МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
Кафедра конструкції літальних апаратів

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
д.т.н., проф.
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«_____» ___________ 2022 рік

ДИПЛОМНА РОБОТА
ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ "БАКАЛАВР"
ЗІ СПЕЦІАЛЬНОСТІ
«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Аванпроект середньомагістрального літака пасажиромісткістю 134 осіб»

Виконав: ___________ **Лю ЦЗЯНЬВЕЙ**

Керівник: канд.техн.наук, доцент ___________ **Тетяна МАСЛАК**

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Київ 2022

MINISRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
Department of Aircraft Design

PERMISSION TO DEFEND
Head of the department
Dr.Sc., Professor
_________ Sergiy IGNATOVYCH
«___» _______ 2022

BACHALOR DEGREE THESIS
ON SPECIALTY
"AVIATION AND AEROSPACE TECHNOLOGIES "

Topic: «Preliminary design of a mid-range aircraft with 134 passenger capacity»

Prepared by: __________ **Liu JIANWEI**

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

Standard controller: PhD, associate professor __________ **Sergiy KHIZNYAK**

Kyiv 2022

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty

Department of Aircraft Design

Academic Degree «Bachelor»

Specialty: 134 "Aviation and Aerospace Technologies"

APPROVED BY
Head of the Department
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«___» _______ 2022

TASK
for the bachelor degree thesis

LIU JIANWEI

1. Topic: «Preliminary design of a mid-range aircraft with 134 passenger capacity» confirmed by Rector's order № 489/ст from 10.05.2022.

2. Thesis term: from 23.05.2022 to 19.06.2022.

3. Initial data: cruise speed V_{cr}=830 kmph, flight range L=5200 km, operating altitude H_{op}=9.8 km, 134 passengers.

4. Content (list of topics to be developed): choice and substantiations of the airplane scheme, choice of initial data; engine selection, aircraft layout, center of gravity position calculation, designing of automatic lifting aircraft luggage rack.

5. Required material: general view of the airplane (A1×1); layout of the airplane (A2×1); 3D model of automatic lifting aircraft luggage rack and drawing of it (A1×1).

Graphical materials are performed in AutoCAD, SOLIDWORKS.

6. Thesis schedule:

Task	Time limits	Done
Task receiving, processing of statistical data	23.05.2022–28.05.2022	
Aircraft geometry calculation	28.05.2022–31.05.2022	
Aircraft layout	31.05.2022–03.06.2022	
Aircraft centering	03.06.2022–05.06.2022	
Graphical design of the parts	05.06.2022–12.06.2022	
Completion of the explanation note	12.06.2022–14.06.2022	
Defense of diploma work	14.06.2022–19.06.2022	

7. Date: 23.05.2022

Supervisor ___________ Tetiana MASLAK

Student ___________ Liu JIANWEI

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
«_____» _____________ 2022 р.

ЗАВДАННЯ
на виконання дипломної роботи студента

ЛЮ ЦЗЯНЬВЕЙ

1. Тема роботи: «Аванпроект середньомагістрального літака пасажиромісткістю 134 осіб», затверджена наказом ректора № 489/ст від 10 травня 2022 року.

2. Термін виконання роботи: з 23 травня 2022 р. по 19 червня 2022 р.

3. Вихідні дані до роботи: максимальна кількість пасажирів 134, дальність польоту з максимальним комерційним навантаженням 5200 км, крейсерська швидкість польоту 830 км/год, висота польоту 9,8 км.

4. Зміст пояснювальної записки: вибір параметрів та обгрунтування схеми проектованого літака, вибір двигунів, розрахунок геометрії та центрування літака, проектування механізму автоматичного відкривання полки для ручної поклажі.

5. Перелік обов’язкового графічного матеріалу: загальний вигляд літака (A1×1), компонувальне креслення фюзеляжу (A2×1), 3D модель автоматичної підйомної багажної стійки літака, та її креслення (A1×1).

6. Календарний план-графік:

Завдання	Термін виконання	Відмітка про виконання
Вибір вихідних даних, аналіз льотно-технічних характеристик літаків-прототипів	23.05.2022–28.05.2022	
Вибір та розрахунок параметрів проєктованого літака	28.05.2022–31.05.2022	
Виконання компонування літака	31.05.2022–03.06.2022	
Розрахунок центрування літака	03.06.2022–05.06.2022	
Виконання креслень літака	05.06.2022–12.06.2022	
Оформлення пояснювальної записки та графічної частини роботи	12.06.2022–14.06.2022	
Захист дипломної роботи	14.06.2022–19.06.2022	

7. Дата видачі завдання: 23.05.2022 рік

Керівник дипломної роботи __________ Тетяна МАСЛАК

Завдання прийняв до виконання __________ Лю ЦЗЯНЬВЕЙ

РЕФЕРАТ

Дипломна робота «Аванпроект середньомагістрального літака пасажиромісткістю 134 осіб» містить:

70 сторінок, 34 рисунків, 12 таблиць, 12 літературних посилань

Об’єктом проектування є середньомагістральний пасажирський літак для перевезення 134 осіб. Предмет проектування - це механізм підйому ручної поклажі.

Метою роботи є аванпроект середньомагістрального пасажирського літака та визначення його основних льотно-технічних характеристик.

В роботі застосовано метод порівняльного аналізу літаків-прототипів для вибору найбільш обґрунтованих технічних рішень, а також методи інженерних розрахунків для отримання основних параметрів проектованого літака. В спеціальній частині необхідно розробити концепцію механізму підйому ручної поклажі з завантаженням в полку для багажу.

Актуальність роботи полягає у підвищенні ефективності та комфорту пасажирів - автоматична підйомна полка для ручної поклажі дозволяє мінімізувати сили та час на посадку пасажирів, зменшити пошкодження від того, що пасажири не завжди знають як ними користуватись, а отже, і полегшити роботу стюартам.

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

АВАНПРОЕКТ ЛІТАКА, КОМПОНУВАННЯ ПАСАЖИРСЬКОЇ КАБІНИ, ЦЕНТРУВАННЯ ЛІТАКА, РУЧНА ПОКЛАЖА

ABSTRACT

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

70 sheets, 34 figures, 12 tables, 12 references

Object of study is a mid-range aircraft with a capacity of 134 passengers. Subject of study is the conceptual design of automatic lift luggage rack. The aim of bachelor thesis – is a preliminary design of an aircraft, choice the best flight performances of the designing aircraft.

Research and development methods which are used in the thesis are: the design methodology is based on the analysis of prototypes, the most advanced technical decisions and engineering calculations to get the technical data of designed aircraft. In special part, it is about the concept design of automatic lift aircraft luggage rack.

Novelty of the results – automatic lifting aircraft luggage rack can improve the boarding efficiency of passengers and to provide ensuring of flight safety by minimizing the time for boarding, by reducing the loads on hinges of luggage rack of storage bins, to delete failures from not correct operation of storage bins.

The results of the work could be used in the aviation industry and in the educational process of aviation specialties.

AIRCRAFT PRELIMININARY DESIGN, PASSENGER CABIN LAYOUT, CENTER OF GRAVITY POSITION, LUGGAGE RACK

Format	№	Designation	Name	Quantity	Notes
			General documents		
A4	1	NAU 22 13L 00 00 00 02 TW	Task for work	1	
	2	NAU 22 13L 00 00 00 02	Mid-range passenger aircraft	2	
A1		Sheet 1	General view		
A2		Sheet 2	Fuselage layout		
A4	3	NAU 22 13L 00 00 00 02 EN	Mid-range passenger aircraft	49	
			Explanatory note		
A1	4	NAU 22 13L 00 00 00 02 AD	Drawing of automatic lifting aircraft luggage rack	1	

NAU 22 13L 00 00 00 02 EN

Done by	Liu Jianwei	Preliminary design of a mid-range passenger aircraft with 138 passenger capacity (List of diploma work)	list	sheet	sheets
Checked by	Maslak T.P			12	70
			402 AF 134		
St.control.	Khyzhniak S.V.				
Head of dep.	Ignatovych S.R.				

INTRODUCTION

Civil aviation has been hit hard by the COVID-19 pandemic, with aircraft deliveries falling sharply throughout the year. During this period of the COVID-19 pandemic, the airline industry experienced a significant decline in passenger traffic compared to the previous period, but the overall airline market was still worth $169.72 billion.

The aviation market is expected to grow at least 4% a year for the next five years [1]. This is certain to lead to a large number of airlines in the next few years for short - and medium-range narrow-body aircraft demand will increase significantly. The number of passengers in China has dropped significantly due to the COVID-19 pandemic, the volume of cargo carrying medical supplies such as masks and protective suits has increased, further boosting the demand for short - and medium-range cargo planes, which can be obtained by refits of short - and narrow-body passenger planes.

With the development of all countries in the world and the impact of economic globalization, people's living standards continue to rise, and more and more people will choose more efficient means of travel for short trips or business trips. Moreover, compared with train and ship travel, air travel has the absolute advantage of being more convenient, fast and efficient in long-distance travel.

The main transport objects of civil aircraft are passengers and luggage. Different from cargo planes, passenger planes pay more attention to passengers' experience and the safety of the plane. It has the following characteristics: narrow body design; low wing design; it has high flexibility and security; smoother and quieter during takeoff and landing.

Considering that the designed in bachelor thesis aircraft carries a total of 134 passengers and has a flight range of 5200 kilometers, it can meet the needs of domestic and even transnational medium and short distance travel.

After analyzing most of the existing aircraft in the aviation market, I chose the Boeing 737-700 as the prototype, because it is not only widely recognized in the civil aviation field, but also the Boeing 737-700 after its conversion into a freighter is still very popular.

My design goal was to Preliminary design a short-range narrow-body airliner with a capacity of 134 passengers. Its main task is to carry out short and medium range transport, when necessary to carry out the ability to carry out cross-border transport. It can also be converted into a cargo plane to transport supplies during the COVID-19 pandemic.

The key idea of the diploma work is the design of an airliner equipped with advanced science and technology and equipment and the appropriate improvement of the luggage rack system in the cabin under the environment of economic globalization through the analysis of existing models. The main issues discussed in the diploma work includes:

1. Analyze the design method of the prototype, select the appropriate aircraft parameters, and design the main structure and aerodynamic shape;
2. Design the size of the cabin inside the fuselage, and the layout of the cabin, seats and other equipment;
3. Estimate the center of gravity of the aircraft fuselage, wing and the overall center of gravity of the aircraft;
4. Calculate the main parameters of the luggage rack and design the main structure;
5. Select and test materials used to make luggage racks.

CONTENT

Department of Aircraft Design				NAU 22 13L 00 00 00 02 EN		
Performed by	Liu Jianwei			Content	Letter	Sheet	Sheets
Supervisor	Maslak T.P.						
					402 AF 134		
Stand.contr.	Khizhnyak S.V.						
Head of dep.	Ignatovych S.R.						

1. PRELIMINARY DESIGN OF A MID-RANGE AIRCRAFT

1.1 Analysis of prototypes

The design of modern aircraft mainly pursues absolute safety, complete functions, comfortable flying experience and high economic benefits. This is a very complex process, mainly including the following steps [2]:

Conceptual design → preliminary design → scheme review→ detailed design → design review → pilot production testing machine → design finalization →obtaining airworthiness license → test flight → mass production.

The main task of this thesis is to complete the preliminary design of an aircraft, which is the first stage of the aircraft design process. The purpose of this stage is to make a preliminary design of the aircraft's purpose, aerodynamic shape, main components and internal layout. Then, the aerodynamic shape is tested by experiments and modified according to the experimental data to obtain a more perfect shape design.

The selection of aircraft parameters is particularly important in the aircraft design process, because the various parameters of the aircraft will affect each other. For example, the larger the take-off weight of the aircraft, the larger the wing area is required. Therefore, for purpose to complete the concept and preliminary design of the aircraft successfully, it is necessary to select appropriate parameters at the initial stage.

The first step in this thesis is to select suitable prototypes, collect their data, and then use a computer program to obtain initial data for the aircraft to be designed. My purpose is to design a mid-range aircraft, so I chose to use Boeing 737-300, Boeing 737-700 and Airbus A320 as prototypes, all of which are mid-range aircraft. Through a computer program, the initial data I obtained was a mid-range aircraft with a capacity of 134 passengers and a range of 5,200 kilometers.

Prototype Boeing 737-700 is a mid-range narrow-body jet. In order to be able to compete with the Airbus 320 with the new generation of avionics and aerodynamics at the same time, Boeing upgraded the Boeing 737-300 based on the original aerodynamic characteristics, updated the latest avionics and interior, and named the Boeing 737-700. Today, Boeing's 737 and Airbus's A320 families are the world's two best-selling models. The specific data of the prototype is shown in Table 1.1.

Table 1.1 – Operational-technical data of prototypes [3]

Parameter	Planes		
	A320	B737-300	B737-700
The purpose of airplane	Passenger	Passenger	Passenger
Crew/flight attend. persons	2/4	2/2	2/2
Maximum take-off weight, kg	68000	62822	77565
Most payload, kg	19500	14250	14850
Passenger's seat	117	145	148
The height of the flight, m	12000	11278	12500
Range max, km	3300	4176	5200
Take off distance, m	2090	1940	1909
Number and type of engines	2x IAE V2500-A5	2x CFM56-3B	2x CFM26-3B-1
The form of the cross-section fuselage	Circular	Circular	Circular
Fineness ratio of the fuselage	7.42	8.02	8
Fineness ratio of the nose and tail part	7.68	9.12	9.43
Sweepback on 1/4 chord, °	25	25	27

The main reason I chose them as prototypes is because these three prototypes are the three best-selling mid-range aircrafts in the world. The reason why they can be popular must have their unique advantages. In addition, this also reflects the needs of airlines. Comparing the data in Table 1.1, it can be found that they all have unique advantages, and I chose the Boeing 737-700 as the main prototype because it not only has a large take-off weight and a long range, but also has a large passenger capacity and a short take-off distance. At the same time, even though it was converted from a passenger aircraft to a cargo aircraft, it is still loved by airlines.

