, such as medicines, food products, or live animals, require specific temperature conditions during transport. The cargo hold should be equipped with a reliable temperature control system that ensures stability of the temperature regime.

Ventilation and Pressurization Systems: The cargo hold must be airtight and equipped with an efficient ventilation system that helps maintain correct pressure and air exchange in the cabin.

Fire Suppression Systems: The equipment in the cargo hold should include modern fire suppression systems. This can include smoke detectors, automatic fire suppression systems, as well as devices for manual fire extinguishing.

Cargo Tracking Systems: Modern technologies allow for real-time tracking of cargo, which facilitates monitoring its condition and movement. This is important for high-value or critical cargo.

Lighting System: The cargo hold should be equipped with an efficient lighting system that contributes to the safe work of personnel and quality of service.

Ergonomics of Equipment: Ergonomics in the equipment of an aircraft cargo hold is crucial for ensuring efficient, safe, and comfortable operation for the crew. It involves the thoughtful design and arrangement of equipment and systems to fit with human capabilities and limitations. The key is to boost productivity while reducing fatigue and discomfort.

For example, the equipment should be user-friendly, with controls that are readily accessible and simple to use.

The physical strain on the crew should be minimized. This involves considering factors such as the force needed to operate equipment, the frequency and duration of tasks, and the posture required to perform these tasks.

Safety is another important ergonomic consideration. Equipment design and arrangement should facilitate safe operation. This includes providing enough space for movement, using non-slip surfaces, and making sure equipment is devoid of sharp edges or corners that could cause injury.

The equipment should also be intuitive and easy to operate, reducing the need for extensive training and helping prevent operational errors. Finally, adaptability is key.

By focusing on ergonomics in the design and layout of an aircraft cargo hold, airlines can improve working conditions for their crew, enhance operational efficiency, and increase the overall safety of their operations.

Communication System with Pilots: For the coordination of actions between cabin staff and pilots, a well-established communication is necessary. This includes radio or intercom systems that ensure quality exchange of information.

Cargo Compartment Door Control System: It's important to have means of controlling the cargo compartment doors to guarantee their reliable closing and opening.

2.4 Determination of the tail unit geometrical parameters

Tail unit geometrical parameters play a crucial role in determining the stability, control, and overall aerodynamic characteristics of the aircraft.

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

$$S_{HTU}=(0.18...0.25)\ S_w;$$

$$S_{VTU}=(0.12\ldots0.20)\cdot S_w;$$

For more exact:

$$S_{HTU}=\frac{b_{MAC}\cdot S_w}{L_{HTU}}\cdot A_{HTU}=\frac{3.23\cdot 97.666}{6.778}\cdot 0.5=23.254\,\mathrm{m}^2,$$

$$S_{VTU}=\frac{l_w\cdot S_w}{L_{HTU}}\cdot A_{HTU}=\frac{32.45\cdot 97.666}{8.07}\cdot 0.07=27.49\ \mathrm{m}^2,$$

where: L_{HTU} and L_{VTU} – arms of horizontal TU and vertical TU;

l_w, S_w – wing span and wing area;

$A_{HTU,}$ A_{VTU} – coefficients of static moments, values of which may be taken from the table.

The values of L_{HTU} and L_{VTU} are influenced by several factors. Primarily, their values are determined by the length of the nose and tail sections of the fuselage, the degree of sweepback of the wings, the positioning of the wings, and the stability and control requirements of the aircraft.

During the initial analysis, it is often assumed that L_{HTU} is approximately equal to L_{VTU}, and their values can be estimated using certain relationships or dependencies.

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

Trapezoidal scheme, normal scheme

$$L_{VTU} = (0.2...3.5) \cdot b_{MAC} = 2.5 \cdot 3.23 = 8.07 \text{ m};$$

$$L_{HTU} = (2.0...2.3) \cdot b_{MAC} = 2.1 \cdot 3.228 = 6.78 \text{ m};$$

Determination of the elevator area and direction:

elevator area:

$$S_{el} = (0.3...0.4) \cdot S_{HTU} = 23.254 \cdot (0.35) = 8.139 \text{ m}^2,$$

rudder area:

$$S_{rudder} = (0.2...0.22) \cdot S_{VTU} = 27.488 \cdot 0.2 = 5.498 \text{ m}^2,$$

the area of elevator trim tab:

$$S_{el\ tr} = (0.22...0.25) \cdot S_{el} = 8.139 \cdot 0.22 = 1.791 \text{ m}^2,$$

area of rudder trim tab is equal:

$$S_{rudder\ tr} = (0.2...0.22) \cdot S_{rudder} = 5.497 \cdot 0.2 = 1.099 \text{ m}^2,$$

TU span is related to the following dependence:

$$l_{HTU} = (0.32...0.5) \cdot l_w = 0.38 \cdot 32.777 = 12.455 \text{ m},$$

In this dependence the lower limit corresponds to the turbo jet engine aircraft, equipped with all-moving stabilization.

The height of the vertical TU h_{VTU} is determined accordingly to the location of the engines. Taking it into account we assume:

Engine in the root part of the wing h_{VTU} =(0.13…0.165) l_w;

For high wing airplanes we need to set the upper limit.

