МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Кафедра конструкції літальних апаратів

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
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«___» __________ 2022 р.

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

Тема: «Аванпроект дальньомагістрального пасажирського літака пасажиромісткістю 200 пасажирів»

Виконавець: ___________ **Сюй Деке**

Керівник: к.т.н., ___________ **Володимир Краснопольський**

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Київ 2022

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

PERMISSION TO DEFEND
Head of department
Dr.Sc., Professor
________ Sergiy IGNATOVYCH
«___» ___________ 2022

BACHELOR DEGREE THESIS
ON SPECIALTY
"AVIATION AND AEROSPACE TECHNOLOGIES"

Topic: "Preliminary design of the long-range passenger aircraft with up to 200 seats capacity"

Prepared by:	__________	**Xu Deke**
Supervisor: PhD	__________	**Volodymyr KRASNOPOLSKII**
Standard controller: PhD, associate professor	__________	**Sergiy KHYZHNYAK**

Kyiv 2022

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

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Освітньо-кваліфікаційний ступінь «Бакалавр»

Спеціальність 134 «Авіаційна та ракетно-космічна техніка»

Освітня програма «Обладнання повітряних суден»

ДОПУСТИТИ ДО ЗАХИСТУ
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«___» __________ 2022 р.

ЗАВДАННЯ

на виконання дипломної роботи студента

СЮЙ ДЕКЕ

1. Тема роботи: «Аванпроект дальньомагістрального пасажирського літака пасажиромісткістю 200 пасажирів», затверджена наказом ректора від 10 травня 2022 року №489/ст.

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

3. Вихідні дані до проекту: крейсерська швидкість V_{cr} = 850 км/год, дальність польоту L = 7200 км, крейсерська висота польоту H_{op} = 11000m, 200 пасажирів.

4. Зміст пояснювальної записки: вступ, основна частина, що включає аналіз літаків-прототипів і короткий опис проектованого літака, обґрунтування вихідних даних для розрахунку, розрахунок основних льотно-технічних та геометричних параметрів літака, компонування пасажирської кабіни, розрахунок центрування літака, спеціальна частина, введення та розрахунок пасажирського сидіння.

5. Перелік обов'язкового графічного матеріалу: загальний вигляд літака (А1×1), компонувальне креслення фюзеляжу (А1×1), дизайн пасажирського сидіння (А1×1).

6. Календарний план-графік

№ пор.	Завдання	Термін виконання	Відмітка про виконання
1	Отримання завдання, обробка статистичних даних.	23.05.2022-28.05.2022	
2	Розрахунок мас літака та його основних льотно-технічних характеристик.	28.05.2022-31.05.2022	

3	Розрахунок центрування літака.	31.05.2022-03.06.2022	
4	Розробка креслень по основній частині.	03.06.2022-05.06.2022	
5	Проектування пасажирського сидіння та розрахунки. Креслення спеціальної частини.	05.06.2022-12.06.2022	
6	Оформлення пояснювальної записки.	12.06.2022-14.06.2022	
7	Захист дипломної роботи	14.06.2022-19.06.2022	

7. Дата видачі завдання: «23» травня 2022 року.

Керівник дипломної роботи ____________ Володимир Краснопольський

(підпис керівника) П.І.Б.

Завдання прийняв до виконання ____________ Сюй Деке

(підпис студента) П.І.Б.

NATIONAL AVIATION UNIVERSITY

Faculty ____Aerospace______
Department __of Aircraft Design__
Educational degree __«Bachelor»__
Specialty 134 "Aviation and space rocket technology"
Educational program __"Aircraft equipment"__

APPROVED BY
Head of department D.Sc., professor
__________ Sergiy IGNATOVYCH
«___» _________ 2022.

TASK
for the bachelor thesis
XU DEKE

1. Topic: «Preliminary design of the long-range passenger aircraft with 200 passenger capacity» approved by the Rector's order №489/ст. «10» May 2022 year.
2. Thesis terms: since 23.05.2022 year till 19.06.2022 year.
3. Initial data: cruise speed V_{cr} = 850 km/h, flight range L = 7200 km, operating altitude H_{op} = 11000 m, 220 passengers.
4. Content: introduction; main part: analysis of prototypes and brief description of designing aircraft, choice of initial data, wing geometry calculation and aircraft layout, landing gear design, engine selection, center of gravity calculation, special part: introduction and calculation of the passenger seat.
5. Required material: general view of the airplane (A1×1), layout of the airplane (A1×1), passenger seat design (A1×1).
6. Thesis schedule

№	Task	Time limits	Done
1	Task receiving, processing of statistical data.	23.05.2022-28.05.2022	
2	Aircraft take-off mass determination and flight performances calculation.	28.05.2022-31.05.2022	
3	Aircraft centering determination.	31.05.2022-03.06.2022	
4	Graphical design of the aircraft and its layout.	03.06.2022-05.06.2022	
5	Design of passenger seat and calculations. Drawings of the special part.	05.06.2022-12.06.2022	
6	Completion of the explanation note.	12.06.2022-14.06.2022	

7	Preliminary examination and defense of the diploma work.	14.06.2022-19.06.2022	

7. Date: «23» May 2022 year.

Supervisor _____________ Volodymyr KRASNOPOLSKII

Student _____________ Xu Deke

РЕФЕРАТ

Дипломна робота «Аванпроект дальньо магістрального пасажирського літака пасажиромісткістю 200 пасажирів» містить:

57 сторінок, 15 рисунків, 8 таблиць, 13 літературних посилань

Об'єкт дослідження: процес проектування далекобійного пасажирського літака на 220 пасажирів.

Мета роботи: скласти ескізний проект авіалайнера та оцінити його льотні характеристики.

Методи проектування та розробки: за вихідними даними вибирається для аналізу найбільш підходящий прототип, вибирається найбільш досконала стратегія компоновки та геометричний розрахунок, отримуються технічні параметри та експлуатаційні характеристики літака, що проектується. Спеціальна частина розроблена з урахуванням зовнішнього вигляду та функціональності. Потім виконайте аналіз сил і міцність, щоб перевірити, чи відповідає міцність сидіння.

Інноваційність результатів: легше і зручніше пасажирське сидіння в спеціальному дизайні.

Зміст проектної роботи: розрахунки та креслення геометрії конструкції та компонування літака, розрахунки та креслення полегшеного пасажирського сидіння.

ПАСАЖИРСЬКИЙ ЛІТАК, АВАНПРОЕКТ ЛІТАКА, КОМПОНУВАННЯ ПАСАЖИРСЬКОЇ КАБІНИ, ЦЕНТРУВАННЯ ЛІТАКА, ЛЕГКЕ ПАСАЖИРСЬКЕ СИДІННЯ, РОЗРАХУНОК НА МІЦНІСТЬ

ABSTRACT

Bachelor thesis «Preliminary design of a long-range passenger aircraft with 200 passenger capacity»

57 pages, 15 figures, 8 tables, 14 references

Object of study – the design process of a long-range passenger aircraft with 220 passenger capacity.

Aim of bachelor thesis – to establish a preliminary design of an airliner and estimate its flight characteristics.

The methods of design and development – the most suitable prototype is selected for analysis according to the initial data, the most advanced layout strategy and geometric calculation are selected, and the technical parameters and performance data of the designed aircraft are obtained. Special part is designed with appearance and function. Then carry out force analysis and strength analysis to check whether the strength of the seat is qualified.

Innovativeness of results – a lighter and more comfortable passenger seat in special part design.

The content of design work – the calculations and drawings of geometry structure and aircraft layout, the calculations and drawings of lighter passenger seat.