In summary, the passenger aircraft to be designed in this thesis is a mid-range passenger aircraft, and the main characteristics obtained through the computer program are as follows:

1) The fuselage has a circular cross section and a low-wing design;
2) A total of two engines are symmetrically distributed under both wings;
3) Capacity for 134 people;
4) The maximum payload is 14850 kg and the maximum takeoff weight is 76983 kg;
5) The cruising speed is 830 km/h and the range is 5,200 km;
6) Narrow body aircraft fuselage width is 4 meters, the fuselage 32 meters long;

The aircraft designed in this thesis adopts a low-wing design, mainly because the low-wing design has high flexibility and low maintenance cost, and a swept angle of 27 degrees can obtain better aerodynamic performance. The horizontal stabilizer has a sweep angle of 32 degrees with elevators, and the vertical stabilizer has a sweep angle of 35 degrees with a rudder.

1.2 The brief description of the aircraft

The aircraft is a single-aisle narrow-body aircraft. There are a total of two engines located under the wings. It also has a nose landing gear at the front of the fuselage, and two main landing gears on either side of the mid-fuselage.

The fuselage will be made of composite materials that are lighter in mass than aluminum alloys, and it also meets airworthiness standards.

A large number of longitudinal beams are distributed along the longitudinal direction of the fuselage, and their function is to evenly distribute the local loads received on the aircraft skin on the fuselage. In the lateral direction of the fuselage, there are many frames used to support the aerodynamic shape of the aircraft. These two structures are mainly connected to the skin by rivets to form the fuselage.

There are two seats in the cockpit, the pilot seat and the co-pilot seat. The front and sides of the seats are equipped with instruments that display flight parameters and various knobs that control the flight of the aircraft. An emergency hatch is installed on the roof of the cockpit for emergency escape if the cockpit door cannot be opened.

Windows are installed on the left and right sides of the fuselage. In the middle of the fuselage, above the wings, there are two emergency exits that serve as escape routes in the event of an emergency. Emergency exit doors are marked with instructions in many different languages. Luggage racks are symmetrically distributed on both sides of the top of the cabin for the storage of passengers' personal luggage. The bottom of the luggage rack is equipped with a passenger operation panel, including lights corresponding to different seats, a button to call a flight attendant, and an air conditioner outlet. Inside the operation panel are oxygen masks for emergency use. Life jackets for emergency use are fitted under each passenger's seat and safety manuals are placed in front of the seat. The front of the cabin and the cockpit, the business class and economy class connection, economy class tail are equipped with a kitchen and toilet. Two crew members are assigned to the front and rear exits of the cabin, and there are crew seats.

There are two luggage compartment doors on the left side of the bottom of the fuselage, one at the front of the fuselage and one at the rear of the fuselage. At the same time, the nose and main landing gear are also mounted on the bottom of the fuselage.

The main stress structures on the fuselage include: frame, truss, wing spar and fuselage skin.

The wings are connected to the fuselage by a central wing box. The structure of the wing includes ribs, stringer, spars and skin. The wing ribs are mainly arranged longitudinally, while the truss and wing spar are arranged laterally. Their shape supports the skin of the wing and forms the aerodynamic shape of the wing. The engines of an aircraft are located on the wings under the wings near the passenger cabin. Spoilers, flaps and ailerons are mounted on the trailing edge of the wing, and leading-edge slats are mounted on the leading edge.

The wings (Fig. 1.1) are fitted with warning lights at the wingtips to ensure the safety of the aircraft in the air.

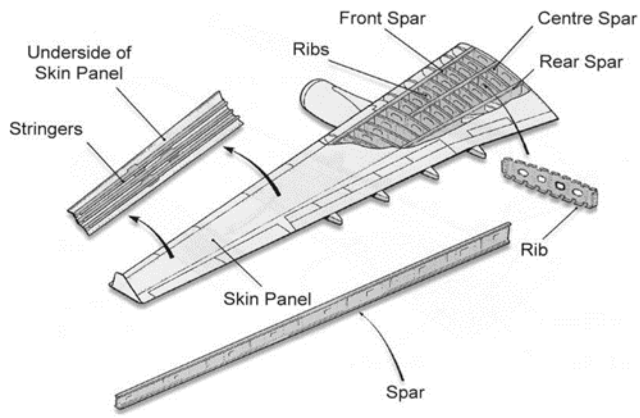

Fig. 1.1 – Wing structure

Because the low-wing design is adopted, the distance between the wing and the ground is reduced, and the lift coefficient C_Y is increased, thus greatly improving the takeoff and landing performance of the aircraft.

The aircraft is a mid-range passenger aircraft, so the take-off and landing weight of the aircraft is not large. Therefore, the landing gear solution I chose was: one nose landing gear, equipped with two tires. A main landing gear, including two main bodies, a total of 4 tires. In addition, the kind of tire is a low-pressure tire. The purpose of choosing this tire is to enhance the passenger's flying experience. Because when landing, the pressure in the low-pressure tires will rise, which achieves the purpose of absorbing vibration, thereby reducing the vibration experienced by passengers.

The swept wing design can increase the critical Mach number of the aircraft at high speed and reduce shock wave drag. But things have two sides, and the swept wing design also has the following problems:

- Turbulence is easy to occur at the wing tip;
- The decrease of lift coefficient leads to the decrease of efficiency;
- Swept-back wings have poor torsional stiffness, so they need to be reinforced, which means they have more mass.

- The components inside the aircraft vary in length longitudinally, so that less force is applied to the leading edge of the component and more force is applied to the trailing edge as the aircraft flies. Thus, when flying, the load of the wing is concentrated towards the trailing edge of the wing, resulting in the "swept-back effect".

The tail fin is also swept-back and attached to the rear of the fuselage (Fig. 1.2).

Fig. 1.2 – Tail unit of aircraft

The vertical stabilizer is mounted on the rear of the fuselage, and it also has a rudder. Its task is to control the heading, flight stability and maneuverability of the flight.

The horizontal stabilizer is symmetrically mounted on the rear of the fuselage, and each is equipped with an elevator. Its task is to control the longitudinal balance and stability of the aircraft. In order to better control the center of gravity of the aircraft, I chose an adjustable horizontal stabilizer.

The cockpit (Fig. 1.3) of the aircraft is located at the front of the fuselage. It mainly includes various instruments and operating equipment required for the flight of the aircraft. And in order to ensure that the driver is not disturbed, a high-strength password door is also installed between the cockpit and the passenger cabin, and the password is only known to the crew.

Fig. 1.3 – Cockpit of aircraft

In order to reduce air resistance and ensure the pilot has a good flight field of view, the windshield of the cockpit adopts a tapered design. In an emergency, the pilot can also open the front windshield to escape from the inside of the cockpit. At the same time, the front windshield can be heated in order to prevent ice formation during high-altitude flight.

An escape hatch at the top of the cockpit opens with a high-strength rope that allows the pilot to safely glide from the top of the cockpit to the ground along the surface of the fuselage.

In order to ensure a good flying experience, both the passenger seat and the pilot seat are adjustable. The cabin is mainly divided into business class and economy class, and business class is located between the cockpit and economy class. There are 3 bathrooms and 3 kitchens in the cabin. They are located between the cockpit and business class, between business and economy class, and aft of economy class. Because of the large number of people in the economy class, the kitchen area at the rear of the economy class is 3 square meters, and the rest of the kitchen and toilet area are 1.5 square meters.

The bathroom includes a sink and toilet. The kitchen includes storage cabinets, heating facilities, trash cans and a sewage system.

Necessary emergency equipment is also installed inside the cabin, including ropes, oxygen masks, fire extinguishers, medical kits, radio communication equipment, life jackets and life rafts, etc.

Aircraft control equipment includes: stabilizer, elevator, rudder, ailerons, flaps, spoilers, and slats.

The control system of the aircraft includes the onboard automatic control system, which is used to automatically fly along the flight path during the cruise phase. The automatic control system has the following advantages: reduce the workload of the pilot, and can assist the pilot to control the flight state of the aircraft in bad weather or environment.

The landing gear (Fig. 1.4) of the aircraft is mainly used to ensure the stability of the aircraft during take-off, landing and ground taxiing.

Fig. 1.4 – Landing gear of aircraft

During the flight phase, the nose landing gear of the aircraft is folded forward and retracted into the landing gear bay, and the main landing gear of the aircraft is folded inward and retracted into the central wing box.

The nose landing gear is mounted at the front of the center of gravity of the aircraft, and two low-pressure tires are attached to a high-strength bracket.

The main landing gear is located at the rear of the plane's center of gravity, and when it is deployed, it is at an angle to the horizontal plane, which helps to reduce the force of landing. Each main landing gear is equipped with two low pressure tires.

The main body of the landing gear is made of high-strength alloy. And the force on the landing gear at each stage will be evenly distributed in the entire landing gear structure through the conducting structure.

Both the nose and main landing gear are controlled by hydraulic systems inside the aircraft.

1.3 Geometric calculations of major aircraft components

The geometric calculation of the aircraft should include the calculation of the main structural parts of the aircraft, the loads on the main parts of the aircraft (such as landing gear, etc.), and the calculation of the overall center of gravity of the aircraft. Also, I need to finish designing the interior layout of the aircraft.

The parameters and layout of aircraft components should be designed in accordance with airworthiness regulations.

Through the analysis of the parameters of the prototype, the initial data I obtained through the computer program are in Appendix A, and I will complete the geometric calculation of the aircraft and the calculation of the center of gravity based on these initial data.

1.3.1 Wing geometry calculation

The geometry of the wing [4] is determined by its weight m_0 and the specific wing load P_0.

According to the initial data, P_0 (at take off) = 5.992 kPa

Full wing area with extensions is:

$$S_{wfull} = \frac{m_0 \cdot g}{P_0} = \frac{76983 \cdot 9.8}{5.992 \cdot 1000} = 125.91\ [m^2];$$

Relative wing extensions area is 0.06.

So, the wing area is:

$$S_w = S_{wfull} \cdot (1 - 0.06) = 125.91 \cdot 0.9 = 118.36\ [m^2];$$

Wing span is:

$$l = \sqrt{S_w \cdot \lambda_w} = \sqrt{125.91 \cdot 9.8} = 35.13 \text{ [m]};$$

Root chord and tip chord is:

$$\frac{S_w}{2} = \frac{C_{root}C_{tip}}{2} \cdot \frac{Span}{2} \rightarrow \frac{125.91}{2} = \frac{C_{root}C_{tip}}{2} \cdot \frac{35.13}{2};$$

$$TR = \frac{C_{root}}{C_{tip}} \rightarrow 3 = \frac{C_{root}}{C_{tip}};$$

$$C_{root} = 5.38 \text{ [m]};$$

$$C_{tip} = 1.79 \text{ [m]}.$$

Where TR – taper ratio, which equal to 3 according to the initial data.

When choosing the wing structure, we need to determine the position of each component of the wing (including: spar, stringer, rib).

According to the geometric determination of the mean aerodynamic chord length, we can plot the location of the mean aerodynamic chord length, as shown in Fig. 1.5.

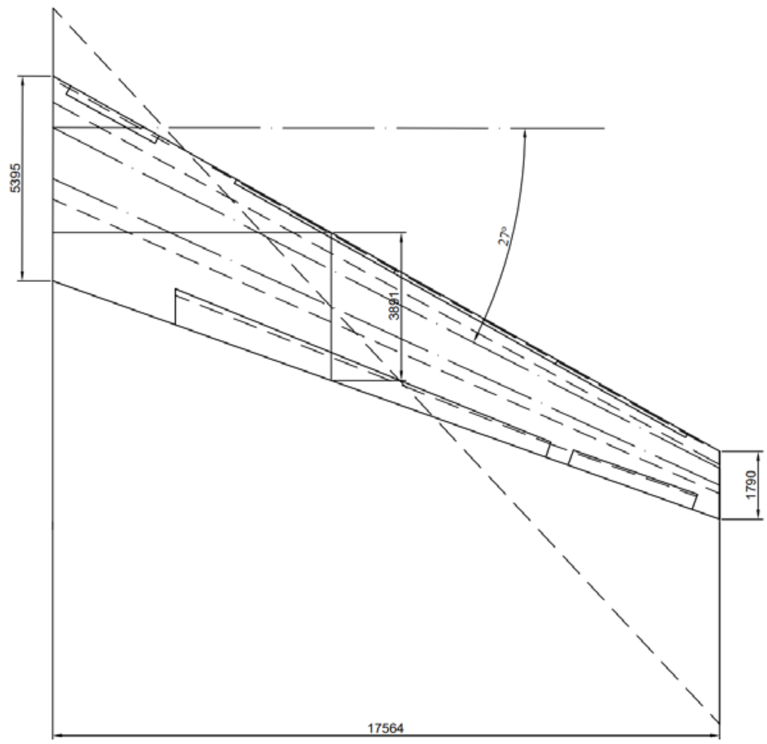

Fig. 1.5 – Determination of mean aerodynamic chord

After the initial determination of wing geometry, start to calculate aileron and high lift device geometry.