Tapper ratio of horizontal and vertical TU we need to choose:

Determination of TU chords b_{end}, b_{CAX}, b_{root}:

$$b_{tip} = \frac{2 \cdot S_{HTU}}{(\eta_{HTU} + 1) l_{HTU}} = \frac{2 \cdot 23.253}{(2.3 + 1) \cdot 12.455} = 1.13 \text{ m};$$

$$b_{MAC} = \frac{2}{3} \cdot \frac{\eta_{HTU}^2 + \eta_{HTU} + 1}{\eta_{HTU} + 1} \cdot b_{htutip} = \frac{2}{3} \cdot \frac{2.3^2 + 2.3 + 1}{2.3 + 1} \cdot 1.131 = 1.94 \text{ m};$$

$$b_{root} = b_{tip} \cdot \eta_{HTU} = 1.131 \cdot 1.94 = 2.199 \text{ m};$$

Width/chord ratio of the airfoil.

For horizontal and vertical TU in the first approach, $\bar{C}_{TU} \approx 0.8 \cdot \bar{C}_w$.

For more accurate:

Subsonic $\bar{C}_{TU} = 0.8...0.10$

If the stabilizations fixation is on the fin we need to use upper limit of $\bar{C}_{TU}$, to provide fixation base on the fin.

The tail unit of the aircraft is designed with a sweptback configuration, where the horizontal and vertical stabilizers are angled backward relative to the fuselage. This sweptback design helps improve the aircraft's aerodynamic performance by reducing drag and increasing stability. The angled position of the tail unit allows for smoother airflow over the surfaces, minimizing turbulence and enhancing control during flight.

2.5 Calculation of basic parameters and layout of landing gear

In the early stages of aircraft design, the aircraft's landing gear must be considered, despite significant uncertainties. Critical parameters like the center of gravity are not yet well defined and the comprehensive aircraft drawing is not yet completed. Despite these uncertainties, the landing gear's crucial role in the aircraft's performance, safety, and operability necessitates these early considerations.

Based on the conceptual design of the aircraft, experiences with similar aircraft, and preliminary calculations, estimations can be made about various aspects of the landing gear. For example, the configuration of the landing gear is influenced by the estimated size, weight, and intended operation of the aircraft, with common configurations being tailwheel, tricycle, and tandem layouts.

The decision on whether to make the landing gear retractable depends on the aircraft's size and mission, with a retractable gear reducing drag during flight. The complexity of such a mechanism is a balance between weight, reliability, and aerodynamic efficiency.

The number of wheels the landing gear should have can be estimated based on factors like the aircraft's weight, runway conditions, and tire technology. A larger number of wheels distributes the load over a larger area, reducing pressure on runway surfaces.

The size of the wheels affects the ground clearance of the aircraft, necessary to protect the fuselage and other structures from ground contact. Larger wheels, while better for handling rough runways, add weight and require more space when retracted figure 2.5.

The landing gear's shock absorption capabilities are also important to consider. To prevent damage to the airframe and provide a smooth ride, landing gear often utilize shock-absorbing mechanisms like oleo-pneumatic struts or leaf springs.

Lastly, the braking system must be adequately sized to stop the aircraft within a reasonable distance, without causing overheating or tire failure. Brake types and the need for an anti-skid system can be considered at this stage.

The landing gear's impact on aircraft maintainability, reliability, and lifecycle cost, along with certification requirements, must also be considered.

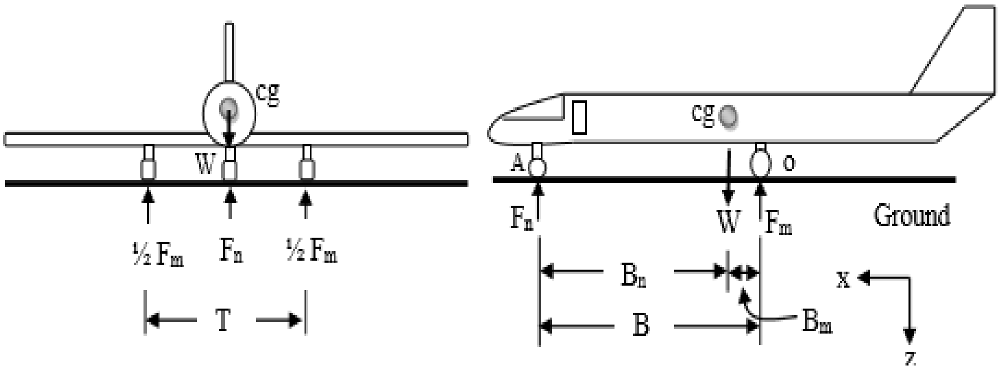


Figure 2.5 – Schematic diagram of aircraft landing gear length.

The distance from the centre of gravity to the main LG

$$B_m = \left(0.15...0.20\right) \cdot b_{MAC},$$

$$B_m = 3.228 \cdot 0.2 = 0.646 \text{ m}.$$

In the design phase, considerations about the placement of the landing gear are crucial. If the nose landing gear is placed too far forward, it becomes difficult to generate enough lift to raise the nose for take-off.

On the other hand, if it's located too close to the airplane's center of gravity, there's a risk of the airplane's tail striking the ground during take-off, especially when the airplane's rear is heavily loaded.

Moreover, if the load on the nose landing gear is too small, the aircraft might not maintain stability during taxiing on a slippery runway or in crosswind conditions. Landing gear wheel base comes from the expression:

$$B = (0.3...0.4) \cdot l_f = 10 \cdot 0.645 = 6.45 \text{ m.}$$

Aircraft with engines mounted on the wings usually possess a larger value. This refers to the specific configuration where engines are situated on the wings, which can impact various aspects of the aircraft's design and operation, including the center of gravity and consequently, the landing gear design and placement..