PASSENGER AIRCRAFT, PRELIMINARY DESIGN, PASSENGER CABIN LAYOUT, CENTER OF GRAVITY CALCULATION, LIGHT PASSENGER SEAT, STRENGH CALCULATION

Format	№	Designation	Name	Quantity	Notes
			<u>General documents</u>		
A4	1	NAU 22 14X 00 00 00 97 TW	Task for work	1	
	2	NAU 22 14X 00 00 00 97	long-range passenger aircraft	2	
A1		Sheet 1	General view		
A1		Sheet 2	Fuselage layout		
A4	3	NAU 22 14X 00 00 00 97 EN	long-range passenger aircraft	57	
			Explanatory note		
			<u>Documentation for assembly units</u>		
A1	4	NAU 22 14X 00 00 00 97	Design of passenger seat	1	

		NAU 22.14X.00.00.00.97 EN				
Done by	Xu Deke	Preliminary design of long-range passenger aircraft with 220 passenger capacity (List of diploma work)	list	sheet	sheets
Supervisor	Krasnopolskii V.S.			9	57
St.control.	Khyzhniak S.V.				
Head of dep.	Ignatovich S.R.				

CONTENT

INTRODUCTION

The rapid development of the world economy has brought about economic and cultural exchanges between countries. At this time, the aviation industry has played a key role. It promotes world economic exchanges, promotes cultural exchanges and provides many employment opportunities. The development of the industry is mutually reinforcing. According to the survey, the commercial aircraft market is worth $85.3 billion in 2020 and is expected to reach $194.5 billion by 2026[1]. The level of the civil aviation industry can also express a country's technological manufacturing level and economic level, so in recent decades, countries around the world have vigorously developed the air transport industry. Especially in the context of the rapid development of China's social and economic development, there is a huge demand in the civil aviation transportation market.

Modern aircraft design Modern aircraft design has higher and higher requirements for economy while continuously pursuing safety, environmental protection and comfort. To evaluate the advanced nature of the aircraft, the first and foremost is the aerodynamic design level of the aircraft to reduce drag and increase lift [2].

General planning for the design of new passenger aircraft:

-aerodynamic optimization；

-technology;

-performance;

-manufacturing;

-operation;

-economics.

The purpose of this diploma work is to design an aircraft capable to transport 220 passengers and luggage over long distance and decrease the weight of the passenger seat by changing the material of seat’s frame.

1. PROJECT PART. PRELIMINARY DESIGN OF LONG RANGE AIRCRAFT

1.1 Analysis of prototypes and short description of designed aircraft

Aircraft design is a very complex and multi-process task. All the data of the aircraft is the best choice after complicated calculation and many experiments. And many aspects of optimization should be considered before choosing, such as aerodynamic geometry, flight performance and technology, manufacturing difficulty and economic characteristics, etc. Statistics and calculations were first used in this design work, and initial data and selected parameters were obtained after the experiment. These will be used by design calculations and data processing.

The maximum take-off weight determines the size of the wing, which is an important factor in determining flight performance, and the payload affects the size and shape of the fuselage, as well as the design of the landing gear. The shape and layout of an airliner affects the aerodynamic distribution and the location of the center of gravity.

In order to make the designed aircraft more in line with the aerodynamic requirements and performance requirements, the existing passenger aircraft in the market can be used as a reference to make the aircraft design work more reasonable. The selection of the optimal prototype based on initial data aids in the progress of the aircraft design.

The number of passengers of the prototype is about 220. It is a long-distance passenger aircraft, which has the characteristics of good performance and environmental protection. I chose Airbus 321neo and Boeing 767-300 as reference prototypes for this design work. The basic technical and functional data of prototypes are presented in table 1.1.

Table1.1-Basic technical and functional data of prototypes

PARAMETER	PLANES	
	A321neo	Boeing767-300
The type of airplane	Passenger	Passenger
Crew/flight attendant	2/6	2/6
Maximum take-off weight, m_{tow}, kg	97000	158760
Passenger's seat	240	218
The height of the Flight H_f, m	12100	13100
Most pay-load, $m_{c.max}$, kg	25500	40230
Range $m_{K.max}$, km	7400	9700
Take off distance L, m	1988	2410
Landing distance, m	1600	1700
Cruising speed, V, km/h	828	850
Number and type of engines	2×CFM International LEAP-1A	2×CF6-80C2
Thrust of each engine, KN	160	275
Pressure ratio	50	31.8
Bypass ratio	12.5	5.3
Length of aircraft, m	44.51	54.95
Diameter of fuselage, m	3.95	5.03
Wingspan, m	35.8	47.57
Wing sweepback on 1/4 chord, °	25	25

Research on the prototype and analysis of the data in the table above can provide very good application conditions for the design of the new aircraft in terms of shape and layout, so that the subsequent design tasks of the new aircraft can be carried out more reasonably and completed more smoothly.

1.2 Designed plane description

Here I choose the main data of A321neo as my design reference, because it is a medium and long-range narrow-body airliner, which is very close to the parameters of the design aircraft, and has many other advantages, such as high fuel efficiency and flight durability, etc. The prototype has a low-wing and sweepback wing, the sweepback angle on 1/4 chord equal to 25 degrees. It also has two high bypass ratio turbofan engines.

The overall goal of this design is to transport 220 passengers and their luggage, with a cruising Mach number of 0.7966, a cruising altitude of 11 kilometers, and a flight distance of 7200 meters with maximum payload. The main parts of the target aircraft are briefly described below.

1.2.1 Wing

The wing is a low-wing monoplane and its sweepback angle is 25°. The supercritical airfoil is used in this design work. The supercritical airfoil generally has a relatively small internal layout space. It needs to meet the requirements of the aerodynamic shape, motion mechanism and composite materials of the airfoil. relative position requirements. Supercritical wings generally undergo elastic deformation during flight, and it is necessary to combine different flight conditions to analyze the wing structure and system, and the gap requirements between systems and systems in detail under different motion limit states [3].

The wing is usually constructed from spars, stringers, ribs, and skin. The spars are the longitudinal force member of the wing, which mainly bear the bending moment and shear force [4]. The stringers support the skin, which absorb part of the axial force caused by the wing's bending moment. Ribs support the skin and maintain the cross-sectional shape of the wing, and are stiffening ribs where there are concentrated loads (such as landing gear and engines). The skin defines the outer surface of the wing that creates a streamlined shape. In order to keep the drag on the wing as low as possible, the lateral bending stiffness of the skin should be increased to reduce its deformation in flight. The aerodynamic loads act directly on the skin, which also suffers from bending moments.

While providing lift, the wing, together with the tail, ensures the stability of the aircraft, and can provide some lateral stability for the aircraft when there is a dihedral. Ailerons and spoilers are installed on the wings, and there are six spoilers on both sides. Two of them on the inner side are used as speed brakes, four on the outer side for rolling control, and all six are used for reducing lift force during landing. There are also high-lift devices such as slats and flaps on the leading and trailing edges of the wings, which can improve the take-off, landing or maneuverability of the aircraft. Other components such as engines and landing gear are installed on the wing, and the interior space of the wing is used to retract the landing gear, place some small equipment and store fuel.

1.2.2 Fuselage

The fuselage is circular section and semi-monocoque construction, which is constructed by the skin, stringers, longitudinal beams and frames. The fuselage has a diameter of 3.95 meters and is a narrow-body airliner. The fuselage fixes the wings, tail, landing gear and other components so that they are connected as a whole. At the same time used to load personnel, cargo, fuel and various equipment [5]. The girder mainly bears the axial force caused by bending, and also supports the skin. The skin constructs the aerodynamic shape of the fuselage and keeps the surface smooth to withstand localized aerodynamics. The bulkheads are divided into ordinary bulkheads and reinforced bulkheads. Ordinary bulkheads are used to maintain the cross-sectional shape of the fuselage and bear the local loads of the skin. Reinforcing bulkheads also transfer loaded mass forces and loads from other components (such as wing, tail, etc.) to the skin.