The calculation results of aileron's geometric parameters are as follows:

Ailerons span:

$$l_{ai} = 0.35 \cdot \frac{\lambda_{w}}{2} = \frac{35.13}{2} \cdot 0.35 = 6.15 \text{ [m]};$$

Aileron area:

$$S_{ail} = 0.07 \cdot \frac{S_w}{2} = 0.07 \cdot \frac{125.91}{2} = 4.4 \text{ [m}^2\text{]};$$

The values of l_{ai} and S_{ai} should not be too large. Because when l_{ai} reaches a certain value, the growth rate of the aileron coefficient will decrease, and the span of high lift device will also decrease.

Aerodynamic balance of the ailerons.

$$S_{axinail} \leq (0.25 \dots 0.28) S_{ail} = 0.26 \cdot 4.4 = 1.144 \text{ [m}^2\text{]};$$

The area of aileron’s trim tabs.

$$S_{tail} = (0.05 \dots 0.06) \cdot S_{ail} = 0.05 \cdot 4.4 = 0.22 \text{ [m}^2\text{]};$$

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

In the previous calculation, we selected the appropriate lift device and airfoil, and determined their parameters, in order to be able to obtain the lift coefficient of the aircraft during take-off and landing.

Before proceeding to the next calculation, according to the selected airfoil, determine the value of the lift coefficient C_{ymaxbw}, and the increment required by lift device coefficient ΔC_{ymax} should be calculated and determined by formula:

$$\Delta C_{ymax} = (\frac{C_{ymax}}{C_{ymaxbw}})$$

In the formula, C_{ymax} is the relatively safe lift coefficient required by the aircraft in landing mode (the value of C_{ymax} is determined by the parameters of the aircraft).

In this aircraft, the relative chord ratio of the wing high lift device is:

b_f = 0.28...0.3 – one slotted and two slotted flaps;

b_s = 0.1...0.15 – slats.

The efficiency of the high lift device is proportional to the span of the wing. The area of the spoiler will affect the span of high lift device. Therefore, in order to obtain the maximum span of high lift device, it is necessary to select an appropriate spoiler area.

As for the selection of structural dynamics scheme and hinge assembly scheme of the high lift device, through the analysis of the experience of the existing aircraft manufacturing industry and the majority of the existing high lift device structure, most of the high lift device adopts the longitudinal beam structure power scheme.

Through the calculation of the wing geometry, we can get a preliminary design of the wing, and it is shown in Fig. 1.6.

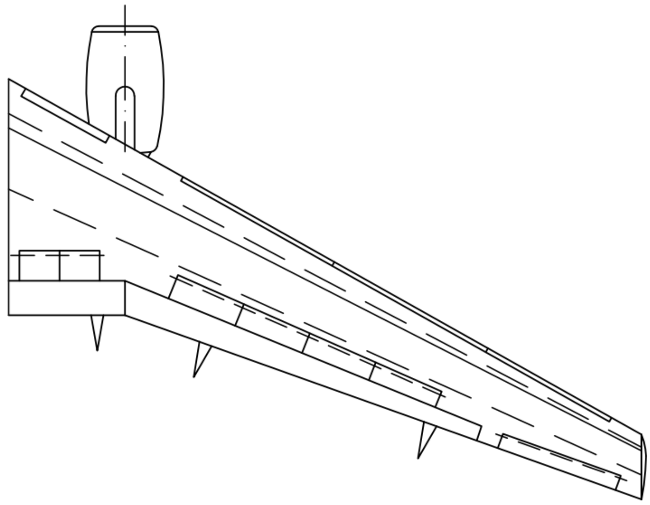

Fig. 1.6 – Preliminary design of the wing

1.3.2 Fuselage layout

During the flight phase, the cross-section of the fuselage also creates a certain drag. Therefore, the aerodynamic properties of the fuselage cross-section should be considered during the aircraft design process.

Drag is one of the important factors affecting the flight performance of an aircraft. The amount of drag increases as the speed of the aircraft increases. Although the impact of wave drag can be ignored for subsonic aircraft (V< 850 km/h), but also need to select appropriate drag coefficient C_{xf} and profile drag C_{xp} according to the characteristics of the aircraft.

In transonic or subsonic flight, the shape of the aircraft's cabin will affect the shock wave drag during flight [5]. Therefore, the shape of the aircraft cabin nose is particularly important to the performance of the aircraft, and the circular design can significantly reduce the impact of shock wave drag on flight.

In order to achieve the optimal flight performance of the aircraft, the fuselage cross section is the existing most models of the round. And in this case, reduce the aircraft skin area, effectively reduce the weight of the aircraft.

Parameters required for this part of the calculation:

1) Fuselage diameter D_f;
2) Fuselage length l_f;

3) Fineness Ratio of the fuselage λ_f;

4) Fuselage nose part aspect ratio λ_{np};

5) Aspect ratio of tail unit λ_{TU}.

The length of the fuselage is affected by various aircraft parameters, such as the Angle of attack required for landing.

Fuselage length is equal:

$$l_f = FR \cdot D_f = 4 \cdot 8 = 32\ [m];$$

Where: D_f – Diameter of fuselage

FR - Fineness Ratio of the fuselage

Length of the fuselage nose part is equal:

$$l_{fwd} = 32 \cdot \frac{2.4}{19} = 4.04\ [m];$$

Length of the fuselage rear part is equal:

$$l_{aft} = 32 \cdot \frac{3.2}{19} = 5.39\ [m];$$

In order to reasonably design the layout of the cabin, it is necessary to find the cross-section with the smallest area in the middle of the fuselage (excluding the head and tail of the fuselage).

The length of the fuselage is mainly determined by the parameters of the passenger aircraft and the layout of the cabin inside. For an airliner, the size of the middle part of the fuselage is mainly the size of the cabin, and the height of the cabin is one of its main parameters.

Passenger aircraft with different voyages have different cabin design requirements. For mid-range aircraft, the height of fuselage: h_1=1.75m; passage width b_p=0.45...0.5m; the distance from the window to the flour h_2=1m; luggage altitude h_3=0.6...0.9m.

Cabin height is equal:

$$H_{cabin} = 1480 + 0.17 \cdot 4 = 2160\ [mm];$$

The use of a fuselage with a circular cross-section can effectively reduce air drag during flight. Although this design is not suitable for cargo loading, its advantages far outweigh the disadvantages compared to the benefits of reducing air drag.

The bulkhead is used to maintain the pressure balance in the cabin, which is about 360mm to 500 mm thick and are mainly distributed in the nose of the fuselage and the rear of the fuselage.

The windows on both sides of the cabin have an oval design, the main reason for this design is when the aircraft is flying at high altitudes, the cabin pressure is greater than the external pressure to make the skin expand, part of the action will act on the window structure, the oval design is convenient for the smooth transmission of pressure in the structure, will not be damaged because of local pressure is too large, avoid the aircraft in flight disintegration.

The seating layout in the cabin is 3+3 for economy class and 2+2 for business class. The width of the cabin is calculated as follows:

$$B_{cabin} = n_{bl}\beta_{seat} + n_{aisle}\beta_{asile} + 2\delta_{wall} + 2\delta;$$

$$B_{cabin.eco} = 2 \cdot 1550 + 500 + 2 \cdot 100 + 2 \cdot 100 = 4\ [m];$$

$$B_{cabin.first} = 2 \cdot 1400 + 800 + 2 \cdot 100 + 2 \cdot 100 = 4\ [m];$$

Where: n_{bl} - seat number of block of seats;

β_{seat} - Single row seat width;

n_{aisle} – number of aisles;

β_{asile} - Aisle width;

δ_{wall} - The thickness of the wall;

δ – Distance between wall and seat.

The length of passenger cabin is equal:

$$L_{cabin} = L_1 + (n-1) \cdot L_{seatpitch} + L_2;$$

$$L_{cabin.first} = 1200 + (3-1) \cdot 1080 + 250 = 3.61\ [m];$$

$$L_{cabin.eco} = 1200 + (21-1) \cdot 870 + 250 = 18.85\ [m];$$

$$L_{cabin} = 3.61 + 18.85 = 22.46\ [m];$$

So, the cabin layout is shown in Fig. 1.7.

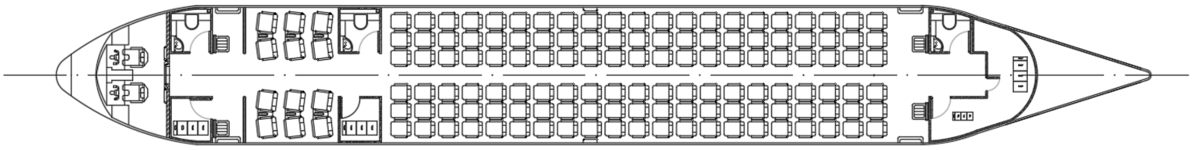

Fig. 1.7 – Fuselage layout of aircraft

1.3.3 Luggage compartment

The unit load on the ground inside the fuselage is: K = 400… 600 kg/m^2, the weight of checked baggage stipulated by most airlines is 20kg, so take M_{bag}=20 kg; Weight of luggage and mail $M_{cargo\,\&mail}$=15kg, the volume of luggage carried by each passenger is 0.2m^3.

The area of cargo compartment is equal:

$$S_{cargo} = \frac{M_{bag}}{0.4K} + \frac{M_{cargo\,\&\,mail}}{0.6K} = \frac{20 \cdot 134}{0.4 \cdot 600} + \frac{15 \cdot 134}{0.6 \cdot 600} = 17.25\ [m^2];$$

The volume of cargo compartment is equal:

$$V_{cargo} = V \cdot n_{pass} = 0.2 \cdot 134 = 27.6\ [m^3];$$

1.3.4 Galleys and buffets

According to the airworthiness regulations, there must be multiple kitchens on the aircraft for storing food, and the cabinets in the galleys must be placed at the door of the galley. In addition, if the flight time exceeds 3 hours, the passengers must be provided with adequate amounts of water and food. Based on the cruise speed of 830 km/h and the range of 5200 km, the rough calculation of the journey time is 6,3 h. The total volume of food, packaging and cupboard storage required by each passenger for a single trip is 0.11 m^3.

Volume of buffets(galleys) is equal:

$$V_{galley} = 0.11 \cdot 138 = 14.74\ [m^3];$$

Area of buffets(galleys) is equal:

$$S_{galley} = \frac{V_{galley}}{H_{cabin}} = \frac{14.74}{2.16} = 6.82\ [m^2];$$

According to the rules, passengers should be provided with food and tea after 3.5 to 4 hours of flight. Therefore, the weight of breakfast, lunch and dinner served to passengers is 0.8kg/ meal; tea and other drinks 0.4kg/ meal.

1.3.5 Lavatories

The number of lavatories should be selected according to the number of passengers and the flight range of the aircraft. Because the designed aircraft is a mid-range passenger aircraft, the passenger capacity is 134 people. According to airworthiness regulations, there should be at least one toilet for every 40 passengers in the cabin design.

Considering that there are two types of cabins: business class and economy class. And the number of passengers is 134, set up a total of 3 toilets respectively located in the cockpit and the junction of the cabin, business class and economy class intersection and the tail of the cabin.

$$n_{lav} = 3;$$

Area of lavatory:

$$S_{lav} = 0.035 \cdot 134 = 4.69\ [m^2];$$

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

1.3.6 Design and calculation of main characteristics of the tail unit

Tail design is an extremely important part of aircraft design. Because it is related to the position of the center of gravity of the aircraft at different stages. In order to ensure the longitudinal stability of the aircraft under no load, full load or even mild overload, the center of gravity of the aircraft as a whole should be located in front of the focus of the aircraft. The position of these points and the distance between them directly determine the longitudinal stability of the aircraft.

$$m_x^{Cy} = \bar{x}_T - \bar{x}_F < 0;$$

Where: m_x^{Cy} - moment coefficient;

$\bar{x}_T, \bar{x}_F$ - coordinates of the center of gravity and the focus;

If m_x^{Cy}=0, it indicates that the aircraft has neutral longitudinal stability; if it is greater than 0, which means the aircraft is in statically indeterminate state [6].

Calculation of geometric parameters of tail element:

Area of vertical tail unit is equal:

$$S_{VTU} = (0.12 \ldots 0.2)S_{wing} = 0.15 \cdot 125.91 = 18.89\ [m^2];$$

Area of horizontal tail unit is equal:

$$S_{HTU} = (0.18 \ldots 0.25)S_{wing} = 0.2 \cdot 125.91 = 25.18\ [m^2];$$

Chose the length of the tail unit.

$$A_{HTU} = 0.65 \dots 0.8, A_{VTU} = 0.08 \dots 0.12;$$

Length of horizontal tail unit is equal:

$$L_{HTU} = \frac{A_{HTU} \cdot S_{wing} \cdot b_{MAC}}{S_{HTU}} = \frac{0.7 \cdot 125.91 \cdot 3.89}{25.18} = 13.62 \text{ [m]};$$

Length of vertical tail unit is equal:

$$L_{VTU} = \frac{A_{VTU} \cdot S_{wing} \cdot b_{MAC}}{S_{VTU}} = \frac{0.08 \cdot 125.91 \cdot 35.13}{18.89} = 18.73 \text{ [m]};$$

This calculation is rough and deliberate, because the values of horizontal and vertical tail lengths L_{htu} and L_{vtu} are influenced by many factors during the design process, such as the length of the nose units, the length of the tail units, the swept-back wing, wing position, the stability of the aircraft, and the operation of the aircraft.