The final equation suggests that the nose gear is designed to bear between 6 and 10 percent of the total weight of the aircraft. This is a critical factor in ensuring the stability of the airplane during landing, take-off, and ground movement.

The distance from the centre of gravity to the nose LG

$$B_n = B - B_m = 6.456 - 0.645604 = 5.8 \text{ m.}$$

Wheel track is:

$$T = 0.7 \cdot 6.456 = 4.5192 \leq 12 \text{ m.}$$

On a condition of the prevention of the side nose-over the value *T* should be > 2*H*, where *H* – is the distance from runway to the center of gravity.

Wheels for the landing gear is chosen by the size and run loading on it from the take off weight; for the front support we consider dynamic loading also Figure 2.6.

Type of tires and the pressure in it is determined by the runway surface, which should be used. We install breaks on the main wheel, and sometimes for the front wheel also.

The load on the wheel is determined:

$$F_{main} = \frac{(B - B_m) \cdot m_0 \cdot 9.81}{B \cdot n \cdot z} = \frac{(6.46 - 0.65) \cdot 30685 \cdot 9.81}{6.46 \cdot 4 \cdot 1} = 67729.42 \text{ N},$$

$$F_{nose} = \frac{B_m \cdot m_0 \cdot 9.81 \cdot K_g}{B \cdot z} = \frac{0.646 \cdot 30685 \cdot 9.81 \cdot 1.5}{6.46 \cdot 2} = 22576.62 \text{ N},$$

where n, and z – is the quantity of the supports and wheels on the one leg,

$K_g = 1.5..2.0$ – dynamics coefficient.

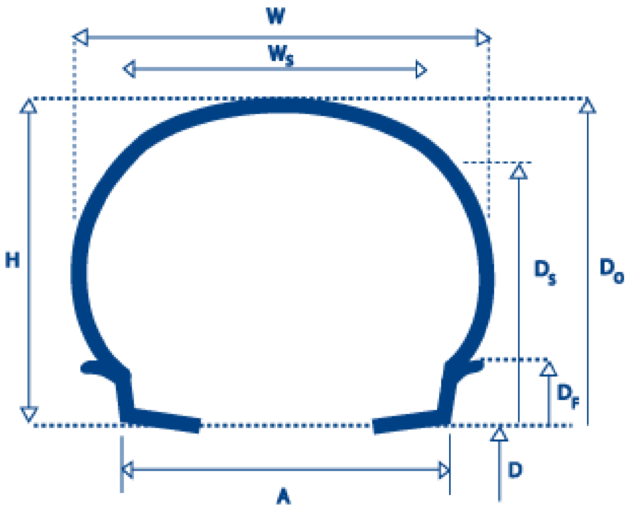


Figure 2.6 – Fundamental measurements of the tire.

Table

Aviation tires for designed aircraft

TIRE SIZE	PLY RATING	TIRE SIZE	PLY RATING
39x13	14/16 TL	29x11.00	12 10 TL

The pressure in aircraft tires are usually close to 13 bar (200 psi, 13 atm).

2.6 Engine description

The prototype model employs a pair of Rolls-Royce AE2100-D2A turboprop engines as its power source. Designed for robust performance and dependable operation even under demanding circumstances, these engines are proven reliable, being the same ones used in the Lockheed Martin C-130J Super Hercules - a testament to their proficiency and reliability figure 2.7.

Each of these AE2100-D2A engines is capable of generating a hefty 4,637 shaft horsepower (or 3,458 kW), contributing significantly to the prototype's commendable performance traits, notably its short take-offand landing (STOL) ability.

To effectively convert the engine power into thrust, the prototype is equipped with six-bladed Dowty Propellers. The six-blade design, compared to the more common three or four-bladed propellers on many other aircraft, allows the prototype to optimize the engine power into thrust more efficiently, thus enhancing its acceleration and climb rate.

Moreover, these engines afford the prototype superior maneuverability and flight traits. The aircraft can execute its mission proficiently even under harsh weather conditions or in tough environments, attributed to the resilience and reliability of its AE2100-D2A engines.

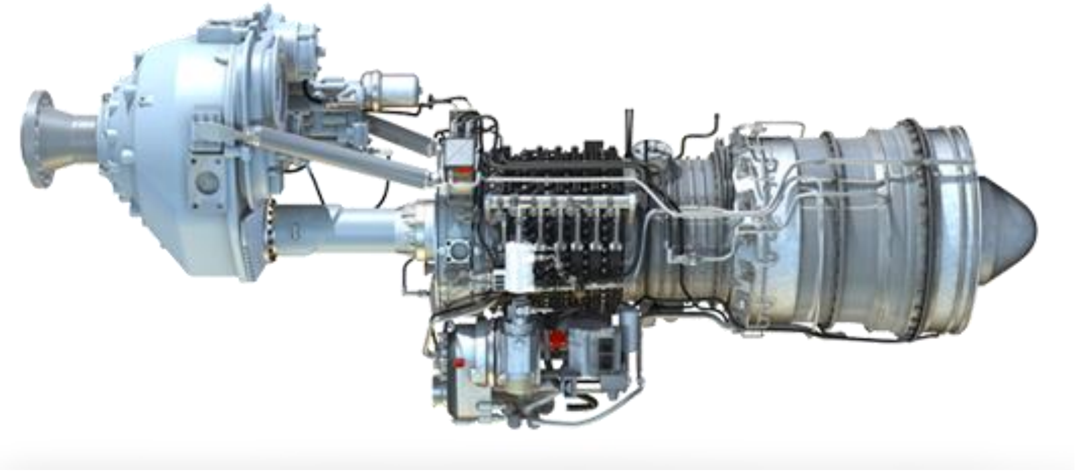


Figure 2.7 – Rolls-Royce AE2100-D2A turboprop engines.