The decision to use new materials for the body structure of a new generation of large passenger aircraft is based on the fact that the overall layout of large passenger aircraft in the next 20 to 30 years will not be very different from the current airline aircraft, but the overall performance, safety, economy and environmental protection requirements, etc. In terms of development, there will be a great increase in the development trend and the growth of demand for wide-body passenger aircraft on the route is formulated [6].

1.2.3 Tail unit

The tail plays a vital role in the stability and maneuverability of the aircraft, and is divided into a horizontal tail and a vertical tail. The horizontal and vertical sweep angles are 29 degrees and 34 degrees respectively, which are larger than the wing sweep angle, making the aircraft less likely to lose control during high-speed flight. The aerodynamic shape and layout of the rear wing must be symmetrical so that the same loads are maintained. In terms of material use, most of the tail is made of duralumin, and the front and rear edges of the horizontal and vertical tail can be made of composite materials such as glass fiber.

1.2.4 Crew cabin

The aircraft cockpit is equipped with various flight instruments and aircraft control systems, separated from the passenger cabin by a door, as well as emergency exits and equipped with some emergency items, such as life jackets, oxygen masks, fire extinguishers, etc. A total of six windshields provides the driver with a clear forward view and are electrically heated to prevent fogging and icing. The cockpit uses a digital fly-by-wire flight control system and side joysticks, and performance data is displayed digitally. It also uses a double-pilot system, with a captain and a co-pilot. Utilize advanced cockpit technology to enhance cockpit interactivity, increase safety, increase efficiency, and reduce pilot workload.

1.2.5 Control system

According to the source of the manipulation command, it can be divided into manual control (main control system and auxiliary control system) and automatic control system. The main control system controls the elevator, rudder and ailerons through the joystick to control the flight trajectory and attitude of the aircraft. Auxiliary systems include flaps, spoilers, fins, etc. to control the flight state. The automatic control commands come from the system's sensors and can respond to external disturbances to maintain a specified flight state. Self-driving technology reduces the workload of the crew.

The use of fly-by-wire systems is very common, and its reliability cannot be lower than that of mechanical control systems, which can improve aircraft handling quality and performance. When the system detects an error in the control state, the ECAM display will light and sound to alert the pilot.

1.2.6 Landing gear

Landing gear is an important load-bearing and maneuverable component of an aircraft. It is a necessary support system for aircraft take-off, landing, rolling, ground movement and parking. Its performance is directly related to the use and safety of the aircraft. Most of the energy at the moment of landing and touchdown is absorbed by the shock absorber of the landing gear. The retractable system generally uses hydraulic pressure as the normal power source, it reduces drag and improves aircraft performance. The landing gear also has the wheel braking system and the turning system [7].

This design uses the front three-point landing gear. The layout has the advantages of stability in the roll direction, simpler landing maneuvers, shortened landing roll distance, and short take-off distance. The nose landing gear has two wheels, and each main landing gear has four wheels, and the main landing gear carries about 80% of the aircraft's load.

1.3 Geometry calculations for the main parts of the aircraft

The computational task is particularly important in the preliminary design, which determines the geometric parameters of the aerodynamic shape of the aircraft, especially the need to obtain a good wing, which lays the foundation for all aircraft layouts. All calculated data and parameters must meet the requirements to provide the optimal configuration for the aircraft design.

1.3.1 Wing geometry calculation

In the first step, we use the aircraft's maximum takeoff weight m_0 and the wing load p_0 to determine the area of the wing.

Full wing area with extensions is by the formula:

$$S_w = \frac{m_0 \cdot g}{p_0} = \frac{116422 \cdot 9.8}{5557} = 205.35\ m^2,$$

where S_w – wing area, m^2; g –gravitational acceleration, m/s^2.

Relative wing extensions area is 0.05.

Wing span is by the formula:

$$l = \sqrt{S_w \cdot \lambda_w} = \sqrt{205.35 \cdot 9.4} = 43.9\ m,$$

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

The root chord and tip chord are determined by the following calculations:

$$\frac{S_w}{2} = \frac{C_{root}C_{tip}}{2} \cdot \frac{Span}{2} \rightarrow \frac{205.35}{2} = \frac{C_{root}C_{tip}}{2} \cdot \frac{43.9}{2}$$

$$TR = \frac{C_{root}}{C_{tip}} \rightarrow 4.11 = \frac{C_{root}}{C_{tip}}$$

$$C_{root} = 7.52\text{m}$$

$$C_{tip} = 1.84\text{m}$$

Where TR–taper ratio; C_{root}–root chord; C_{tip}–tip chord.

Maximum wing thickness is by the formula:

$$c_i = c_w \cdot b_t = 0.12 \cdot 1.84 = 0.221\ m,$$

where c_i – wing thickness, m; c_w – related wing thickness.

On board chord is by the formula:

$$b_{ob} = b_0 \cdot \left(1 - \frac{(\eta_w - 1) \cdot D_f}{\eta_w \cdot l_w}\right) = 7.52 \cdot \left(1 - \frac{(4.11 - 1) \cdot 3.95}{4.11 \cdot 43.9}\right) = 6.995\ m,$$

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

The wings of modern civil airliners are all swept wings, and the swept angle of the wing is the angle between the quarter chord and the vertical line of the longitudinal axis of the fuselage. If the taper ratio is large, the fuel use of the aircraft will increase, and it will also affect the resistance in all aspects. An aspect ratio of 9.4 and a taper ratio of 4.11 are acceptable here.

Here I use the geometrical method of mean aerodynamic chord determination (fig.1.1). And I get the value of mean aerodynamic chord is equal: $b_{MAC} = 5.254\ m$.

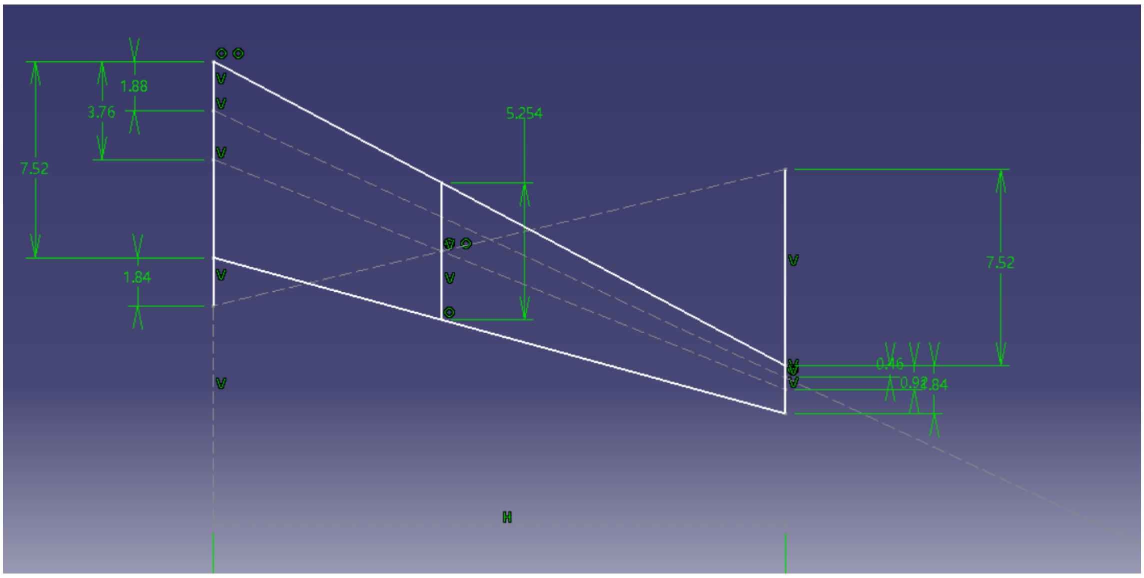

Fig. 1.1. Determination of mean aerodynamic chord.