Determine the area and direction of the elevator:

Elevator area:

$$S_{el} = 0.2765 \cdot S_{HTU} = 6.962 \text{ [m}^2\text{]};$$

Rudder area:

$$S_{rud} = 0.2337 \cdot S_{VTU} = 4.415 \text{ [m}^2\text{]};$$

Choose the area of aerodynamic balance:

$$0.3 \le M \le 0.6, S_{eb} = (0.22 \dots 0.25) S_{el}, S_{rb} = (0.2 \dots 0.22) S_{rd}$$

Elevator balance area is equal:

$$S_{eb} = (0.22 \dots 0.25)S_{el} = 0.24 \cdot 6.962 = 1.67\ [m^2];$$

Rudder balance area is equal:

$$S_{rb} = (0.2 \dots 0.22)S_{rud} = 0.21 \cdot 4.415 = 0.93\ [m^2];$$

The area of elevator trim tab:

$$S_{te} = 0.08 \cdot S_{el} = 0.08 \cdot 6.962 = 0.557\ [m^2];$$

Area of rudder trim tab is equal:

$$S_{tr} = 0.06 \cdot S_{rud} = 0.06 \cdot 4.415 = 0.265\ [m^2];$$

Span of horizontal tail unit:

$$L_{HTU} = (0.32 \dots 0.5) \cdot l = 0.4 \cdot 35.13 = 14.052\ [m];$$

Span of vertical tail unit:

$$L_{VTU} = (0.14 \dots 0.2) \cdot l = 0.18 \cdot 35.13 = 6.3234\ [m];$$

Aerodynamic balance area:

$$S_{aero\ banlance} = (0.15 \dots 0.23);$$
$$S_{control\ surface} = 0.2 \cdot 15.89 = 3.178\ [m^2];$$

Rudder area (for aircraft with two engine):

$$S_{tr} = 0.1 \cdot S_{rud} = 0.1 \cdot 4.415 = 0.4415\ [m^2];$$

The height of the vertical tail:

$$l_{vtu} = 0.2 \cdot l_w = 0.2 \cdot 30.47 = 12.2\ [m];$$

According to my protype, the taper ratio of horizontal and vertical tail unit:$\eta_{htu} = 4.93$; $\eta_{vtu} = 3.69$. Tail unit aspect ratio: $\lambda_{htu} = 6.16$; $\lambda_{vtu} = 1.91$.

The tip chord of horizontal tail unit:

$$b_{htip} = \frac{2S_{HTU}}{(\eta_{htu} + 1)L_{HTU}} = \frac{2 \cdot 25.18}{(4.93 + 1) \cdot 13.62} = 0.624\ [m];$$

Root chord of horizontal stabilizer:

$$b_{hroot} = b_{htip} \cdot \eta_{htu} = 0.624 \cdot 4.93 = 3.08\ [m];$$

Tip chord of vertical tail unit:

$$b_{vtip} = \frac{2S_{VTU}}{(\eta_{vtu} + 1)L_{VTU}} = \frac{2 \cdot 18.89}{(3.69 + 1) \cdot 18.73} = 0.43\ [m];$$

Root chord of vertical stabilizer:

$$b_{vroot} = b_{vtip} \cdot \eta_{htu} = 0.43 \cdot 3.69 = 1.59\ [m];$$

Mean aerodynamic chord of horizontal tail unit:

$$b_{MAChtu} = 0.66 \cdot \frac{\eta_{htu}{}^2 + \eta_{htu} + 1}{\eta_{htu}} \cdot b_{htip} = 2.10 \text{ [m]};$$

Mean aerodynamic chord of vertical tail unit:

$$b_{MACvtu} = 0.66 \cdot \frac{\eta_{vtu}{}^2 + \eta_{vtu} + 1}{\eta_{vtu}} \cdot b_{vtip} = 1.11 \text{ [m]};$$

1.3.7 Landing gear design

In the early landing gear design [7], part of the landing gear parameters was obtained after the center of gravity of the aircraft was determined. Moreover, the landing gear of the early design was of fixed structure and could not be recycled, so it would produce large air resistance during flight. The ability to have three views of the aircraft and determine the landing gear parameters in advance (Fig. 1.8), as well as the ability to use a retractable landing gear, improves the performance of the aircraft in flight.

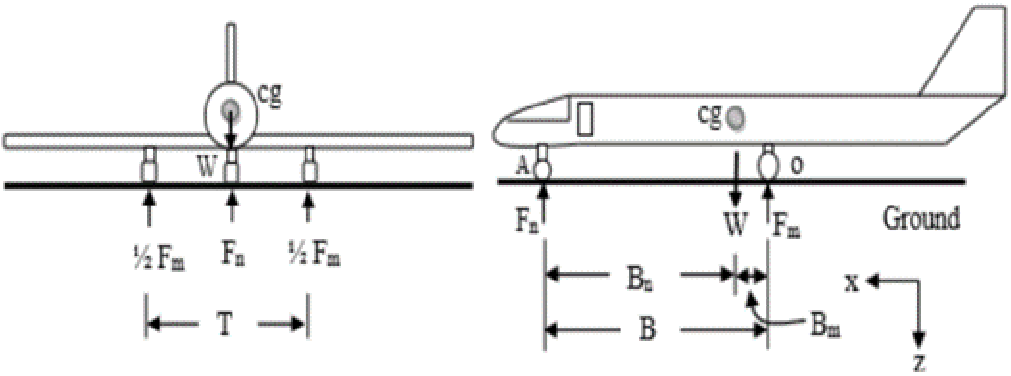

Fig. 1.8 – Parameters of the landing gear

Main wheel distance from the center of gravity is:

$$B_m = (0.15 \ldots 0.2) b_{MAC} = 0.2 \cdot 3.89 = 0.778 \text{ [m]};$$

where: b_{MAC} – mean aerodynamic chord

The wheelbase of the landing gear should be selected appropriately. If the wheel base is too large, it will complicate the landing gear structure, which leads to an increase in the mass of the landing gear structure; if it is too small, the tail of the aircraft may collide with the ground. Wheelbase between nose landing gear and main landing gear:

$$B = (0.3 \ldots 0.4) l_f = 0.4 \cdot 32 = 12.8 \text{ [m]};$$

Where: l_f – length of fuselage.

This formula says that the nose of the plane will carry 8... 20% of the plane's total weight.

The distance from the nose landing gear to the center of gravity is equal:

$$B_n = 12.8 - 0.778 = 12.022 \text{ [m]};$$

Landing gear tires (Table 1.2) need to be selected according to the weight of the aircraft when taking off and landing. For the nose landing gear, dynamic loads also need to be considered in the design process. Therefore, in the process of landing gear design, it is necessary to consider the loads on the aircraft landing gear during the take-off and landing phases.

Determine the load act to the landing gear tire. K_g = 1.5...2.0 – dynamics coefficient. Load on main wheel is equal:

$$F_{main} = \frac{(B - B_m) \cdot m_0 \cdot 9.8}{B \cdot n \cdot z} = \frac{12.022 \cdot 76983 \cdot 9.81}{12.8 \cdot 2 \cdot 2} = 177.325 \text{ [KN]};$$

Load on nose wheel is equal:

$$F_{NOSE} = \frac{B_m \cdot m_0 \cdot 9.81 \cdot K_g}{B \cdot Z} = \frac{0.778 \cdot 76983 \cdot 9.81 \cdot 2}{12.8 \cdot 2} = 45.902\ [KN];$$

Table 1.2 – Aviation tires for designing aircraft

Main gear		Nose Gear	
Tire size	Ply rating	Tire size	Ply rating
Width:368 mm Diameter: 1130mm	28	Width:197 mm Diameter:686mm	12

1.3.8 Choice and description of aircraft engine

CFM 56-7B26, CFM 56-7B24, CFM 56-7B22 are used in Boeing 737-600/700/800 and Boeing 737-900 series respectively. Its parameters are shown in Table 1.3, and its appearance is shown in Fig. 1.9.

Table 1.3 – Examples of application CFM 56-7B [8]

Model	Thrust	Bypass ratio	Dry weight
CFM 56-7B26	26300 lbf (117KN)	5.1	2370 kg
CFM 56-7B24	24220 lbf (108KN)	5.3	2370 kg
CFM 56-7B22	22700 lbf (101KN)	5.3	2370 kg

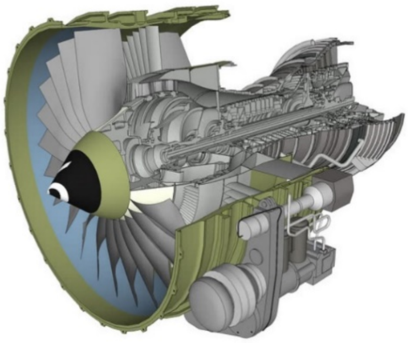

Fig. 1.9 – Structure of aircraft engine

The CFM56-7 series, which is used on Boeing's 737 series, has a wider thrust range, higher fuel efficiency and lower maintenance costs than the previous generation of CFM56-3. Although its mechanical properties are similar to those of the -3 series, its internal structure has been improved, resulting in improved aerodynamics, and the -7 series turbofan blades also use the latest single crystal turbine blades.

Therefore, CFM56-7B26 is chosen as the engine of the aircraft. The main reasons include its wide application, safety and reliability, high bypass ratio, large thrust and other advantages, very suitable for the design of the aircraft.

1.4 Aircraft center of gravity calculation

1.4.1 Trim-sheet of equipped wing

The total mass of a wing mounted on an aircraft should include: wing structural mass; wing internal equipment mass; fuel mass.

For landing gear, regardless of where it is installed, its mass should be included in the total wing mass. Taking the projection of the horizontal datum of the intersection of the average aerodynamic chord of the wing and the leading edge as the plane's centroid, and taking it as the origin, the coordinates extending to the tail of the aircraft are positive and the coordinates extending to the head of the aircraft are negative.

The wing structure mass, relative coordinates and moment are shown in Table 1.4. According to the calculation, the total mass of the equipped wing is 45311kg, and the moment center of the equipped wing is mainly determined by the following formula:

$$X_w^{\prime} = \frac{\Sigma m_i^{\prime} x_i^{\prime}}{\Sigma m_i^{\prime}}$$

Where: m_i' - the mass of systems or components in the wing;

x_i' - coordinates of a system or component with respect to the center of mass;

Table 1.4 - Trim sheet of equipped wing:

N	Object name	Mass		C.G coordinates Xi,m	Mass moment, Xi*mi
		units	total mass m(i)		
1	wing (structure)	0.11056	8511.24048	1.7116	14567.83921
2	fuel system	0.0091	700.5453	1.7505	1226.304548
3	airplane control, 30%	0.00186	143.18838	2.334	334.2016789
4	electrical equipment, 10%	0.00325	250.19475	0.389	97.32575775
5	anti-ice system, 50%	0.0111	854.5113	0.389	332.4048957
6	hydraulic system, 70%	0.01183	910.70889	2.334	2125.594549
7	power plant	0.09404	7239.48132	-3	-21718.44396
8	Equipped wing without landing gear and fuel	0.24174	18609.87042	-0.163073318	-3034.773325
9	nose landing gear	0.007568	582.607344	-10.855	-6324.202719
10	main landing gear	0.030272	2330.429376	1.945	4532.685136
11	fuel	0.26878	20691.49074	1.7505	36220.45454
12	fuel reserve	0.04023	3097.02609	1.7505	5421.344171
	total	0.58859	45311.42397	0.812499467	36815.5078

1.4.2 Trim-sheet of equipped fuselage

It extends to the rear end of the fuselage with the projection of the most front point of the fuselage on the horizontal datum as the origin. The positions of different structures relative to the fuselage can be marked with coordinates relative to the origin. Specific parameters and calculations are shown in Table 1.5. The formula for determining the moment center of the equipped fuselage is the same as the equipped wing.