In conclusion, the Rolls-Royce AE2100-D2A engines utilized in the prototype Spartan are pivotal to the aircraft's performance and operational proficiencies. They empower the aircraft with STOL abilities, provide exceptional maneuverability and flight traits, and enable the prototype to function effectively under a diverse array of conditions and environments.

Conclusion to the design part

The geometry calculations for the main parts of the aircraft, including the wing, fuselage, and tail unit, have been performed.

For the wing, the area, span, root chord, tip chord, and onboard chord have been determined. The wing construction follows a torsion box type with two spars. The mean aerodynamic chord has been calculated using both the geometrical method and approximate formulas for trapezoidal wing shape. The aileron's geometry, including span and area, has also been assessed. Simple slotted flaps without slats have been considered for the design, and the relative chord (bf) for the flaps has been determined based on prototypes.

In the fuselage layout, the semi-monocoque design has been followed, comprising bulkheads, stringers, longerons, and skin. The fuselage is divided into the front, middle, and rear parts, accommodating the cockpit, passenger or cargo compartments, and tail unit. The diameter, length, fineness ratio, and other geometric parameters have been carefully considered. The circular cross-section is preferred for its efficiency in providing strength with minimum weight.

The tail unit geometry, including the horizontal and vertical stabilizers, plays a vital role in maintaining aircraft stability and control. The lengths of the horizontal and vertical tail units have been determined, taking into account factors such as fuselage length, wing sweepback, wing positioning, and stability and control requirements. The areas of the elevator and rudder, as well as the trim tab areas, have been calculated based on percentages of the respective tail unit areas.

3. AIRCRAFT CARGO CABIN EQUIPMENT AND POSSIBLE UPGRADES

3.1 Cargo cabin equipment

The equipment of an aircraft cargo cabin is designed to ensure the safety and protection of cargo during flight, as well as to facilitate efficiency and promptness of service. The requirements for the equipment of an aircraft cargo cabin affect the reliability of cargo transportation, their integrity, and timely delivery.

One of the key elements of cargo cabin equipment is cargo systems and securing devices. Cargo systems allow for efficient organization of cargo placement inside the aircraft, ensuring stability and preventing shifting during flight. Securing devices such as straps, clamps, beams, and nets provide secure fastening of the cargo, preventing movement and damage.

An important aspect of cargo cabin equipment is the cargo loading and unloading system. It may include various mechanisms and devices such as loading ramps, cargo lifts, and conveyors, facilitating and expediting the process of loading and unloading cargo.

Additional cargo cabin equipment may include fire suppression systems, vibration monitoring systems, and cargo monitoring devices, helping detect and prevent potential issues or damage to the cargo during flight.

The equipment of the cargo cabin emphasizes the importance of safety and reliability in cargo transportation by aircraft.

3.2 Power drive unit

As an integral part of Aircraft Cargo Handling Systems (ACHS), the Power Drive Unit (PDU) figure 3.1, epitomizes the amalgamation of mechanical engineering and advanced control systems in aviation technology.

PDU is an electromechanical device, embedded within the aircraft's cargo hold, playing an instrumental role in facilitating automated movement of cargo, ensuring optimal efficiency, precision, and safety in loading and unloading processes.