After this it is necessary to determine the geometry of the ailerons and high lift devices on the wing.

The following is the parameter determination process of the aileron:

Aileron's span is by the formula:

$$l_{ail} = 0.4 \cdot \frac{l}{2} = 0.4 \cdot \frac{43.9}{2} = 8.78\ m,$$

Aileron's chord is by the formula:

$$b_{ail} = 0.24 \cdot C_{tip} = 0.24 \cdot 1.84 = 0.442 m$$

Aileron's area is by the formula:

$$S_{ail} = 0.065 \cdot \frac{S_w}{2} = 0.065 \cdot \frac{205.35}{2} = 6.67\ m^2$$

Here are the calculations of aerodynamic compensation of the ailerons:

Axial compensation $S_{axinail} \le (0.25\ldots0.28)\ S_{ail} = 0.26 \cdot 6.67 = 1.734 m^2$

Inner axial compensation $S_{inaxinail} = (0.3 \sim 0.31) \cdot Sail = 0.305 \times 6.67 = 0.8 m^2$

The calculations of area of ailerons trim tab:

For two engine airplanes: $S_{tail} = (0.04 \sim 0.06) \cdot S_{ail} = 0.05 \times 6.67 = 0.334 m^2$

Modern airliners are increasingly concerned with reducing relative wingspan and aileron area, and we use spoilers in conjunction with ailerons for better lateral stability control. Improve the take-off and landing characteristics of the aircraft by increasing the span and area of the high-lift device.

It is also necessary to determine the geometric parameters of the wing high lift device.

In the modern aircraft design the rate of the relative chords of wing high-lift devices is:

b_{sf} = 0.25…0.3 – for the split edge flaps;

b_f = 0.28…0.3 – for the one slotted and two slotted flaps;

b_f = 0.3…0.4 – for three slotted flaps and Fowler's flaps;

b_s = 0.1…0.15 –for the slats.

For my high lift devices design I use the two-slotted flaps and slats, so the flap chord and slat chord are:

$$b_{fl} = (0.28 \sim 0.3) \cdot C_{tip} = 0.29 \times 1.84 = 0.533 \text{ m}$$

$$bs = 0.12 \times 1.84 = 0.211 m$$

When choosing the layout of the high-lift device, we need to learn from the advanced design technology at domestic and abroad. The structural scheme and hinge connection scheme must be reasonable and meet the requirements of designing the wing of the aircraft.

1.3.2 Fuselage layout

The interior of the fuselage carries passengers, crew members and cargo, etc., which plays an important role in ensuring their safety. The payload of the aircraft is closely related to the diameter of the fuselage. The cross-section of the fuselage of the passenger aircraft designed this time is circular, and it is a narrow-body passenger aircraft, which also has certain restrictions on the internal layout.

First, the length of the fuselage is by the formula:

$$l_f = FR \cdot D_f = 11.26 \cdot 3.95 = 44.477 \ m$$

where FR-fineness ratio of the fuselage.

According to the scale measurement results of the prototype, the fineness ratio of the front fuselage and the rear fuselage can be determined as λ_{fnp}=2.1 and λ_{frp}=2.64.

So, the length of fuselage nose part is equal to:

$$l_{fwd} = 2.1 * 3.95 = 8.295\ m$$

The length of the fuselage rear part is equal to:

$$l_{aft} = 2.64 * 3.95 = 10.428\ m$$

Now determine the height, width, and layout of the mid-cabin of the aircraft.

For passenger aircraft, the mid-fuselage is mainly determined by the size and layout of the cabin. For long-haul aircraft, cabin height h1 = 1.9 m; aisle width bp = 0.6 m; window-to-floor distance h2 = 1 m; luggage space height h3 = 0.9~1.3 m.

The cabin height is equal to:

$$H_{cabin}=1480+0.17B_{cabin}=1480+0.17\cdot 3920=2146.4m$$

where H_{cabin} – cabin height, m; B_{cabin} – width of the cabin, m.

There are 30 business class passengers and 190 economy class passengers. Their seating arrangement is a row of '3+3'. The width and length of the cabin should be reasonable and should not exceed the diameter of the fuselage and the length of the middle of the fuselage.

The formula for the cabin width is：

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

where n_3 – number of blocks with 3 seats; b_3 – width of three-seat blocks, mm; n_{aisle} – number of aisles; b_{aisle} – width of aisle, mm; δ_{wall} – width of the wall， mm； δ – distance between external armrests to the decorative panels, mm.

The width of business class is：

$$B_{cabin.B} = 2\cdot 1585 + 510 + 2\cdot 50 + 2\cdot 80 = 3930mm$$

The width of economy class is:

$$B_{cabin.eco} = 2 \cdot 1550 + 550 + 2 \cdot 50 + 2 \cdot 1000 = 3950\ mm$$

The length of passenger cabin is by formula:

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

where L_{cabin} – length of passenger cabin, mm; L_1 – distance from the wall to the back of the seat in first row, m; L_2 – distance from the back of the seat in last row to the wall, mm; n – number of rows; $L_{seatpitch}$ – seat pitch, mm.

So, the length of business class is:

$$L_{cabin.B} = 1200 + (5-1) \cdot 900 + 250 = 5050mm$$

The length of economy class is:

$$L_{cabin.eco} = 1200 + (32-1) \cdot 670 + 250 = 22220mm$$

1.3.3 Luggage compartment

Taking into account the unit load on the floor K = 400…600 kg/m^2

The area of cargo compartment is by formula:

$$S_{cargo} = \frac{M_{bag}}{0.4K} + \frac{M_{cargo\,\&mail}}{0.6K} = \frac{20 \cdot 220}{0.4 \cdot 600} + \frac{15 \cdot 220}{0.6 \cdot 600} = 27.5\ m^2$$

where S_{cargo} – area of cargo compartment, m^2; M_{bag} – mass of the baggage, kg; $M_{cargo\&mail}$ – mass of the cargo and mail, kg; K=600kg/m^2.

The volume of cargo compartment is equal to:

$$v_{cargo} = v_c \cdot n_{pass} = 0.2 \cdot 220 = 44\ m^3,$$

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

The design layout of the luggage compartment is carried out according to the prototype.

1.3.4 Galleys

Volume of galleys is by the formula:

$$\nu_{galley} = \nu_g \cdot n_{pass} = 0.11 \cdot 220 = 24.2\ m^3,$$

where ν_{galley} – volume of galleys, m^3; ν_g – galley volume coefficient; n_{pass} – number of passengers.

Area of galleys is equal to:

$$S_{galley} = \frac{\nu_{galley}}{H_{cabin}} = \frac{24.2}{2.1464} = 11.27\ m^2,$$

where S_{galley} – area of galley, m^2;H_{cabin}–the height of cabin,m.

The design of the galleys are carried out according to the prototype.

1.3.5 Lavatories

Number of toilet facilities is determined by the number of passengers and flight duration: with t > 4h, one toilet for 40 passengers. The number of lavatories is equal to:

$$n_{lav} = \frac{n_{pass}}{40} = \frac{220}{40} = 5.5$$

where n_{lav} – number of lavatories.

So, the number of lavatories should be 6.

Area of one lavatory:

$$S_{lav} = 0.95 \cdot 1.15 = 1.0925\ m^2$$

Total area of lavatories:

$$S_{Total\ lav} = 1.0925 \cdot 6 = 6.555\ m^2$$

The design of the lavatories are carried out according to the prototype.