Table 1.5 – Trim sheet of equipped fuselage

N	Object names	Mass		C.G coordinates Xi, m	Mass moment, Xi*mi
		units	total mass m(i)		
1	fuselage	0.0771	5936.1591	16	94978.5461
2	horizontal tail	0.0086	664.3633	29.5	19598.7171
3	vertical tail	0.0084	648.9667	30.5	19793.4841
4	navigation equipment	0.0047	361.8201	0.5	180.9101
5	radio equipment	0.0024	184.7592	4	739.0368
6	radar	0.0032	246.3456	0.5	123.1728
7	instrument panel	0.0055	423.4065	4	1693.626

Continuation of the Table 1.5

8	Flight control system 70%	0.0043	334.1062	16	5345.6995
9	hydraulic system 30%	0.0051	390.3038	22.4	8742.8053
10	anti-ice system 25%	0.0056	427.2557	25.6	10937.7446
	Air conditioning system 25%	0.0056	427.2557	16	6836.0904
11	electrical equipment 90%	0.0293	2251.7528	16	36028.0441
12	lining and insulation	0.0067	515.7861	16	8252.5776
13	Not typical equipment	0.0046	354.1218	24	8498.9232
14	Additional equipment (emergency equipment)	0.0124	953.0495	5	4765.2477
15	Operational items	0.0196	1508.0969	5	7540.4849
	lavatory 1, 15%	0.0018	139.7242	4.5	628.7587
16	lavatory 2, 15%	0.0018	139.7242	8.8	1229.5725
	lavatory 3, 15%	0.0018	139.7242	26	3632.8278
	galley 1, 15%	0.0018	139.7242	4.5	628.7587
	galley 2, 20%	0.0024	186.2989	8.8	1639.4299
	galley 3, 20%	0.0024	186.2989	26.5	4936.9198
17	passenger seats (economy class) 1 seat/block of 2/block of 3/ 6-8kg/12-15kg/18-20kg	0.0131	1008	16	16128
	passenger seats (business class) 1 seat/block of 2/block of 3/ 8-10kg/14-18kg/20-25kg	0.0016	120	8.5	1020
	seats of flight attendances	0.0004	32	6	192
	seats of pilots	0.0007	56	2.8	156.8
18	equipment fuselage without payload	0.2309	17775.0433	14.8663	264248.1774
19	Passenger (business)	0.0109	840	7	5880
20	Passenger (economy)	0.1146	8820	16	141120
21	on board meal (galley 1)	0.0009	69	4.5	310.5
	on board meal (galley 2)	0.0009	69	8.8	607.2
	on board meal (galley 3)	0.0009	69	26.5	1828.5
22	Cargo, mail	0.0104	800	20.3	16240

Continuation of the Table 1.5

23	Baggage (forward compartment)	0.0239	1840	10.6	19504
	Baggage (rear compartment)	0.0120	920	20.3	18676
24	flight attendance	0.0036	280	6	1680
25	crew	0.0021	160	2.8	448
	Total	0.4111	31642.0433	14.8708	470542.3774

After calculating the center of gravity of the equipped wing and equipped fuselage, it is necessary to construct a torque balance equation relative to the fuselage head through the following equation:

$$\mathrm{m_f x_f + m_w(x_{MAC} + x'_w) = m_0(x_{MAC} + C)}$$

According to the above formula, the position of the point where the average aerodynamic chord (MAC) of the wing is projected vertically on the fuselage can be determined. Therefore, X_{MAC} can be determined by the following formula:

$$X_{MAC} = \frac{m_f x_f + m_w x'_w - m_0 C}{m_0 - m_w}$$

Where: m_0 – Aircraft take off weight;

m_f – Weight of equipped fuselage;

m_w – Weight of equipped wing;

$C -$ The distance from the intersection of the mean aerodynamic chord (MAC) with the leading edge of the wing to the center of gravity;

C = (0.22…0.25) B_{MAC} – Low wing design;

Therefore, The calculation process of X_{MAC} is as follows:

$$X_{MAC} = \frac{31642.0433 \cdot 14.8708 + 45311.4240 \cdot 0.8125 - 76983 \cdot 0.25 \cdot 3.89}{76983 \cdot 45311.4240}$$

$$= 13.6692\ [m];$$

1.4.3 Calculation of center of gravity position variants

The list of mass objects in table 1.6 is used to calculate the center of gravity variant calculation. The data in the table are mainly derived from the data in table 1.4 and 1.5

Table 1.6 – Calculation of C.G. positioning variants

Name of the object	Mass, Kg	Coordinate	Mass moment
	mi	C.G., M	Kg.m
Nose landing gear (extended)	582.61	3.77	2196.43
main landing gear (extended)	2330.43	13.37	31157.84
equipped wing (without fuel and landing gear)	18609.87	13.51	251346.81
fuel	20691.49	15.42	319056.07
fuel reserve	3097.03	15.42	47755.14
equipped fuselage (without payload)	17775.04	14.87	264248.18
passengers of business class	840.00	7.00	5880.00
passenger of economy class	8820.00	16.00	141120.00
baggage	2760.00	15.45	42642.00
Cargo, mail	800.00	20.30	16240.00
Galley (meal)	207.00	13.27	2746.20
crew	440.00	4.40	1936.00
nose landing gear (retracted)	582.61	2.77	1613.82
main landing gear (retracted)	2330.43	13.37	31157.84

The data in Table 1.7 are used to calculate the variables of the center of gravity of the aircraft, which are mainly derived from the data in Table 1.6.

Table 1.7 – Aircraft C.G. position variants

No.	Variants of the loading	Mass, kg	Moment of the mass, kg*m	Center of mass, m	Center of gravity position
1	take off mass (L.G. extended)	76953.47	1126324.66	14.64	0.25
2	take off mass (L.G. retracted)	76953.47	1125742.06	14.63	0.25
3	landing weight (L.G. extended)	53164.95	759513.46	14.29	0.16
4	ferry version (without payload, max fuel, LG retracted)	63526.47	917113.86	14.44	0.20
5	parking version (without payload, fuel for flight and LG extended)	42394.98	596704.39	14.08	0.11

Conclusions to the part

Through the preliminary design of the aircraft, the following conclusions are obtained:

- The preliminary design of aerodynamic shape of a mid-range passenger aircraft with a capacity of 134 passengers;
- Internal layout of aircraft fuselage, compartments and seating arrangements;
- The center of gravity of the wing is preliminarily calculated and the position of the wing relative to the fuselage is determined.
- The center of gravity of the fuselage and the aircraft as a whole is preliminarily calculated.
- The geometric parameters and forces of landing gear were calculated, and the suitable engine and landing gear tires were selected.

The engines are arranged symmetrically under the wings. Mainly because such a design has the following advantages:

- The weight of the engine can be used to offset some of the torque generated between the wings and the fuselage;

- Keep the engine away from the fuselage to reduce the impact of faults and noise on the fuselage body;
- The engine is close to the ground, which is conducive to maintenance and improves economic benefits;
- Close to the center of gravity of the aircraft is easy to control, and the large area of the wing is convenient to design the engine position;

According to the calculation results, CFM56-7B26 turbofan jet engine is selected as the engine of the aircraft, mainly because of its high bypass ratio and high thrust. At the same time, it has been widely used in the world also shows its superior performance, high security.

2. CONCEPTUAL DESIGN OF AUTOMATIC LIFTING AIRCRAFT LUGGAGE RACK

2.1 Technical background

With the development of the international community, the global social and economic development is becoming more and more integrated. The communication between countries and continents is becoming closer, and such development is bound to make aircraft, a fast and efficient mode of transportation, the main means of communication. Just like this, more and more people choose to travel by aircraft. Although large luggage can be checked, there are still many passengers who choose to carry some carry-on luggage aboard the aircraft. However, the existing luggage rack of all aircraft, are installed in the cabin at the top of the box structure, passengers need to lift their luggage over their heads to place the luggage on the luggage rack. In the actual investigation, it is found that the following concentrated phenomena often occur in the process of luggage placement during flight:

a) The large size of the luggage makes it difficult to lift the luggage and put it on the luggage rack;
b) Due to the narrow aisle between the seats, it takes time to pack up and ensure that the luggage does not loose, which will cause congestion and affect the flight experience.
c) When the luggage is too much, it will be difficult to close the luggage rack door;
d) Luggage in the overhead compartment is disorganized, easy to pick up the wrong baggage, forget luggage, and may be scattered items injury passengers.

To sum up, the reasons for these phenomena are attributed to the existing deficiencies of aircraft luggage racks.

Due to the COVID-19 pandemic, air traffic worldwide in 2021 is estimated to be just over 2.2 billion passengers, which is only half of all air traffic in 2019. Therefore, the importance of the plane in the field of transportation, but also because of this, it is more necessary to improve the existing problems, improve the comfort of passengers in the aircraft, not only people have a perfect travel experience, but also let more people choose to travel by aircraft.

2.2 Requirements for aircraft luggage racks

According to Federal Aviation Regulation (FAR) [9], there are the following requirements for carry-on luggage:

a) for carry-on baggage (e.g., hand luggage, backpacks, etc.), it is necessary to avoid the possibility of the baggage moving during the flight or during the ground phase, and to prevent the movement of the baggage when the aircraft encounters turbulence;
b) carry-on baggage needs to be packed or covered to avoid injury to passengers or crew;
c) baggage must not be located in any emergency exit, cabin door, or aisle between crew and cabin that may be used in an emergency, also do not block any safety signs and no smoking signs;
d) baggage compartment doors should be closed during take-off and landing.

During the take-off and landing of the aircraft, due to the acceleration and deceleration of the aircraft, the baggage will produce loads other than its own gravity, which will act on the partitions and components of the luggage rack. Because the overall quality of luggage is large, although it will be packed and placed in the luggage rack, accidents may still occur in an emergency. Therefore, it is necessary to consider the impact of luggage and luggage rack on all parties and passengers. Refer to FAR25.561, the load coefficients for passengers to withstand in all directions in an emergency are as follows: the front - 3g; above - 3g; lateral - 4g; below - 6g; the rear - 2.5g.

To sum up, in order to solve the problems of overweight luggage, cluttered luggage rack, long time for luggage storage, improve passengers' flight experience, ensure the safety of aircraft during flight, and meet the requirements of aircraft design. The luggage rack should have the following conditions:

a) efficiently, quickly and safely place luggage on top of the passenger's seat;
b) with high reliability, will not occur in the process of transportation failure;
c) in case of emergency, it has high safety and is not easy to cause structural loss to threaten passengers.
d) the luggage can be collected completely, and the luggage will not be scattered during takeoff, landing and turbulence.

2.3 Design steps and overall description of automatic lifting aircraft luggage rack

The design steps of aircraft luggage rack mainly include the following stages:

1) The preliminary conceptual design of the structure and movement components of the luggage rack;
2) Design parameters and shapes of related components, and draw 3D models with software;
3) Select alloy materials suitable for manufacturing luggage rack structure;
4) Test the tensile and bending strength of the selected materials to test whether the strength of the alloy meets the requirements of manufacturing luggage racks;
5) Calculate the total weight of the moving structure and calculate the power to select the appropriate motor.

Automatic lift aircraft luggage rack is composed of a number of structures, including sprocket drive structure, baggage transport structure and luggage rack, they include sprockets, chains, rollers and other components.

Sprocket drive structure includes sprocket, chain and rotating shaft, their design process is as follows:

Sprocket design:

The chain number (ISO) of the chain is 48B, the number of rows is single row, the number of sprocket teeth z=17 and the diameter of sprocket hole is 50 mm.

According to the table, the pitch p is 76,2 mm and the diameter of the roller d_r is 48.26 mm.

The diameter of indexing circle of sprocket is:

$$\mathrm{d} = \frac{\mathrm{p}}{\sin\left(\frac{180}{\mathrm{z}}\right)} = \frac{76.2}{\sin\left(\frac{180}{17}\right)} \approx 414.69\ [\mathrm{mm}];$$

Crown circle diameter:

$$\mathrm{d_a} = \mathrm{p}\left(0.54 + \cot\frac{180}{\mathrm{z}}\right) = 76.2 \times \left(0.54 + \cot\frac{180}{17}\right) = 448.80\ [\mathrm{mm}];$$

Root circle diameter:

$$\mathrm{d_f} = \mathrm{d} - \mathrm{d_r} = 414.69 - 48.62 = 366.43\ [\mathrm{mm}];$$

To sum up, 3D model of sprocket can be drawn according to the calculation results (Fig. 2.1):

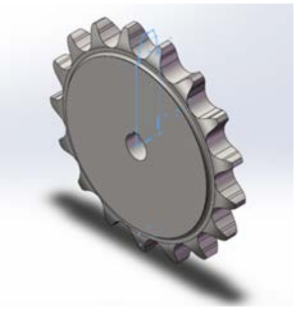

Fig. 2.1 — Sprocket

Chain design:

According to the table, the inner width of the inner chain section b_1 is 45.72mm; The height of inner chain plate h_2 is 63.88mm; The tooth width coefficient $\emptyset d$ is 0.93.

Tooth width:

$$b_c = \emptyset d \cdot b_1 = 45.52 \text{ [mm]};$$

Tooth side flange (diameter of groove between rows):

$$d_c = p\cot\frac{180}{z} - 1.04h_2 - 0.76 = 76.2 \times \cot\frac{180}{17} - 1.04 \times 63.88 - 0.76 \approx 340.44 \text{ [mm]};$$

Gear center distance:

$$a_0 = 25p = 25 \times 76.2 = 1905 \text{ [mm]};$$

Take 1905mm as the center distance;

The number of links:

$$X_0 = \frac{2a_0}{p} + \frac{(z_1 + z_2)}{2} + \frac{p(z_1 - z_2)^2}{4\pi^2 a_0} = \frac{2 \times 1905}{76.2} + 17 = 67$$

Take 68 as the number of links X;

To sum up the chain length:

$$L = X \cdot p = 68 \times 76.2 = 5181.6 \text{ [mm]};$$

According to the calculation, the chain is shown in Fig. 2.2:

Fig. 2.2 — Chain

According to the diameter of the sprocket aperture is 50mm, we need to draw a shaft with 50mm diameter, it used to connect the motor to drive the sprocket rotation. The sprocket drive structure after matching is shown in Fig. 2.3:

Fig. 2.3 — The transmission structure

Most airlines stipulate that passenger are allowed to carry only one piece of luggage with a size of 5KG and no larger than 20 x 40 x 55CM. Therefore, a suitcase of the same size is designed to carry passengers' luggage and transport it to the luggage rack. According to the specifications of the box, a lifting platform used to lift luggage (Fig. 2.4) is developed and equipped with a limited position plate, so that the platform always remains level.

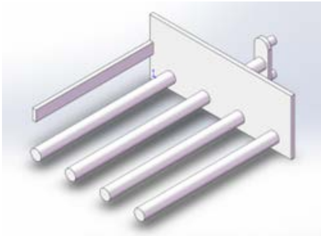

Fig. 2.4 — Lifting platform

Sprocket drive structure of the main components as described above, including: sprocket, chain, shaft, lifting platform, limit position plate and so on.

After assembly, the structure is shown in Fig. 2.5. Passengers put luggage in boxes and place it on the lifting platform (the sprocket wheel on the top is the main driving wheel), which is connected with the motor through the shaft, under the rotation of the motor, the lifting platform is lifted from the bottom to the top and transmitted to the luggage transport structure, which is then transported to the luggage rack.