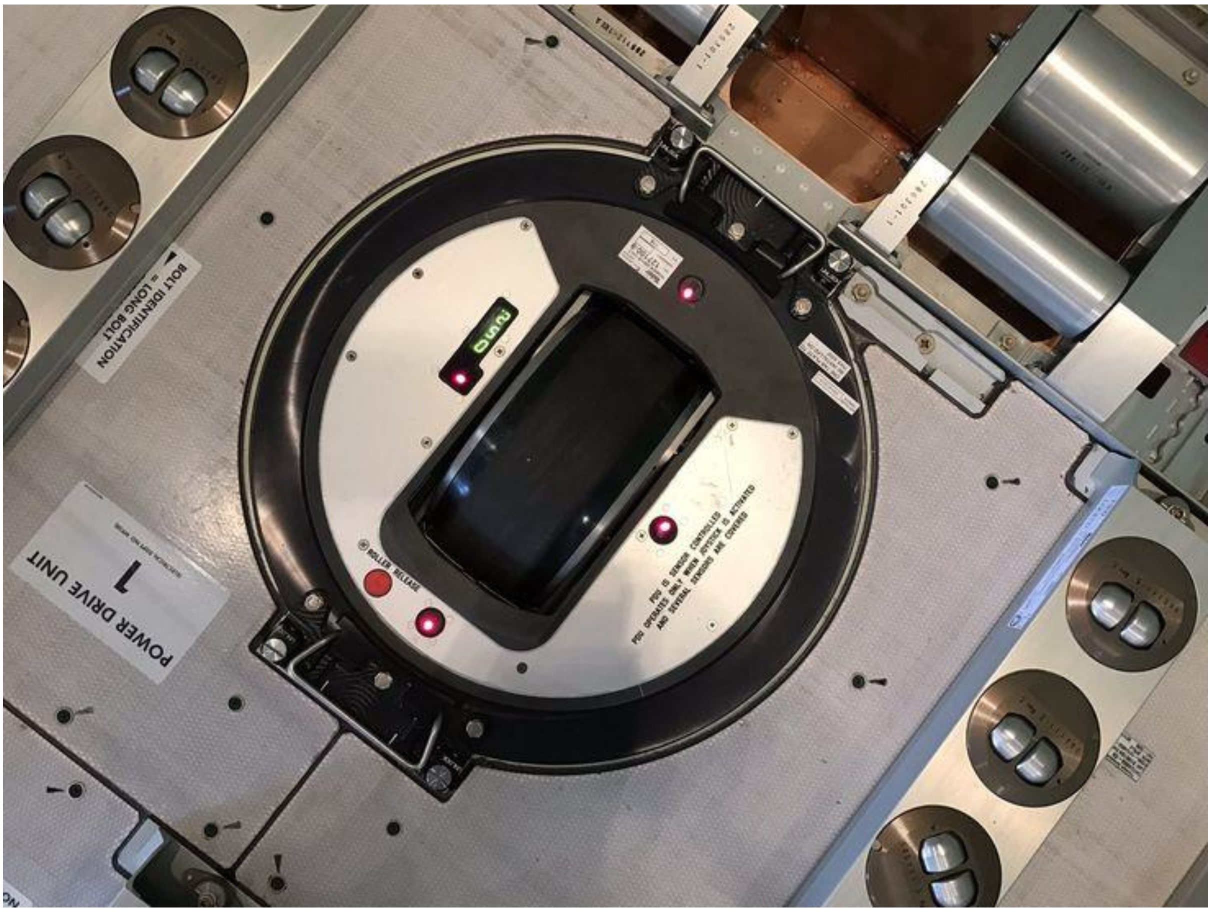


Figure 3.1 – Power drive unit.

A Power Drive Unit's strategic role becomes evident when one considers the operational demands placed upon modern air cargo logistics: large-scale movements of goods across vast geographies, strict time constraints, and high expectations for safety and reliability. In such an intricate matrix, the PDU serves as an engine driving cargo mobilization within the aircraft, working in concert with a plethora of interconnected systems such as track-fitted floors, straps, and cargo nets to secure freight during all flight phases.

This mechanized marvel represents a significant leap over manual handling techniques, thereby reducing human error, enhancing safety, and expediting cargo processing times. The functional robustness of PDUs, coupled with their advanced control mechanisms, enable them to perform under various conditions and adapt to the diverse range of cargo types and sizes.

Design and Operation of PDUs:

The PDU comprises an electric motor that drives cargo along the conveyance system, usually consisting of roller tracks, ball mats, or conveyor belts. Individual PDUs are often controllable independently, offering high precision in cargo movement. In addition, PDUs are designed to withstand harsh conditions, ensuring a reliable performance in various scenarios.

The Power Drive Units (PDUs) patents that have studied appear to have gearboxes that are excessively large for such compact assemblies. Consequently, initiated an analysis of the available gearbox patents with an aim to reduce the overall size while maintaining the same gear ratio.

This decision to explore size reduction in the gearbox design stemmed from the potential benefits such a change could offer. The obvious advantage is the reduction of physical space occupied by the PDU, which could be a significant advantage in the compact, often space-constrained, environments of aircraft cargo holds. A smaller gearbox could also lead to a lighter PDU assembly, which could contribute to the overall reduction of the aircraft's weight and, subsequently, its fuel consumption.

The challenge, however, lies in maintaining the same gear ratio and, thus, the same output torque and speed, despite the reduction in size. This would require innovative approaches in gearbox design and possibly the use of advanced materials and manufacturing technologies.

Therefore, the subsequent step in this research endeavor involved examining gearbox patents that could potentially meet these criteria.

3.3 Spur gears

Spur gears, also known as straight-cut gears, are the simplest type of gear figure 3.2 and are commonly used in a variety of mechanical applications, including in gearboxes for Power Drive Units (PDUs).

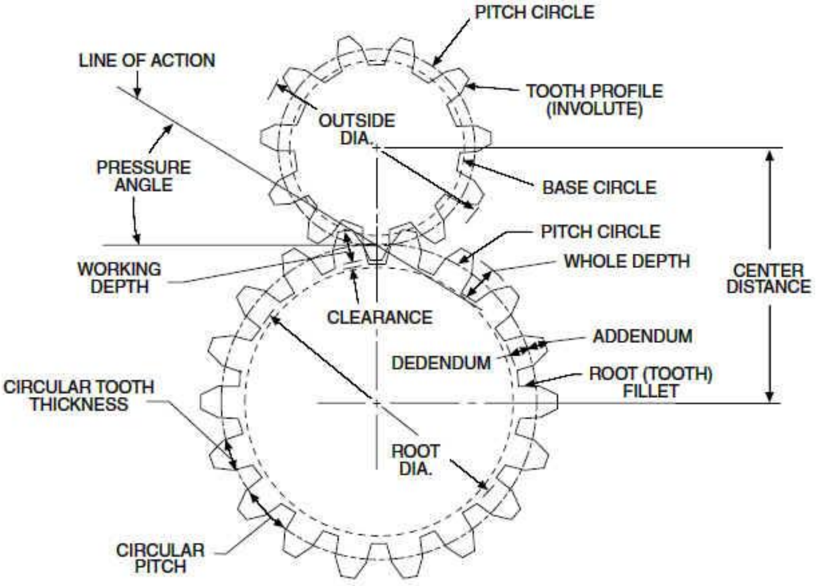


Figure 3.2 – Spur Gear Tooth Component Identification.