1.3.6 Layout and calculation of basic parameters of tail unit

The geometry of the rear wing is very important and complex. It plays a very important role in the stability and maneuverability of the aircraft, and it provides yaw and pitch moment. The center of gravity of the tail should be placed in front of the focal point of the aircraft, so as to ensure the longitudinal stability of the aircraft.

Most of the geometry calculations for the tail will begin below.

Area of vertical tail unit is equal to:

$$S_{VTU} = (0.12 \dots 0.2)S_{wing} = 0.19 \cdot 205.35 = 39.02\ m^2$$

Area of horizontal tail unit is equal to:

$$S_{HTU} = (0.18 \dots 0.25)S_{wing} = 0.2 \cdot 205.35 = 41.07\ m^2$$

Determination of the arms of horizontal TU and vertical TU

$$S_{HTU} = \frac{b_{MAC} \cdot S}{L_{HTU}} \cdot A_{HTU}$$

$$41.07 = \frac{5.254 * 205.35 * 0.7}{L_{HTU}}$$

L_{HTU}=18.39m

$$S_{VTU} = \frac{l \cdot S}{L_{VTU}} \cdot A_{VTU}$$

$$39.02 = \frac{43.9 * 205.35 * 0.1}{L_{VTU}}$$

L_{VTU}=18.48m

Where L_{HTU} and L_{VTU} - arms of horizontal TU and vertical TU; S and l – wing span and area. A_{HTU}, A_{VTU} – coefficients of static moments.

Determination of the elevator area and direction:

Elevator area:

$$S_{el} = (0.3 \dots 0.4)S_{HTU} = 0.3 \cdot 41.07 = 12.321\ m^2$$

Rudder area:

$$S_{rud} = (0.2 \dots 0.22)S_{VTU} = 0.21 \cdot 39.02 = 8.194\ m^2$$

Choose the area of aerodynamic balance.

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

Elevator balance area is equal to:

S_{eb} = (0.22...0.25) Sel=0.23*12.321=2.83m^2

Rudder balance area is equal to:

S_{rb}= (0.2...0.22) Srd=0.2*8.194=1.64m^2

The area of rudder trim tab is equal to:

$$S_{tabs}= (0.08...0.12)\ S_{rudder}=0.1*8.194=0.82m^2$$

Area of elevator trim tab is equal to:

$$S_{etr}=(0.08\sim0.12) \cdot S_{el} = 0.1 \times 12.321 = 1.232\ m^2$$

Span of HTU and VTU for low wing aircraft:

$$L_{HTU}=(0.32\sim0.5) \cdot l_w = 0.373 \times 43.9 = 16.4m$$

$$H_{VTU}=(0.14\sim0.2) \cdot l_w = 0.177\times 43.9=7.757m$$

For aircraft with Mach number less than 1, η_{VTU}=1~3.7, η_{HTU}=2~3.

The values I take here are η_{VTU}=2.67 and η_{HTU}=2.67.

Tip chord of horizontal stabilizer is:

$$b_{tHTU} = \frac{2S_{HTU}}{(1+\eta_{HTU})*l_{HTU}} = \frac{2*41.07}{(1+2.67)*16.4} = 1.2m$$

Root chord of horizontal stabilizer is:

$$b_{rHTU} = b_{tHTU} \cdot \eta_{VTU} = 1.2 \times 2.67 = 3.2\ m$$

Tip chord of vertical stabilizer is:

$$b_{tVTU} = \frac{2S_{VTU}}{(1+\eta_{VTU})*l_{VTU}} = \frac{2*39.02}{(1+2)*7.757} = 2.5m$$

Root chord of vertical stabilizer is:

$$b_{rVTU} = b_{tVTU} \cdot \eta_{VTU} = 2.5 \times 2.6=6.5m$$

Sweep Angle of horizontal tail is 29°;

Sweep Angle of vertical tail is 34°.

1.3.7 Landing gear design

In order to design a landing gear that meets the requirements, it is necessary to strictly calculate the relative position of the main landing gear and the nose landing gear, determine the load on each landing gear according to the landing gear layout and take-off weight, and then select the appropriate size and strength. In this layout, the main scheme of the landing gear is mainly based on the prototype.

Below are the calculations for the position and load of the landing gear.

Main wheel axes offset is equal to:

$$Bm = k_e \cdot b_{MAC} = 0.2 \cdot 5.254 = 1.05\ m,$$

where k_e – coefficient of axes offset; *Bm*– main wheel axes offset, m.

Landing gear wheel base is:

$$B = k_b \cdot l_f = 0.4 \cdot 44.477 = 17.8\ m,$$

where *B* – wheel base, m; k_b – wheel base calculation coefficient.

The nose landing gear only carries 6...10% of aircraft weight.

Front wheel axial offset is equal to:

$$B_n = B - Bm = 17.8 - 1.05 = 16.75m,$$

where B_n – nose wheel axes offset, m.

Wheel track is equal to:

$$T = k_T \cdot B = 0.6 \cdot 17.8 = 10m,$$

where *T* – wheel track, m; k_T – wheel track calculation coefficient.

The wheels of the landing gear are selected according to size and load. Dynamic loads that need to be considered during takeoff and landing of an aircraft. The type and internal pressure of the pneumatic device depend on the surface of the airport runway. The selection of tires suitable for various conditions of the aircraft with size and bearing capacity is the guarantee for the normal use of the aircraft.

Nose wheel load is equal to:

$$F_{nose} = \frac{B_m \cdot m_0 \cdot 9.81 \cdot K_g}{B \cdot Z} = \frac{1.05 \cdot 116442 \cdot 9.81 \cdot 2}{17.8 \cdot 2} = 67.382\ KN$$

Where F_{nose} – nose wheel load, N; k_g– dynamics coefficient; *Z* – number of wheels on each strut.

Main wheel load is equal to:

$$F_{main} = \frac{(B - B_m) \cdot m_0 \cdot 9.81}{B \cdot n \cdot z} = \frac{16.75 \cdot 116442 \cdot 9.81}{17.8 \cdot 2 \cdot 2 * 2} = 134.364\ KN$$

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

The tire specifications selected according to the load borne by each tire of the landing gear are shown in table 1.2.

Table 1.2– The tires for landing gear of designing aircraft

Main gear		Nose gear	
Tire size	Ply rating	Tire size	Ply rating
49×18.0-22 mm	30	30×8.8R15 mm	16

1.3.7 Choice and description of power plant

According to the calculated initial parameters, the thrust required for the take-off of the aircraft is 173.99 kN. I chose two turbofan engines with high bypass ratio used by the prototype. Their specifications are shown in Table 1.3.

Table 1.3 - Parameters of selected engines

Model	Thrust (KN)	Bypass ratio	Pressure ratio	Wet weight (kg)
CFM International LEAP 1A	143.05	11	40	2990
Pratt & Whitney PW1100G-JM	120.43	12.5	35	2857.6

1.4 Determination of the aircraft center of gravity position

The position of the center of gravity of the aircraft has a great influence on the balance and control of the aircraft. This is a safety issue and one of the most important issues to be considered in the aircraft design process. The position of the center of gravity of the aircraft is constantly changing during the flight. Of course, the range of change must have a certain controllable range according to the different aircraft types.

1.4.1 Determination of centering of the equipped wing

The mass of the wing, the mass of some hydraulic systems and anti-icing systems, the mass of some equipment, and the mass of fuel and landing gear all belong to the mass of the equipped wing. Their centroid distributions are shown in Table 1.4. The barycentric coordinates of the equipped wing can be determined by the following formula:

$$X'_w = \frac{\sum m'_i \cdot x_i}{\sum m'_i},$$

where X'_w – center of mass for equipped wing, m; m'_i – mass of a unit, kg; x_i – center of mass of the unit, m.