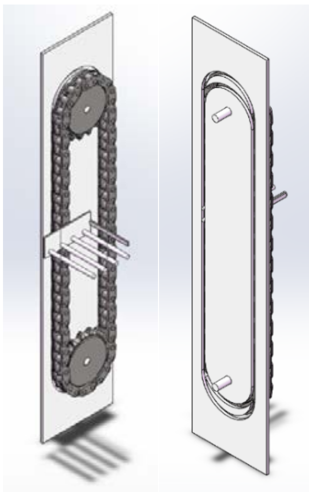

Fig. 2.5 — Sprocket drive structure

Luggage transportation structure includes transportation frame, longitudinal and lateral roller, roller composition. The design process is as follows.

Design of transport frame:

According to the design principle of sprocket drive structure, the luggage is transported to the top by the sprocket drive structure after being put on the lifting platform, and in the process of descending from the highest point of the lifting platform, passengers' luggage is placed on another platform by interleaving the interval between the rollers of the lifting platform and the interval before the rollers of the transportation frame, and moved to the luggage rack above the corresponding seat number through the transportation of rollers and rollers on the transportation frame. And according to the volume of boxes used for loading luggage, the designed transportation frame is shown in Fig. 2.6:

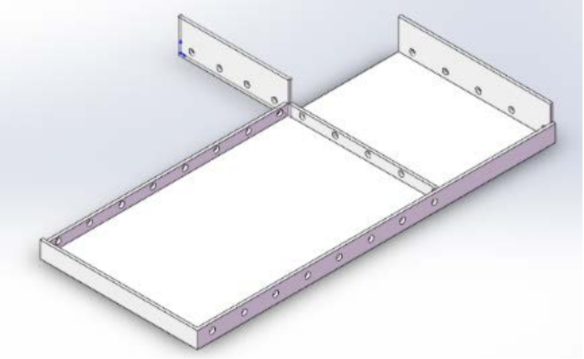

Fig. 2.6 — Transport frame

The transport frame is located at the top of the cabin, and luggage racks are on the left and right sides. Therefore, the luggage racks on both sides can share a baggage aisle.

The 3D model in Fig. 2.7 takes only one side of the transport process as an example. Design longitudinal and transverse rollers and rollers according to the transportation frame. And placed in the figure, the following structure can be obtained, which is the basic structure of the transport frame.

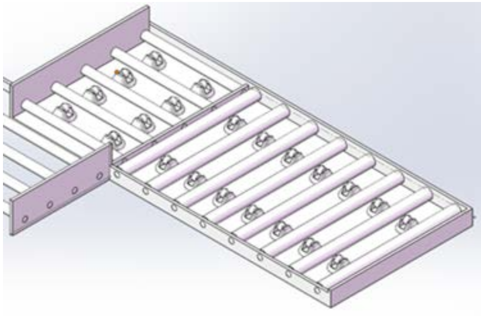

Fig. 2.7 — Luggage transport structure

The structure of the luggage rack is basically similar to the existing luggage rack structure, but the interior will be changed to a specific size to fit the size of the box used for luggage transportation (Fig. 2.8), the luggage of two passengers can be stored in this size.

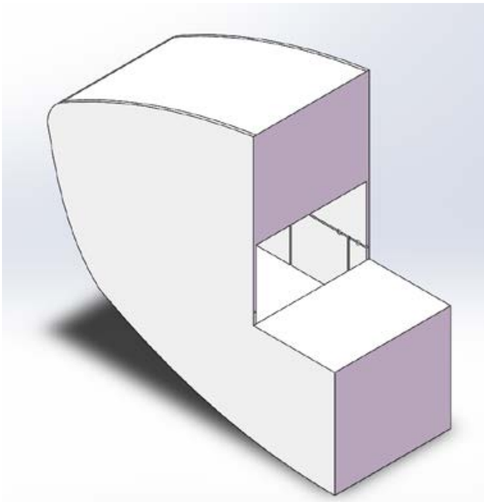

Fig. 2.8 — 3D model of luggage rack

The luggage rack is provided with guide rails and rollers to move the passengers' luggage transmitted by the transportation structure. There are 12 rollers in total, and 6 of them will place the luggage that reaches the luggage rack first in the lower layer according to the movement of the guide rails when there is no luggage in the luggage rack. The automatic lifting aircraft luggage rack compose by sprocket transmission structure, luggage rack transportation structure, luggage rack transportation structure and luggage rack are mainly shown in Fig. 2.9. In the figure, only part of the luggage rack is used as an example. The rest of the luggage rack can be obtained by mirroring and array. The structure is the same as that in the figure.

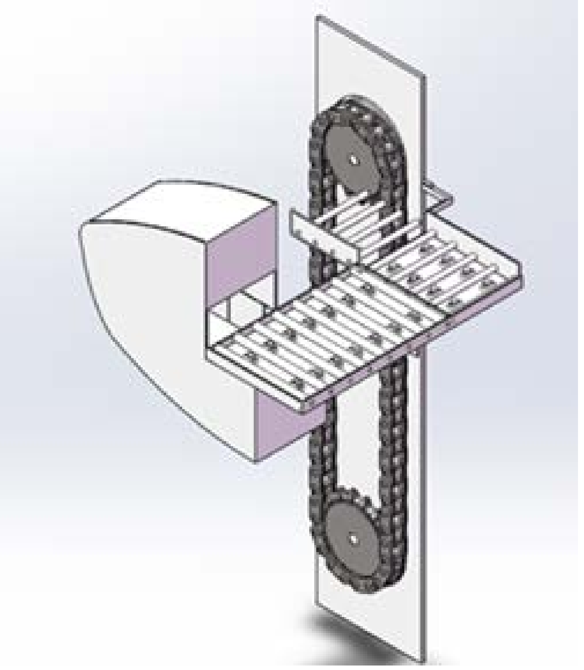

Fig. 2.9 — 3D model of automatic lift aircraft luggage rack

In most of the existing passenger aircraft, the internal volume of the luggage rack is large, which needs to store the luggage of multiple passengers, which means that it needs more force to close the luggage rack, and some things may be scattered in the process of opening and closing the luggage rack, injuring passengers. Secondly, part of the luggage rack is fixed, but it also means that its height cannot be changed and is not suitable for everyone. Rack design in this paper, corresponding to the passenger's seat number, and is a group with two passengers, in the case of moderate weight rack, can open and close, in the form of tilt by card buckle to limit loading passengers' luggage box move, make the two luggage, staged in facilitate the passengers to take the baggage at the same time, also to avoid the items scattered. Luggage rack switch adopts electronic switch, at cruising altitude, in unlocked state, in order to facilitate passengers to pick up luggage; During take-off and landing, the electronic switch is automatically locked to ensure that the luggage rack is in a closed state, so as to avoid the baggage scattered during the special stage when the luggage rack loosens, which may pose a threat to passengers.

2.4 Material selection and testing of automatic lift aircraft luggage rack

The manufacture of the luggage rack is mainly divided into two parts: the basic structure of the luggage rack and the luggage rack partition. Because the luggage rack is mainly distributed on the top of the cabin, and its large volume is an important factor affecting the total weight of the aircraft, so the selection of its material is of great significance to reduce the total weight of the aircraft.

Due to the long-term development and improvement, and long-term application in aircraft, traditional metal materials are still the first choice of aviation materials, in the traditional metal materials mainly dominated by aluminum, magnesium, titanium and high temperature alloys and other materials. Aluminum accounts for 20 to 60 percent of the total mass of most existing aircraft, while magnesium accounts for 5 to 10 percent [10]. Therefore, aluminum alloy and magnesium alloy are mainly selected as the manufacturing materials of luggage rack infrastructure.

The density of magnesium alloy is only about two thirds of that of aluminum alloy, about 1.75 ~ 1.85 g/cm^3. It is one of the lowest mass metals used in structural engineering applications to date. Its main advantages are: high strength, damping noise reduction, good machining performance, can withstand larger impact load, has good corrosion resistance, high recycling utilization rate. Compared with magnesium alloy, aluminum alloy has a perfect system from production, processing, molding, sales and recycling.

2.4.1 Comparison of the strength of magnesium alloys under two processing techniques

Due to the strength of magnesium alloys is different under different processing techniques, I choose to refer to the document "Application Research of

Magnesium Alloy Luggage Racks for EMUs"[11] as a reference, first select a higher strength machining process, and then compare the strength of the magnesium alloy produced by this process with the strength of the aluminum alloy.

Die casting and extrusion are two different processing techniques, and Table 2.3 shows the results of strength testing of magnesium alloys produced by these two processing techniques.

Table 2.3 Strength of magnesium alloys by two processing techniques

<table>
<tr><th colspan="2">Sample</th><th>Tensile strength Rm/MPa</th><th>Average tensile strength /Mpa</th><th>Yield stress Rp0.2/Mpa</th><th>Average yield stress /MPa</th><th>Fracture elongation /%</th><th>Average elongation /%</th></tr>
<tr><td rowspan="3">Magnesium alloy die casting</td><td>1</td><td>231.2</td><td rowspan="3">231.2</td><td>152.0</td><td rowspan="3">153.7</td><td>17.25</td><td rowspan="3">17.2</td></tr>
<tr><td>2</td><td>228.2</td><td>148.9</td><td>17.46</td></tr>
<tr><td>3</td><td>234.3</td><td>160.1</td><td>16.96</td></tr>
<tr><td rowspan="3">Magnesium alloy extrusion sample</td><td>1</td><td>241.2</td><td rowspan="3">241.8</td><td>207.4</td><td rowspan="3">206.5</td><td>18.86</td><td rowspan="3">18.6</td></tr>
<tr><td>2</td><td>242.0</td><td>206.1</td><td>18.80</td></tr>
<tr><td>3</td><td>242.1</td><td>206.0</td><td>18.05</td></tr>
</table>

From the data in the table, it can be found that the tensile strength of magnesium alloy extrusions is slightly better than that of magnesium alloy die castings. However, in terms of yield strength, magnesium alloy extrusions have obvious advantages. Therefore, I think it is more appropriate to choose magnesium alloy extrusions with higher strength for strength comparison with aluminum alloys.

2.4.2 Strength comparison of magnesium alloy extrusions and aluminum alloys

In the previous subsection, we can find that the strength of magnesium alloy extrusions is higher. Therefore, magnesium alloy extrusions can be selected to compare the strength with aluminum alloys. According to the references, we can obtain Table 2.4. AA6005-T6A in the table is a widely used aluminum alloy, and AZ31-R is a magnesium alloy produced by extrusion process. The tensile strength, yield strength and elongation test results of the two alloys are shown in the table.

Table 2.4 Strength test result with two kinds of alloys

Sample		Tensile strength Rm/Mpa		Yield strength Rp0.2/MPa		Elongation A5/%	
		Test values	average	Test values	average	Test values	average
AA6005 -T6A	1	305.5	302	152.1	151	15.81	14.8
	2	298.9		148.9		13.62	
	3	301.3		151.14		14.91	
AZ31-R	1	246.5	250	142.8	155	15.9	15.9
	2	255.6		172.9		17.5	
	3	247.4		149.6		14.2	

According to the test results in the table, it can be found that the tensile strength of magnesium alloy extrusions is lower than that of aluminum alloys, but the yield strength is higher than that of aluminum alloys.

2.4.3 Magnesium alloy flexural strength test results

The strength of magnesium alloy extrusions and aluminum alloys was compared in the previous section, but testing tensile strength, yield strength, and elongation alone is not enough, because the luggage rack structure is also subjected to its own gravity and loads generated by luggage, so it is also necessary to test the flexural strength of the material.

According to the reference, we can get Table 2.5, in which the Charpy pendulum test was carried out on the extrusion of magnesium alloy to test its flexural strength. The test measures the flexural strength of magnesium alloys by measuring the energy they absorb during impact.

Table 2.5 Impact toughness test results of AZ31 magnesium alloy

No.	1	2	3	4	5	6	7	8	9
Temperature/℃	25	25	25	25	25	25	25	25	25
Flexrual strength/MPa	335	340	340	335	335	340	298	299	299

The test was carried out for 6 times, and the average impact absorption of magnesium alloy (AZ31) was 7.2 J. The impact toughness of AZ31 magnesium alloy sample was calculated as $a_{KV} = 0.09\ [\frac{J}{mm^{-2}}]$, Under the condition of room temperature, the impact toughness of AA6063 aluminum alloy is approximately 0.04 ~ 0.06.

Through the test data and consulting data, it can be found that the bending strength of magnesium alloy extrusions is obviously better than that of aluminum alloys. Under the same volume, the quality of magnesium alloy can be significantly smaller than that of aluminum alloy. Therefore, I think it is a good choice to choose magnesium alloy as the manufacturing material of the luggage rack structure.

2.4.4 Material selection of luggage rack partition

The main role of luggage rack partition is to build the shape of the luggage rack, at the same time to meet a certain strength, with good fire resistance, high ignition point, and high temperature or combustion can't produce toxic gas, will not promote the spread of the fire, after leaving the fire extinguish.

Based on the above requirements, polycarbonate board (polycarbonate board), which is widely used in various fields, is chosen as the material for making luggage rack partitions and luggage loading boxes. The density of polycarbonate board is about 1.18 ~ 1.22 g/cm^3, and its own ignition point is about 630℃ [12].