Here are the pros and cons of spur gears:

Pros of Spur Gears:

Simplicity and Ease of Manufacture: Spur gears are simple in design with straight, parallel teeth cut along the gear wheel's surface. This makes them easier and less expensive to design, manufacture, and maintain compared to more complex types of gears.

High Power Transmission: Spur gears are known for efficient power transmission. Because the entire face of the gear tooth engages at the same time, it can handle high loads and transmit large amounts of power.

Precise Motion Control: Spur gears offer a constant drive ratio, meaning the rate of rotation between the input and output shafts remains consistent. This makes them ideal for applications requiring precision.

Cons of Spur Gears:

Noise and Vibration: Spur gears are generally noisier than other types of gears. Because the entire tooth engages at once, it can cause a sudden change in load and a corresponding change in tooth deflection, which leads to increased noise and vibration. This becomes more noticeable and problematic at high speeds.

Axial Thrust: The straight-cut teeth of spur gears generate axial thrust, pushing the gears along the axis of rotation. This axial load needs to be accommodated by appropriate bearing arrangements.

Lack of Smoothness: Spur gears do not operate as smoothly as helical or herringbone gears. The instantaneous contact between the gear teeth can result in a less smooth transmission of motion.

In summary, while spur gears offer a number of advantages, including simplicity and efficient power transmission, they also come with downsides such as increased noise and vibration, axial thrust, and lack of smooth operation. Thus, the choice of gear type in a Power Drive Unit or any other mechanical system would depend on the specific requirements of the application, including factors such as load capacity, operational speed, space constraints, and noise tolerance.

3.4 Planetary gears

Planetary gears, or epicyclic gears, are a type of gear mechanism that consists of one or more 'planet' gears revolving around a central 'sun' gear, typically within an outer 'ring' gear figure 3.3.

Here are some of the pros and cons associated with the use of planetary gear systems:

Pros of Planetary Gear Systems:

Compact and Space-Efficient Design: Planetary gear systems are noted for their compactness and high power density. This allows for significant power transmission in a relatively small space.

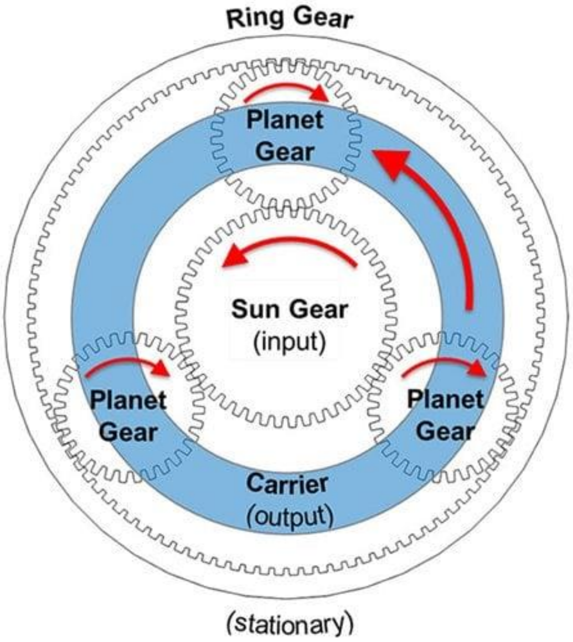


Figure 3.3 – One of the options for the planetary gear.

High Load Capacity: Due to the distribution of the load across multiple planet gears, planetary gear systems can handle higher loads compared to traditional gear systems of similar size. This makes them suitable for high-torque applications.

High Efficiency: Planetary gears can provide high efficiency due to the simultaneous engagement of several planet gears, resulting in smooth and effective power transmission.

Versatility: Planetary gear systems offer versatility in that they can be employed in various configurations to achieve different speed-torque ratios.

Balanced Radial Loads: The balanced radial loads in a planetary gear system reduce the pressure on the bearings and increase the longevity and reliability of the system.

Cons of Planetary Gear Systems:

Complex Design and Manufacturing: The design and manufacturing of planetary gears can be complex due to the need for precision in the construction of the multiple interconnected gears.

Heat Dissipation Issues: Due to the compact nature of the design and multiple gear engagements, planetary gear systems may face issues with heat dissipation, which could potentially affect their performance or lifespan.

Noise and Vibration: Although the engagement of multiple gears can lead to smooth operation, it can also lead to increased noise and vibration levels, especially if there are any inaccuracies or inconsistencies in the gear manufacturing process.

Overall, while planetary gear systems offer several advantages, especially for applications like PDUs where space-efficiency, high load capacity, and versatility are critical, the challenges associated with their design, manufacturing, and maintenance must be taken into account in the decision to employ them.

3.5 Harmonic Drive

A Harmonic Drive, also known as a strain wave gear system, is a special type of mechanical gear system that can offer high gear ratios and exceptional precision figure 3.4.