Table 1.4 - Trim sheet of equipped wing masses

N	Object name	Mass		C.G coordinates X_i, m	Moment of mass
		units	total mass m_i, kg		
1	wing	0.091	10596.222	2.25922	23939.19667
2	fuel system	0.0103	1199.3526	2.23295	2678.094388
3	Flight control system, 30%	0.00153	178.15626	3.1524	561.619794
4	electrical equipment, 10%	0.00307	357.47694	0.5254	187.8183843
5	anti-ice system , 40%	0.00804	936.19368	0.5254	491.8761595
6	hydraulic systems , 70%	0.01022	1190.03724	3.1524	3751.473395
7	power plant	0.09195	10706.8419	-3	-32120.5257
8	equipped wing without landing gear and fuel	0.21611	25164.28062	-0.020284582	-510.4469118
9	nose landing gear	0.00799	930.37158	-12.2923	-11436.40657
10	main landing gear	0.03196	3721.48632	1.0508	3910.537825
11	fuel	0.34294	39932.61948	2.25922	90216.57258

	Total	0.599	69748.758	1.178232549	82180.25692

Finally, the result of calculation through excel to get X'_w=1.1782m.

1.4.2 Determination of centering of the equipped fuselage

Use the same method to obtain the distribution table of the center of gravity of the equipped fuselage (Table 1.5). The CG coordinates of the equipped fuselage are determined by formula:

$$X'_f = \frac{\sum m'_i \cdot x_i}{\sum m'_i}$$

where X'_f – center of mass for equipped fuselage, m; m'_i – mass of a unit, kg; x_i – center of mass of the unit, m.

Table 1.5 - Trim sheet of equipped fuselage masses

N	Objects names	Mass		C.G coordinates Xi, м	Moment of mass
		units	total mass		
1	fuselage	0.09802	11413.64484	22.2385	253822.3408
2	horizontal tail	0.00941	1095.71922	41	44924.48802
3	vertical tail	0.00934	1087.56828	42.5	46221.6519
4	radar	0.0029	337.6818	0.5	168.8409
5	radio equipment	0.0022	256.1724	0.8	204.93792
6	instrument panel	0.005	582.21	1.5	873.315
7	aero navigation equipment	0.0043	500.7006	2	1001.4012
8	flight control system 70%	0.00357	415.69794	22.2385	9244.498639
9	hydraulic system 30%	0.00438	510.01596	31.1339	15878.7859
10	electrical equipment 90%	0.02763	3217.29246	22.2385	71547.75837
11	Anti- ice system, 20%	0.00402	468.09684	35.5816	16655.63452
12	air-conditioning system, 40%	0.00804	936.19368	22.2385	20819.54315
13	lining and insulation	0.0058	675.3636	22.2385	15019.07342
14	Not typical equipment	0.0035	407.547	4.5	1833.9615
15	passenger seats (business)	0.001923705	224	7.5	1680
16	passenger seats (economic class)	0.009893337	1152	24.2	27878.4

Contiuation of the table 1.5

17	seats of flight attendance	0.000412222	48	22.5	1080
18	seats of pilot	0.000137407	16	2	32
19	emergency equipment	0.000533328	62.1018	28	1738.8504
20	lavatory1, galley 1	0.00585	681.1857	9.5	6471.26415
21	lavatory2, galley 2	0.00585	681.1857	42.5	28950.39225
	additional equipment	0.00986	1148.11812	4.5	5166.53154
	operational items	0.006	698.652	23	16068.996
22	equipped fuselage without payload	0.22857	26615.14794	22.00260795	585602.6656
23	Passengers(business)	0.016351488	1904	7.5	14280
24	Passengers(economy)	0.112124491	13056	24.2	315955.2
25	on board meal	0.002834029	330	24.8	8184
26	baggage	0.034008348	3960	21.6	85536
27	cargo, mail	0.002102334	244.8	25	6120
28	crew	0.001202315	140	2	280
29	flight attendant	0.003606946	420	22.5	9450
30	TOTAL	0.400799951	46669.94794	21.97148081	1025407.866
	TOTAL fraction	0.999799951			

Similarly, the calculation result here can be obtained: X'_f=21.9715m.

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

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

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

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

where m_0 – aircraft maximum takeoff mass, kg; m_f – mass of fully equipped fuselage, kg; m_w –mass of fully equipped wing, kg; C – distance from MAC leading edge to the C.G. point, determined by the designer.

C = (0,22...0,25) B_{MAC} – for low wing airplane;

This design choice is C=0.23B_{MAC}

The final calculation result is X_{MAC}=20.7m

1.4.3 Calculation of center of gravity positioning variants

According to the data obtained in the first two tables, and then calculated and analyzed, we can get the list of mass objects for center of gravity variant calculation in table 1.6 and center of gravity position variants in different situations in table 1.7.

Table 1.6 Calculation of the C.G. positioning variants

N	Object name	mass, m_i, kg	C.M. coordinate X_i, м	Mass moment kg·m
1	equipped wing (without fuel and landing gear)	25164.28	20.69	520566.48
2	Nose landing gear (extended)	930.37	8.00	7442.97
3	main landing gear (extended)	3721.49	21.25	79081.58
4	fuel reserve	4063.83	22.97	93330.75
5	fuel for flight	35868.79	22.97	823770.85
6	equipped fuselage (without payload)	26615.15	22.00	585602.67
7	Passengers(economy)	13056	24.2	315955.20
8	Passengers(business)	1904	7.5	14280.00
9	on board meal	330	24.8	8184.00
10	baggage	3960	21.6	85536.00
11	cargo, mail	244.8	25	6120.00
12	flight attend	140	2	280.00
13	crew	420	22.5	9450.00
14	Nose landing gear (retracted)	930.37	6.5	6047.42
15	main landing gear (retracted)	3721.49	21.25	79081.58

Table 1.7 - Airplanes C.G. position variants

N	name	Mass, m_i kg	mass moment m_iX_i, kg·m	center of mass, $X_{c.m.}$	Centre of gravity position
1	take off mass (L.G. extended)	116418.71	2549600.50	21.90026493	0.227114218
2	take off mass (L.G. retracted)	116418.71	2548204.95	21.88827753	0.224832643
3	landing weight (LG extended)	80549.91	1725829.65	21.42559319	0.136769387
4	ferry version (without payload, max fuel, LG retracted)	96783.91	2117849.75	21.88225124	0.223685651
5	parking version (without payload, without fuel for flight, LG extended)	60495.11	1286024.45	21.25831994	0.104932074

Conclusion to the project part

Prototypes were first selected for analysis based on initial data and selected parameters, using an advanced aircraft-like layout design in both the wing and fuselage of the aircraft. This design work mainly focuses on aerodynamic shape and layout design.

The following is the content of the design work:

- geometric calculations of wings, fuselage and tail;
- Calculation and design of the internal layout of the fuselage (cabin, luggage compartment, toilet, galley, etc.)；
- determination of the position and load of the landing gear, selection of tires;
- Reasonable choice of engine;

- Determination of the position of the center of gravity of the aircraft and the range of variation.

The designed aircraft is a long-range narrow-body passenger aircraft, and the cabins are divided into business class and economy class, both of which adopt a single-aisle scheme. The wings are equipped with high lift devices such as flaps and slats. Prototype engines are suitable for this design aircraft, they are CFM International LEAP 1A and Pratt & Whitney PW1100G-JM.

The variation range of the position of the center of gravity of the aircraft is 10.49%~22.71%, the results are reasonable, and the design results meet the requirements of stability and maneuverability.

Aircraft design technology will only develop towards the advanced, pursuing the goals of weight reduction, environmental protection and economy to the future design trend.