Volume of baggage loading box (ignoring chamfered volume):

$$\mathrm{V_b} = 39 \times 55 \times 20 - 37 \times 54 \times 19 = 4938\ [\mathrm{cm}^3];$$

If the density of polycarbonate board is 1.20g/cm3, the weight of luggage loading box is roughly as follows:

$$\mathrm{g_b} = \mathrm{V_b} \times 1.2 = 4938 \times 1.2 = 5925.6\ [\mathrm{g}] \approx 5.93\ [\mathrm{kg}];$$

According to the existing regulations of most airlines, the allowed weight of carry-on baggage is 5 KG, but the actual situation may be greater than the specified weight of carry-on baggage, so the weight of baggage should be 10 KG. Therefore, the total weight of luggage and loading case is:

$$g_a = (5.93 + 10) \times 9.81 \times 2 = 312.56\ [\mathrm{N}];$$

The stressed area of the luggage rack is:

$$S = 55 \times 39 = 2145\ [\mathrm{cm}^2];$$

The stress on the corresponding area is:

$$\sigma = \frac{312.56 \times 1000}{2145} = 1457.16\ [\mathrm{N/m^2}] = 1457.16 \times 10^{-6}\ [\mathrm{MPa}];$$

While the fracture tensile strength of polycarbonate board is 130 MPa, and the stress of calculated results are much lower than the 130MPa. Therefore, polycarbonate board with high strength and good heat resistance can be used as the manufacturing material of luggage rack partition and luggage box. In addition, the use of polycarbonate board as a material has the following advantages:

- Good molding and hot working properties;
- With good sound insulation performance, can reduce the noise generated in the process of baggage transportation;

2.5 Calculation and selection of motor power for automatic lifting aircraft luggage rack

An electric motor is needed to move the luggage from the bottom to the top. The equipment that needs to be moved is: lifting platform, baggage loading box, luggage. Therefore, the total weight of the three parts needs to be calculated. To ensure that the strength of the lifting platform meets the demand, magnesium alloy will be used. According to the description and calculation in section 2.4, the density of magnesium alloy is 1.8g/cm^3.

Volume of lifting platform:

$$\mathrm{V_l} = 2004.82\ [\mathrm{cm}^3];$$

According to 2.4.4, the total mass of luggage and luggage box is 15.93 kg, so the total mass of the three parts is:

$$M = V_l + 15.93 = 2004.82 \times 1.8 \div 1000 + 15.93 \approx 19.54\ [\mathrm{Kg}];$$

According to the calculation of sprocket and chain in 2.3, the center distance of sprocket is 1905 mm, and the diameter of indexing circle of sprocket is 414.69 mm. Therefore, in the vertical direction, the maximum distance of luggage movement is:

$$\mathrm{L_v} = 1905 + 414.69 = 2319.69\ [\mathrm{mm}];$$

To sum up, the work done by the motor in the vertical direction is:

$$\mathrm{W_v} = \mathrm{M} \times \mathrm{g} \times \mathrm{L_v} \div 1000 = 19.54 \times 9.81 \times 2319.69 \div 1000 \approx 444.66\ [\mathrm{W}];$$

In the horizontal direction, the maximum displacement of luggage is 414.69 mm in diameter of the indexing circle of the sprocket, so the work done by the motor in the horizontal direction is:

$$\mathrm{W_h} = \mathrm{M} \times \mathrm{g} \times \mathrm{L_h} \div 1000 = 19.54 \times 9.81 \times 414.69 \div 1000 \approx 79.49\ [\mathrm{W}];$$

It can be concluded that the total work done by the motor in transporting luggage is 524.15 W. In order to improve the efficiency of luggage transportation, at least three lifting platforms should be installed to transport luggage, improve transportation efficiency and avoid transportation congestion. So, the power of the motor shall be at least:

$$W_a = 524.15 \times 3 = 1.573 \text{ [kW]};$$

Therefore, the motor of model Y90L-2 with rated power of 2.2 KW is selected, and then the corresponding reduction motor is used.

Conclusions of the special part

The main content of this part is the conceptual design of the automatic lifting aircraft luggage rack, and the parameters of each main component are designed through calculation. Then, according to the references, suitable materials were selected for the manufacture of this aircraft luggage rack.

Due to the transmission structure in the automatic lifting aircraft luggage rack includes chains and sprockets, the overall weight may be large. Therefore, I chose to replace the alloy used in the luggage rack construction with a magnesium alloy that is lighter in weight and has the required strength, so that the mass saved is used for the mass of the sprocket and chain. In this way, the overall quality of the designed luggage rack can be the same as or similar to the previous one.

To luggage rack partition, I will choose the polycarbonate board with ignition point, high intensity and good sound insulation, which is called “not broken glass”. In terms of motor selection, in order to ensure the efficiency of luggage transportation, a motor with rated power of 2.2 kW is selected to ensure the maximum transportation of three luggage at the same time.

GENERAL CONCLUSIONS

Preliminary design a mid-range aircraft is the task of this diploma work, which with 134 passenger capacity. The models selected for reference include: Boeing 737-700, Boeing 737-300 and A320. According to the parameters of protypes, the aerodynamic shape and initial data of the aircraft to be designed can be obtained by the aviation computer program.

In the first part of the diploma work, mid-range aircraft with a speed of 830 km/h and a range of 5200 km was designed. In the paper, the main components of the aircraft are calculated, such as wings, fuselage, landing gear and high lift device, etc., the internal layout is also designed. The general view and fuselage layout of the designed aircraft are shown in the drawings. And the type of engine the aircraft is equipped with is CFM 56-7B24, which has a large thrust and high bypass ratio. Furthermore, in order to ensure the safe and stable operation of the aircraft, it is necessary to calculate the gravity center of the aircraft in different situations, such as the retraction and opening of the landing gear. In addition, the center of gravity of the aircraft in the ferry state and the parking state is also different. Therefore, in order to ensure the stability and controllability of the aircraft and the stability of taxiing, it is necessary to control the position of the center of gravity within a certain range.

In the special part, the main consideration is to design an automatic lifting aircraft luggage rack system. The main reason is to put forward a solution to the main problem of aircraft luggage rack. The details of operation have been described in the text. And the 3D model of the main structure has been drawn with SolidWorks and shown in the paper. In addition, different alloy materials are selected from relevant literature about the experimentally investigations of their strength, which meet flight requirements. The motor matching the power required by the system operation is also selected.

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Appendix A

INITIAL DATA AND SELECTED PARAMETERS

Passenger Number	134.
Flight Crew Number	2.
Flight Attendant or Load Master Number	4.
Mass of Operational Items	1507.81 кг.
Payload Mass	14850.00 кг.
Cruising Speed	830. км/ч
Cruising Mach Number	0.7662
Design Altitude	9.800 км.
Flight Range with Maximum Payload	5200. км.
Runway Length for the Base Aerodrome	2.95 км.
Engine Number	2.
Thrust-to-weight Ratio in N/kg	2.9000
Pressure Ratio	32.00
Assumed Bypass Ratio	5.00
Optimal Bypass Ratio	5.00
Fuel-to-weight Ratio	0.4700
Aspect Ratio	9.80
Taper Ratio	3.00
Mean Thickness Ratio	0.120
Wing Sweepback at Quarter Chord	27.0 град.
High-lift Device Coefficient	1.050
Relative Area of Wing Extensions	0.060

Wing Airfoil Type – Ламинизированный типа NASA

Winglets – не применяются

Spoilers - установлены

Fuselage Diameter	4.00 м.
Fineness Ratio	8.00
Horizontal Tail Sweep Angle	32.0 град.
Vertical Tail Sweep Angle	35.0 град.

I. CALCULATION RESULTS

Optimal Lift Coefficient in the Design Cruising Flight Point Cy 0.44784

Induce Drag Coefficient Cx.инд. 0.00917

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

Cruising Mach Number	0.76625
Wave Drag Mach Number	0.78475

Calculated Parameter D_m	0.01851

Wing Loading in kPa (for Gross Wing Area):

At Takeoff	5.992
At Middle of Cruising Flight	5.042
At the Beginning of Cruising Flight	5.797

Drag Coefficient of the Fuselage and Nacelles	0.01229
Drag Coefficient of the Wing and Tail Unit	0.00918

Drag Coefficient of the Airplane:

At the Beginning of Cruising Flight	0.03315
At Middle of Cruising Flight	0.03178
Mean Lift Coefficient for the Ceiling Flight	0.44784

Mean Lift-to-drag Ratio	14.09172

Landing Lift Coefficient	1.643
Landing Lift Coefficient (at Stall Speed)	2.464
Takeoff Lift Coefficient (at Stall Speed)	2.033
Lift-off Lift Coefficient	1.484
Thrust-to-weight Ratio at the Beginning of Cruising Flight	0.644
Start Thrust-to-weight Ratio for Cruising Flight	0.377
Start Thrust-to-weight Ratio for Safe Takeoff	2.960

Design Thrust-to-weight Ratio	No	3.108
Ratio $D_r = R_{cruise} / R_{takeoff}$	Dn	0.803

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

Takeoff	36.4606
Cruising Flight	59.0031
Mean cruising for Given Range	62.9903

FUEL WEIGHT FRACTIONS:

II.

Fuel Reserve	0.04023
Block Fuel	0.26878

WEIGHT FRACTIONS FOR PRINCIPAL ITEMS:

Wing	0.11056
Horizontal Tail	0.00863
Vertical Tail	0.00843
Landing Gear	0.03784
Power Plant	0.09404
Fuselage	0.07711
Equipment and Flight Control	0.12958
Additional Equipment	0.01238

Operational Items	0.01959
Fuel	0.30901
Payload	0.19290

Airplane Takeoff Weight = 76983. кг.
Takeoff Thrust Required of the Engine 119.62 кВт

Air Conditioning and Anti-icing Equipment Weight Fraction	0.0222
Passenger Equipment Weight Fraction (or Cargo Cabin Equipment)	0.0158
Interior Panels and Thermal/Acoustic Blanketing Weight Fraction	0.0067
Furnishing Equipment Weight Fraction	0.0121
Flight Control Weight Fraction	0.0062
Hydraulic System Weight Fraction	0.0169
Electrical Equipment Weight Fraction	0.0325
Radar Weight Fraction	0.0032
Navigation Equipment Weight Fraction	0.0047
Radio Communication Equipment Weight Fraction	0.0024
Instrument Equipment Weight Fraction	0.0055
Fuel System Weight Fraction	0.0091

Additional Equipment:

Equipment for Container Loading	0.0078
No typical Equipment Weight Fraction (Build-in Test Equipment for Fault Diagnosis, Additional Equipment of Passenger Cabin)	0.0046

III. TAKEOFF DISTANCE PARAMETERS

IV. Airplane Lift-off Speed	289.24 км/ч
Acceleration during Takeoff Run	2.42 м/с*с
Airplane Takeoff Run Distance	1330 м
Airborne Takeoff Distance	578 м
Takeoff Distance	1909 м

V. CONTINUED TAKEOFF DISTANCE PARAMETERS

VI. Decision Speed	274.77 км/ч
Mean Acceleration for Continued Takeoff on Wet Runway	0.31 м/с*с
Takeoff Run Distance for Continued Takeoff on Wet Runway	2208.83 м
Continued Takeoff Distance	2787.20 м
Runway Length Required for Rejected Takeoff	2886.83 м

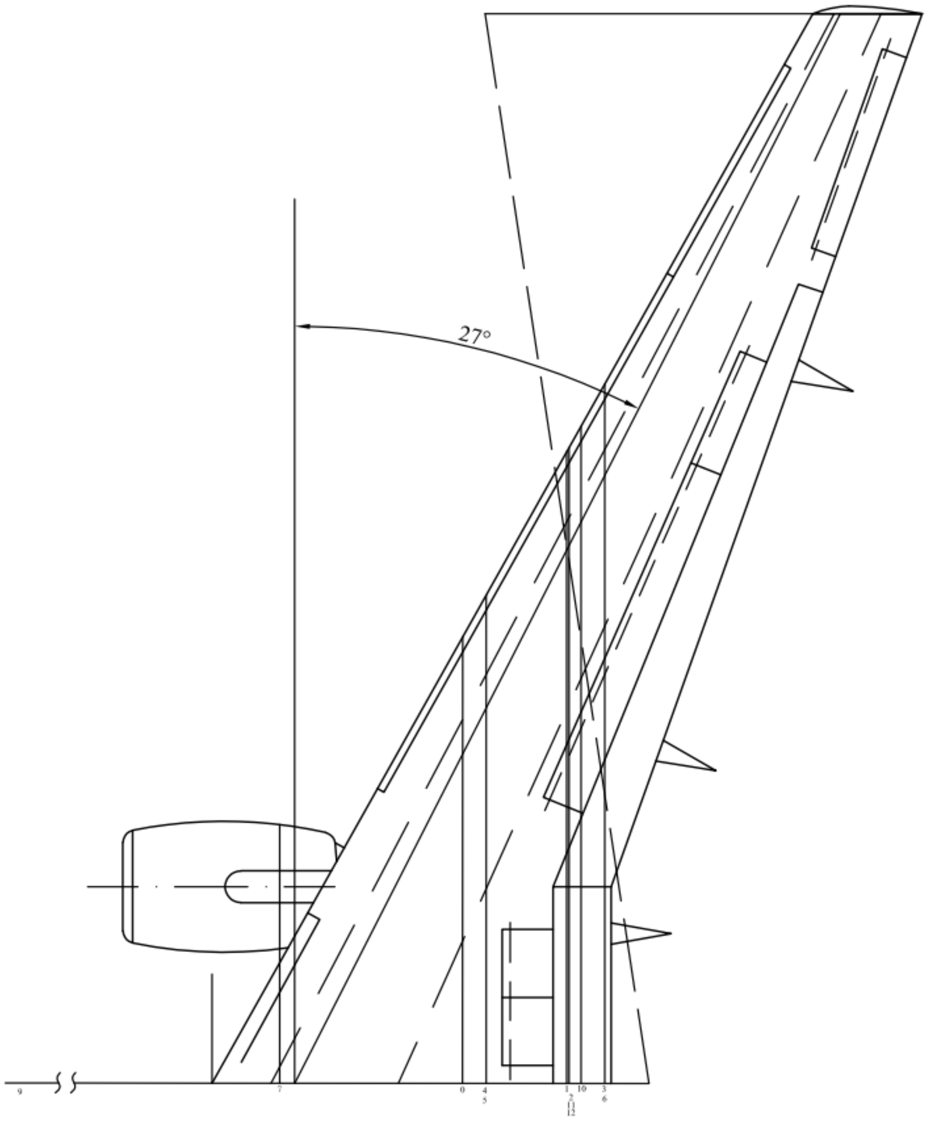
VII. LANDING DISTANCE PARAMETERS

VIII. Airplane Maximum Landing Weight	59323. кг
Time for Descent from Flight Level till Aerodrome Traffic Circuit Flight	19.3 min.
Descent Distance	44.40 км.
Approach Speed	259.50 км/ч
Mean Vertical Speed	2.08 м/с