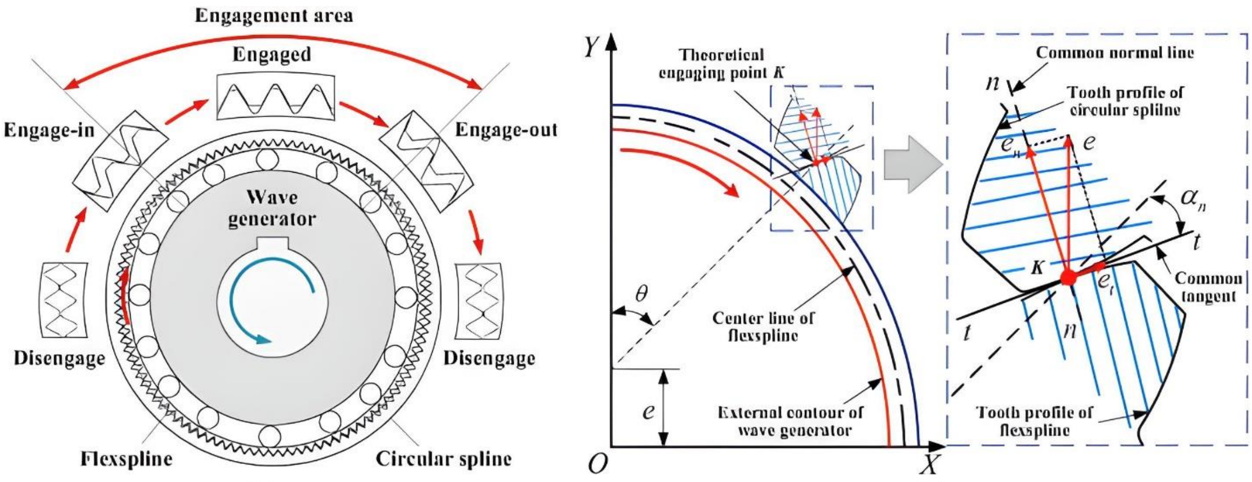


Figure 3.4 – One of the options for the operation of the harmonic Drive.

It is characterized by a compact, lightweight design which makes it an interesting alternative to traditional gear systems, particularly when considering potential application in the Power Drive Units (PDU) of aircraft. Here are the pros and cons of a Harmonic Drive system:

Pros:

High Gear Ratios: Harmonic Drive systems can achieve incredibly high gear ratios, often much higher than traditional gear systems.

Compact and Lightweight: The unique design of the Harmonic Drive allows for a compact form factor and lower weight compared to traditional gear systems. This is beneficial in space-constrained environments, such as an aircraft's cargo hold.

High Precision: Harmonic Drives offer high precision and repeatability, with very low backlash. This characteristic could enhance the precise control of cargo movements in a PDU.

High Torque Capability: Harmonic drives, owing to their high gear ratios, can transmit significant amounts of torque, which is crucial for moving heavy cargo pallets or containers.

Cons:

Cost: One of the significant drawbacks of Harmonic Drives is their cost. They are often more expensive than traditional gear systems due to the complexity of their design and the precision manufacturing techniques required to produce them.

Wear and Tear: The flexspline component of a Harmonic Drive is subject to continual flexing, which over time can lead to material fatigue and failure. The lifespan of these gear systems may be shorter than more traditional gear designs, depending on the specific application and operational conditions.

In conclusion, while the Harmonic Drive presents several compelling advantages for use in a Power Drive Unit, such as its compactness, high gear ratios, and precision, careful consideration must also be given to its drawbacks, such as cost, potential wear and tear. Further research and testing would be required to ascertain its feasibility and effectiveness in this particular system.

Conclusions to the special part

The exploration was conducted with an understanding that the design and efficiency of PDUs significantly influence the operational performance of the entire Aircraft Cargo Handling Systems Given the importance of efficient, reliable, and swift cargo movements in modern air logistics, any improvement in the PDU's operation could have a substantial impact on the overall efficiency of air cargo transportation.

This led us to dive deeper into the technical elements of PDUs, particularly the gearbox, a critical component that drives the movement of cargo. Recognizing that the current gearboxes seem oversized for such compact assemblies, the quest began to seek alternative gearbox designs that could maintain the same gear ratios while achieving a smaller, more space-efficient footprint.

Amongst various gearbox types considered, including spur gears, worm gears, and planetary gears, the Harmonic Drive emerged as a highly suitable option for use within the PDU. The Harmonic Drive presents a set of unique advantages which make it stand out as a promising candidate. Its high gear ratios, compactness, lightweight design, and high precision, all work in favor of the demanding requirements of a PDU.

However, it is also acknowledged that the Harmonic Drive system does come with its set of challenges, most notably its high manufacturing cost. Despite this drawback, there is a certain optimism rooted in the potential of engineering and technological advancements. As the demand and production of Harmonic Drives increase, economies of scale could potentially make it more cost-effective, thereby making it a viable choice for PDUs in the future.

Looking ahead, this optimism encourages further investigation into the suitability of Harmonic Drives in PDUs, bearing in mind the ever-evolving nature of technology and the potential for future cost reductions.

GENERAL CONCLUSIONS

In conclusion, the exploration of aircraft design, cargo cabin equipment, and Power Drive Units (PDUs) has provided valuable insights into the factors that contribute to the efficiency and performance of short-range aircraft.

Geometry calculations for key components such as the wing, fuselage, and tail unit have demonstrated the significance of meticulous design in achieving optimal performance and stability. The determination of wing area, span, and chord length, as well as fuselage length and tail unit geometry, lays the foundation for a well-designed aircraft.

Cargo cabin equipment, including cargo systems, securing devices, and loading/unloading systems, has been recognized as critical for efficient and safe cargo transportation.