2. SPECIAL PART. THE LIGHTER PASSENGER SEAT DESIGN

2.1 Introduction

The role of airline seats is to give passengers safety and comfort during flight, and they are usually installed in rows in the cabin of the fuselage. In the next few decades, the market trend of new aircraft delivery in the world's civil aviation is still very large, which will promote the expansion of the aviation interior market, and aviation seats, as an important part of aviation interiors, account for about 30% of the total interior market share, the future market development of aviation seats will be very rapid [8]. In recent years, my country's civil aviation manufacturing has flourished, and the localization of aviation seats will be one of the trends of my country's aviation manufacturing enterprises in the future.

In 2016 alone, 3.6 billion passengers worldwide chose to travel by air. The most important thing for passengers is nothing more than the safety and comfort of airline seats, among which the comfort of seats is particularly important, which will affect the passenger's riding experience and journey quality [9]. During long-haul flights, passengers may experience physical or psychological discomfort, and the so-called "economy class syndrome" may occur at this time. Therefore, under the constraints of economy and safety, it is an important goal to improve the comfort of economy class seats as much as possible.

The goal of this design is to change the material and structure of the seat frame compared to the traditional economy class seat, so that the seat is lighter, has complete functions, and meets the safety and strength standards.

2.2 Basic structure and important functions of the passenger seat

The seats in the economy class should take into account both comfort and economy issues, and provide passengers with the most complete functions and the best comfort while controlling costs. Especially in the long-range passenger aircraft similar to the design goal of this time, the long-term flight opportunity will increase the tiredness of the flight. The basic structure of the economy class seat is shown in figure 2.1.

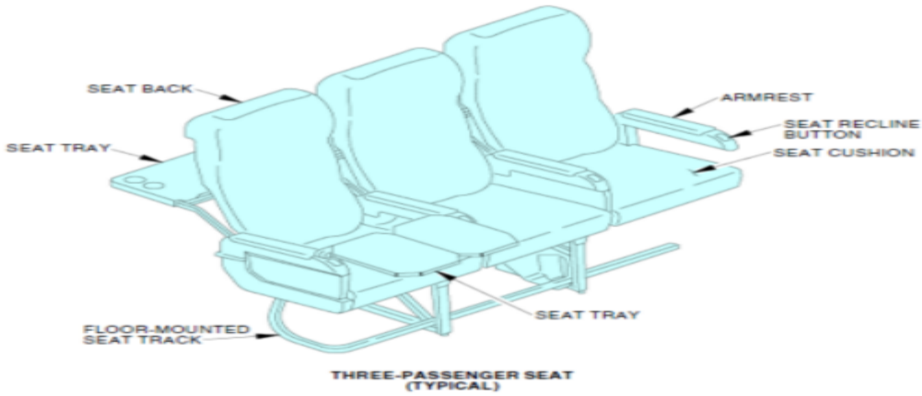

Fig.2.1 The basic structure of the economy class seat

Whether it is a double or triple seat, it is composed of the following parts, that is, the seat frame composed of the seat back, seat surface and chair legs, armrests, seat belt components, shock-proof cushions, folding small dining table, Seat surface decorative cover, life jacket storage bag and other main components. The structure and function of the above components are basically the same as those of the business class seats.

Based on the consideration of the overall layout of the passenger cabin, the economy class seats are divided into two types: double and triple; and because the seat rails installed on the floor of the cabin are comprehensively utilized stress components, the legs of the seats are on the seat frame. Consequences of unreasonable location of the connection. That is to say, the seat slide rails on the floor are arranged and distributed according to the force-bearing components, and the seat installation on it is in an obedient position. For the double seat, the legs of the chair by the central aisle are too biased. outside. If it is not, it will tilt the legs; if the legs are neither, but not tilted, then move the seat to the center aisle. The result is a narrowing of the central aisle and an increased gap between the seat and the side walls. This is also clearly unacceptable.

Important functions of the seat

(1) Adjustable headrest

Most long-haul aircrafts have seats with adjustable headrests in all classes, allowing passengers to adjust the headrest for comfort.

(2) Adjustable lumbar support

Electrically adjustable timber supports are located on most long-haul first and business class seats. Rarely, economy class may also include some mechanically adjustable lumbar support for long-haul flights. However, with the trend towards slimmer seats in economy class, this convenience has all but disappeared in most new economy installations.

(3) Electronic equipment

Seats may be equipped with power ports for small appliances and ports, for headphones Seats may have power ports, for small appliances and headphone ports for audio entertainment. Some airlines also place television screens behind each seat as part of the in-flight entertainment system on long-haul planes [10].

Market seat design example analysis

(1) Airgo economy class aviation concept seat (fig 2.2)

Fig 2.2 Airgo economy class aviation concept seat

Innovative features: 1. Material innovation: lightweight nylon is used for the seat back and seat surface to reduce the thickness and weight of the seat and increase the space.

2. Functional innovation: The seat is separated from the functional area, and the dining table and entertainment screen are installed on the luggage compartment.

(2) "Air Knight" semi-upright seat (fig 2.3)

Fig 2.3 "Air Knight" semi-upright seat

Innovative features: 1. Semi-upright seat, which compresses the space to the maximum extent, while keeping the passengers in a "sit" posture. Increase seating and economic benefits by reducing personal space. This seat is not suitable for long flights.

(3) Morph aircraft seat (fig 2.4)

Fig 2.4 Morph aircraft seat

Innovative features: 1. Functional innovation: The width of each seat can be adjusted according to the size of the person's body. The seat as a whole cannot be tilted. The adjustment of the internal structure can change the tilt angle and the sitting posture of the human body without affecting the rear passengers. Optimized space utilization [11].

2.3 The lighter passenger seat design

For aircraft design, aim for every gram of weight lost, so that an extra gram of cargo can be transported. In this seat design, the weight of other structures other than the seat frame is unlikely to change significantly. So, changing the material and structure of the seat frame to make the overall weight of the seat less than a traditional seat. Secondly, it is full of functions, so that passengers in the economy class have higher comfort. In general, it is worth trying to reduce the weight of the seat and improve the comfort of passengers under the condition of increasing the appropriate cost.

2.3.1 Seat geometry design

First of all, the design of the seat must be a geometric parameter design. According to the design of the cabin layout, the seat arrangement of the economy class is "3+3", and the following table 2.1 is the main size of the designed seat.

Table 2.1 - The main geometric parameters of the seat design

N	Size name	Average size	Lighter seat size design
1	Height of armrest above floor,mm	610	600
2	Height of the seat cushion above the floor,mm	440	470
3	Height of the seat ,mm	1150	1270
4	Seat pitch,mm	810	850
5	Distance between the armrest,mm	440	520
6	Width of the armrest,mm	45	60
7	Width of the block with three seats,mm	1470	1530
8	Angle of seat back deflection,°	25	30
9	Mass of one seat,kg	7	5
10	Mass of the block with three seats,kg	19	13

Comparing the design size with the average size, the size of the various structures of the seat has been increased, which allows economy class passengers to have more room for movement and improve their comfort. According to these basic design dimensions, a preliminary appearance and functional design of the seat are made, and three views of a single seat are drawn using AutoCAD. As shown in fig 2.5.