Airborne Landing Distance	521 м
Landing Speed	244.50 км/ч
Landing run distance	803. м
Landing Distance	1324. м
Runway Length Required for Regular Aerodrome	2211. м
Runway Length Required for Alternate Aerodrome	1880. м

Appendix B

Appendix B



Center of gravity of the wing

NAU 22 13L 00 00 00 02 P3

Ch./Sheet		Sign.	Date
Performed	Liu Jianwei		
Checked	*Maslak T.P.*		

Middle range passenger aircraft

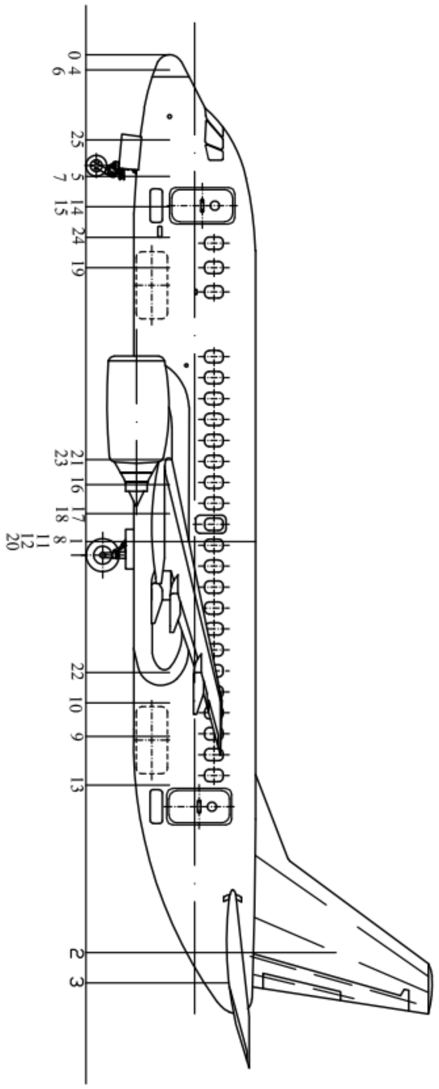
Letter	Weight	Scale
		1:100
Sheet 1		Sheet 2

Appendix B

402 AKF 134

Appendix C

Appendix C



Center of gravity of the fuselage				NAU 22 13L 00 00 00 02 P3			
Ch./Sheet		Sign.	Date	Middle range passenger aircraft	Letter	Weight	Scale
Performed	Liu Jianwei						1:200
Checked	*Maslak T.P.*				Sheet 1		Sheet 2
				Appendix C	402 AKF 134		

Appendix D

表 1 链条主要尺寸、测量力、抗拉强度及动载强度

链号[a]	节距	滚子直径	内节内宽	销轴直径	套筒孔径	链条通道高度	内链板高度	外或中链板高度	过渡链节尺寸[b]			排距	内节外宽	外节内宽	销轴长度			止锁件附加宽度[c]	测量力			抗拉强度 F_u			动载强度[d,e,f] 单排
															单排	双排	三排		单排	双排	三排	单排	双排	三排	
	p nom	d_1 max	b_1 min	d_2 max	d_3 min	h_1 min	h_2 max	h_3 max	l_1 min	l_2 min	c	p_t	b_2 max	b_3 min	b_4 max	b_5 max	b_6 max	b_7 max				min	min	min	F_d min
	mm																		N			kN			N
04C	6.35	3.30[g]	3.10	2.31	2.34	6.27	6.02	5.21	2.65	3.08	0.10	6.40	4.80	4.85	9.1	15.5	21.8	2.5	50	100	150	3.5	7.0	10.5	630
06C	9.525	5.08[g]	4.68	3.60	3.62	9.30	9.05	7.81	3.97	4.60	0.10	10.13	7.46	7.52	13.2	23.4	33.5	3.3	70	140	210	7.9	15.8	23.7	1 410
05B	8.00	5.00	3.00	2.31	2.36	7.37	7.11	7.11	3.71	3.71	0.08	5.64	4.77	4.90	8.6	14.3	19.9	3.1	50	100	150	4.4	7.8	11.1	820
06B	9.525	6.35	5.72	3.28	3.33	8.52	8.26	8.26	4.32	4.32	0.08	10.24	8.53	8.66	13.5	23.8	34.0	3.3	70	140	210	8.9	16.9	24.9	1 290
08A	12.70	7.92	7.85	3.98	4.00	12.33	12.07	10.42	5.29	6.10	0.08	14.38	11.17	11.23	17.8	32.3	46.7	3.9	120	250	370	13.9	27.8	41.7	2 480
08B	12.70	8.51	7.75	4.45	4.50	12.07	11.81	10.92	5.66	6.12	0.08	13.92	11.30	11.43	17.0	31.0	44.9	3.9	120	250	370	17.8	31.1	44.5	2 480
081	12.70	7.75	3.30	3.66	3.71	10.17	9.91	9.91	5.36	5.36	0.08	—	5.80	5.93	10.2	—	—	1.5	125	—	—	8.0	—	—	
083	12.70	7.75	4.88	4.09	4.14	10.56	10.30	10.30	5.36	5.36	0.08	—	7.90	8.03	12.9	—	—	1.5	125	—	—	11.6	—	—	
084	12.70	7.75	4.88	4.09	4.14	11.41	11.15	11.15	5.77	5.77	0.08	—	8.80	8.93	14.8	—	—	1.5	125	—	—	15.6	—	—	
085	12.70	7.77	6.25	3.60	3.62	10.17	9.91	8.51	4.35	5.03	0.08	—	9.06	9.12	14.0	—	—	2.0	80	—	—	6.7	—	—	1 340
10A	15.875	10.16	9.40	5.09	5.12	15.35	15.09	13.02	6.61	7.62	0.10	18.11	13.84	13.89	21.8	39.9	57.9	4.1	200	390	590	21.8	43.6	65.4	3 850
10B	15.875	10.16	9.65	5.08	5.13	14.99	14.73	13.72	7.11	7.62	0.10	16.59	13.28	13.41	19.6	36.2	52.8	4.1	200	390	590	22.2	44.5	66.7	3 330
12A	19.05	11.91	12.57	5.96	5.98	18.34	18.10	15.62	7.90	9.15	0.10	22.78	17.75	17.81	26.9	49.8	72.6	4.6	280	560	840	31.3	62.6	93.9	5 490
12B	19.05	12.07	11.68	5.72	5.77	16.39	16.13	16.13	8.33	8.33	0.10	19.46	15.62	15.75	22.7	42.2	61.7	4.6	280	560	840	28.9	57.8	86.7	3 720
16A	25.40	15.88	15.75	7.94	7.96	24.39	24.13	20.83	10.55	12.20	0.13	29.29	22.60	22.66	33.5	62.7	91.9	5.4	500	1 000	1 490	55.6	111.2	166.8	9 550
16B	25.40	15.88	17.02	8.28	8.33	21.34	21.08	21.08	11.15	11.15	0.13	31.88	25.45	25.58	36.1	68.0	99.9	5.4	500	1 000	1 490	60.0	106.0	160.0	9 530
20A	31.75	19.05	18.90	9.54	9.56	30.48	30.17	26.04	13.16	15.24	0.15	35.76	27.45	27.51	41.1	77.0	113.0	6.1	780	1 560	2 340	87.0	174.0	261.0	14 600
20B	31.75	19.05	19.56	10.19	10.24	26.68	26.42	26.42	13.89	13.89	0.15	36.45	29.01	29.14	43.2	79.7	116.1	6.1	780	1 560	2 340	95.0	170.0	250.0	13 500

表 1（续）

链号[a]	节距	滚子直径	内节内宽	销轴直径	套筒孔径	链条通道高度	内链板高度	外或中链板高度	过渡链节尺寸[b]			排距	内节外宽	外节内宽	销轴长度			止锁件附加宽度[c]	测量力			抗拉强度 F_u			动载强度[d,e,f]
															单排	双排	三排		单排	双排	三排	单排	双排	三排	单排
	p	d_1	b_1	d_2	d_3	h_1	h_2	h_3	l_1	l_2	c	p_t	b_2	b_3	b_4	b_5	b_6	b_7							F_d
	nom	max	min	max	min	min	max	max	min	min			max	min	max	max	max	max				min	min	min	min
	mm																		N			kN			N
24A	38.10	22.23	25.22	11.11	11.14	36.55	36.2	31.24	15.80	18.27	0.18	45.44	35.45	35.51	50.8	96.3	141.7	6.6	1 110	2 220	3 340	125.0	250.0	375.0	20 500
24B	38.10	25.40	25.40	14.63	14.68	33.73	33.4	33.40	17.55	17.55	0.18	48.36	37.92	38.05	53.4	101.8	150.2	6.6	1 110	2 220	3 340	160.0	280.0	425.0	19 700
28A	44.45	25.40	25.22	12.71	12.74	42.67	42.23	36.45	18.42	21.32	0.20	48.87	37.18	37.24	54.9	103.6	152.4	7.4	1 510	3 020	4 540	170.0	340.0	510.0	27 300
28B	44.45	27.94	30.99	15.90	15.95	37.46	37.08	37.08	19.51	19.51	0.20	59.56	46.58	46.71	65.1	124.7	184.3	7.4	1 510	3 020	4 540	200.0	360.0	530.0	27 100
32A	50.80	28.58	31.55	14.29	14.31	48.74	48.26	41.68	21.04	24.33	0.20	58.55	45.21	45.26	65.5	124.2	182.9	7.9	2 000	4 000	6 010	223.0	446.0	669.0	34 800
32B	50.80	29.21	30.99	17.81	17.86	42.72	42.29	42.29	22.20	22.20	0.20	58.55	45.57	45.70	67.4	126.0	184.5	7.9	2 000	4 000	6 010	250.0	450.0	670.0	29 900
36A	57.15	35.71	35.48	17.46	17.49	54.86	54.30	46.86	23.65	27.36	0.20	65.84	50.85	50.90	73.9	140.0	206.0	9.1	2 670	5 340	8 010	281.0	562.0	843.0	44 500
40A	63.50	39.68	37.85	19.85	19.87	60.93	60.33	52.07	26.24	30.36	0.20	71.55	54.88	54.94	80.3	151.9	223.5	10.2	3 110	6 230	9 340	347.0	694.0	1 041.0	53 600
40B	63.50	39.37	38.10	22.89	22.94	53.49	52.96	52.96	27.76	27.76	0.20	72.29	55.75	55.88	82.6	154.9	227.2	10.2	3 110	6 230	9 340	355.0	630.0	950.0	41 800
48A	76.20	47.63	47.35	23.81	23.84	73.13	72.39	62.49	31.45	36.40	0.20	87.83	67.81	67.87	95.5	183.4	271.3	10.5	4 450	8 900	13 340	500.0	1 000.0	1 500.0	73 100
48B	76.20	48.26	45.72	29.24	29.29	64.52	63.88	63.88	33.45	33.45	0.20	91.21	70.56	70.69	99.1	190.4	281.6	10.5	4 450	8 900	13 340	560.0	1 000.0	1 500.0	63 600
56B	88.90	53.98	53.34	34.32	34.37	78.64	77.85	77.85	40.61	40.61	0.20	106.60	81.33	81.46	114.6	221.2	327.8	11.7	6 090	12 190	20 000	850.0	1 600.0	2 240.0	88 900
64B	101.60	63.50	60.96	39.40	39.45	91.08	90.17	90.17	47.07	47.07	0.20	119.89	92.02	92.15	130.9	250.8	370.7	13.0	7 960	15 920	27 000	1 120.0	2 000.0	3 000.0	106 900
72B	114.30	72.39	68.58	44.48	44.53	104.67	103.63	103.63	53.37	53.37	0.20	136.27	103.81	103.94	147.4	283.7	420.0	14.3	10 100	20 190	33 500	1400.0	2 500.0	3 750.0	132 700

a 重载系列链条详见表 2。

b 对于高应力使用场合，不推荐使用过渡链节。

c 止锁件的实际尺寸取决于其类型，但都不应超过规定尺寸，使用者应从制造商处获取详细资料。

d 动载强度值不适用于过渡链节、连接链节或带有附件的链条。

e 双排链和三排链的动载试验不能用单排链的值按比例套用。

f 动载强度值是基于 5 个链节的试样，不含 36A，40A，40B，48A，48B，56B，64B 和 72B，这些链条是基于 3 个链节的试样。链条最小动载强度的计算方法见附录 C。

g 套筒直径。