The Power Drive Unit (PDU) has emerged as a crucial component in aircraft cargo handling systems. The exploration of gearbox designs, including spur gears, planetary gears, and harmonic drives, has revealed the suitability of harmonic drives for PDUs. Their high gear ratios, compact design, and precision make them a promising option, although challenges such as manufacturing costs and wear and tear need to be addressed.

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Appendix A
INITIAL DATA AND SELECTED PARAMETERS

Passenger Number	0
Flight Crew Number	2
Flight Attendant or Load Master Number	1
Mass of Operational Items	538.33kg
Payload Mass	8000.00kg

Cruising Speed	545km/h
Cruising Mach Number	0.4871
Design Altitude	7.500km
Flight Range with Maximum Payload	1150km
Runway Length for the Base Aerodrome	1.33

Engine Number	2
Thrust-to-weight Ratio in N/kg	0.3230
Pressure Ratio	9.00

Fuel-to-weight Ratio	0.2300

Aspect Ratio	11.00m
Taper Ratio	3
Mean Thickness Ratio	0.145
Wing Sweepback at Quarter Chord	6.0
High-lift Device Coefficient	0.800
Relative Area of Wing Extensions	0.000

Wing Airfoil Type - Laminated type NACA
Winglets - do not apply
Spoilers - installed

Fuselage Diameter	2.64
Finess Ratio	9.00
Horizontal Tail Sweep Angle	15.3 deg.
Vertical Tail Sweep Angle	21.3 deg.

CALCULATION RESULTS

Optimal Lift Coefficient in the Design Cruising Flight Point	0.48256

```
Induce Drag Coefficient                                                0.00985

ESTIMATION OF THE COEFFICIENT    Dm = Mcritical - Mcruise
Cruising Mach Number                                 0.48709
Wave Drag Mach Number                                0.64512
Calculated Parameter Dm                              0.15803

Wing Loading in kPa (for Gross Wing Area):
                           At Take-off                            3.218
                           At Middle of Cruising Flight           3.079
                           At the Beginning of Cruising Flight    3.138

Drag Coefficient of the Fuselage and Nacelles                    0.00747
Drag Coefficient of the Wing and Tail Unit                       0.00985

Drag Coefficient of the Airplane:

                           At the Beginning of Cruising Flight    0.03110

                           At Middle of Cruising Flight           0.03091

Mean Lift Coefficient for the Ceiling Flight                     0.48256


Mean Lift-to-drag Ratio                                          15.61288


Landing Lift Coefficient                                               1.763

Landing Lift Coefficient (at Stall Speed)                              0.645

Take-offLift Coefficient (at Stall Speed)                              2.257

Lift-off Lift Coefficient                                              1.625

Thrust-to-weight Ratio at the Beginning of Cruising Flight             0.115

Start Thrust-to-weight Ratio for Cruising Flight                       0.180

Start Thrust-to-weight Ratio for Safe Take-off                         0.203


Design Thrust-to-weight Ratio                                          0.207


Ratio  Dr = Rcruise / Rtake-off                                        0.886
```

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

Take-off	0.2766
Cruising Flight	0.2316
Mean cruising for Given Range	0.2335

FUEL WEIGHT FRACTIONS:

Fuel Reserve	**0.02108**
Block Fuel	0.08596

WEIGHT FRACTIONS FOR PRINCIPAL ITEMS:

Wing	0.11635
Horizontal Tail	0.01523
Vertical Tail	0.01505
Landing Gear	0.05121
Power Plant	0.15642
Fuselage	0.12857
Equipment and Flight Control	0.12864
Additional Equipment	0.00326
Operational Items	0.01754
Fuel	0.10704
Payload	0.26071

Airplane Take-offWeight	30685
Take-offThrust Required of the Engine	3172.9

Air Conditioning and Anti-icing Equipment Weight Fraction	0.0189
Passenger Equipment Weight Fraction (or Cargo Cabin Equipment)	0.0008
Interior Panels and Thermal/Acoustic Blanketing Weight Fraction	0.0075

Furnishing Equipment Weight Fraction	0.0145
Flight Control Weight Fraction	0.0097
Hydraulic System Weight Fraction	0.0243
Electrical Equipment Weight Fraction	0.0299
Radar Weight Fraction	0.0044
Navigation Equipment Weight Fraction	0.0066
Radio Communication Equipment Weight Fraction	0.0033
Instrument Equipment Weight Fraction	0.0078
Fuel System Weight Fraction	

Additional Equipment:

Equipment for Container Loading	0.0000
No typical Equipment Weight Fraction	0.0033

TAKE-OFFDISTANCE PARAMETERS

Airplane Lift-off Speed	201.16
Acceleration during Take-offRun	2.56
Airplane Take-offRun Distance	608
Airborne Take-offDistance	409
Take-offDistance	1017

CONTINUED TAKE-OFFDISTANCE PARAMETERS

Decision Speed	**191.11**
Mean Acceleration for Continued Take-offon Wet Runway	0.45
Take-offRun Distance for Continued Take-offon Wet Runway	892.95
Continued Take-offDistance	1282.74
Runway Length Required for Rejected Take-off	1331.89

LANDING DISTANCE PARAMETERS

Airplane Maximum Landing Weight	**29241**
Time for Descent from Flight Level till Aerodrome Traffic Circuit Flight	14.8
Descent Distance	22.43

Approach Speed	204.14
Mean Vertical Speed	1.72
Airborne Landing Distance	380
Landing Speed	192.62
Landing run distance	555
Landing Distance	936
Runway Length Required for Regular Aerodrome	1562
Runway Length Required for Alternate Aerodrome	1329