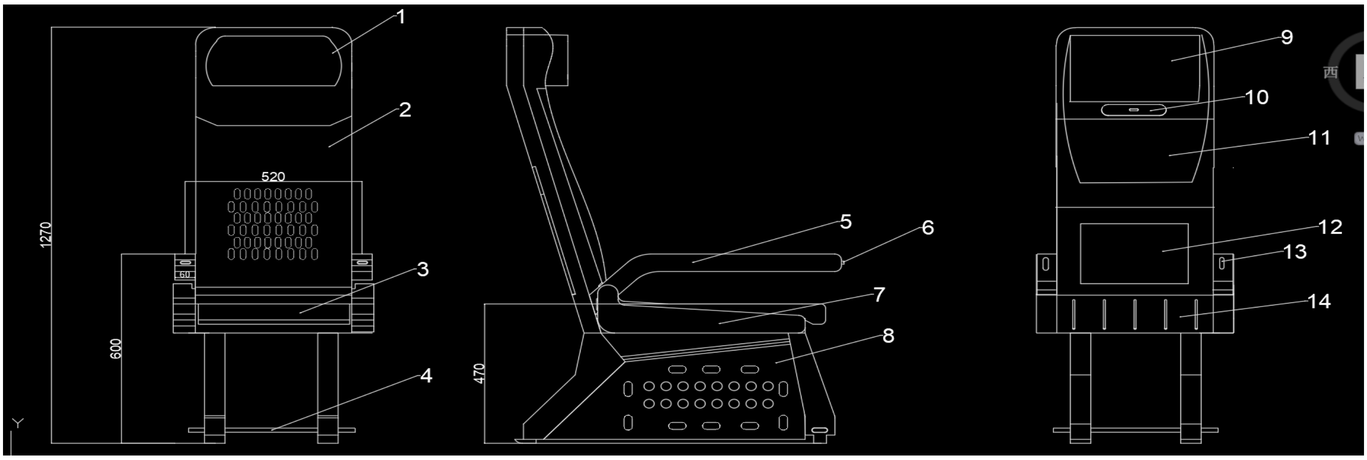

Fig 2.5 Three views of a single seat design

1. Headrest 2. Cushion 3. Seat Cushion 4. Luggage rail
5. Armrest 6. Charging port 7. Armrest baffle 8. Battery
9. Display screen 10. Electronic product storage box 11. Desk board
12. Magazine bag 13. Armrest shaft structure 14. Rear side baffle

2.3.2 Short descriptions of the function of the design seat

The seat frame is composed of a back frame, a seat cushion bottom frame and a support frame. The armrest can be lifted with the help of the rotating shaft structure. The battery assembly of the base for power supply makes good use of the space structure. In terms of appearance, there are some raised hexagonal textures on the cushions, which can press the seats on the backs of passengers, which may have the effect of relieving flight fatigue. Wider armrests and seats increase the passenger's range of motion, reducing the potential for physical discomfort on long flights. Figure 2.6 shows the headrest frame and backrest frame drive.

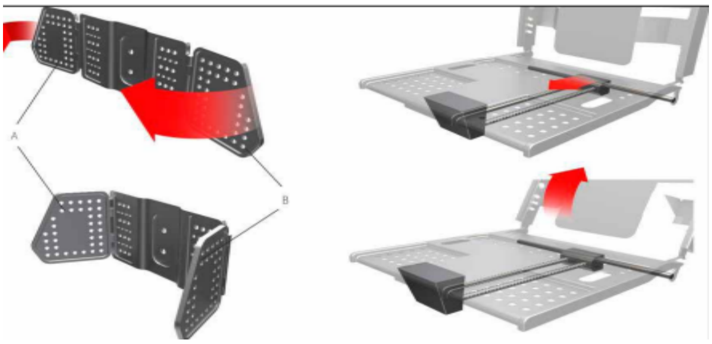

Fig 2.6 The headrest frame and backrest frame drive.

The functional design of the seat is relatively complete.The first is the adjustment function. In the adjustment of the backrest inclination angle, the passenger only needs to press the adjustment button, the internal transmission will be unlocked, and then the angle can be controlled by the force of the backrest. The headrest frame is a folding structure, and passengers can use buttons to adjust the folding angle. According to the observation method and the pressure distribution experiment, the comfort of different modes of passengers during the flight corresponds to different sitting postures. In reading mode, the backrest is reclined at 8°, and the backrest frame is raised for placing elbows; in sleep mode, the backrest is reclined at 16°, and the headrests on both sides are folded; in entertainment mode, the backrest is reclined by 10° . The experimental results can be used to optimize the design of aircraft seats [12].

In the function of placing and storing passengers' belongings, the table board and magazine pocket play a major role. There are also electronics storage boxes, which can be put in and closed when passengers are uncomfortable with their phones or tablets.

In terms of charging function, the charging port is designed on the armrest, which makes the use of passengers more convenient, and there is no need to bend over to find the location of the charging port.

In this design, the seat function has also achieved the maximum utilization of space under the relatively perfect limitation.

2.3.3 Choice of seat materials

This seat frame design uses carbon fiber composite material, which will be one of the best choices to replace the traditional metal frame such as steel and aluminum. Light weight and high strength are one of its distinctive features. It has good high and low temperature resistance, fatigue resistance, corrosion resistance, and good structural and dimensional stability. It has been widely used in aerospace and other fields. According to the data provided, the seat frame made of carbon fiber composite material can reduce the weight by more than 50% compared with the steel frame of the same size, and can also reduce the weight by about 30% compared with the aluminum alloy frame [13].

The back cushion and seat cushion are made of highly flame-retardant materials such as polyurethane foam, and the seat surfaces are made of flame-retardant muslin fabric and leather.

2.3.4 Selection of suitable connection and fixing methods

Due to the anisotropy of carbon fiber composite materials, low interlayer strength and low ductility, the design and analysis of composite material joints are much more complicated than metal materials. Therefore, the connection and fixing method of composite seat frame must be reasonable.

Mechanical connection and gluing are both common connection and fixing methods of carbon fiber composite materials, which should be combined in the seat frame according to the different parts and load-bearing conditions of the frame. For components whose thickness, length or overall volume account for a large proportion of the entire seat, it is recommended to use a mechanical connection method that can transmit concentrated loads. Metal connectors do not increase the weight of the skeleton itself.

2.3.5 Seat safety tests

The most important thing for aviation seats is safety. Seat products, like other aviation products, must meet the corresponding quality standards, pass the required tests and obtain the required airworthiness certificates. Once it fails the standards and tests, it is not allowed to be installed on the aircraft.

Among the standards set by the EASA, one of the provisions for seats is:

Each occupant in a seat at an angle of more than 18 degrees from the vertical must protect the head including the aircraft centerline from head injury with a seat belt, and an energy-absorbing rest device that supports the arms, shoulders, head and spine, or by means of a safety device lap and shoulder straps, to prevent the head from coming into contact with any harmful objects. The occupant of each other seat must be protected from head injury by a seat belt and, as appropriate for the type, position and orientation of each seat, meet one or more of the following [14]:

(1) A shoulder strap that prevents the head from touching any harmful objects.

(2) Eliminate any damaging objects within the radius of the head impact.

(3) An energy-absorbing brace that supports the arms, shoulders, head, and spine.

This is especially important for the Head Injury Criteria (HIC) test, as shown in Figure 2.7.

Figure 2.7 HIC test

Head Injury Criteria (HIC) formula:

$$HIC = (t_2 - t_1) \left\{ \frac{1}{t_2 - t_1} \int_{t_1}^{t} a(t)\, dt \right\}^{2.5} \leq 1000 \qquad (2.1)$$

Where t_1 - initial integration time； t_2 - final integration time; a(t)-curve equation of total acceleration of head impact versus time.

As long as the results of multiple experiments are less than 1000, this test of the seat is considered qualified.

Secondly, there is the safety test of seat structure strength. The dynamic and static strength test standards of the seat are 16g seats that meet the TSO-C127a standard, and 9g seats that meet the TSO-C39b standard. For seat material flame retardant test, any material on the seat must have a burning report, such as the 12-second vertical burning test and 15-second horizontal burning test in accordance with CCAR 25.853(a). In addition, the Civil Aviation Administration of China, Airbus and Boeing have mandatory smoke and toxicity tests for seat cushions, such as the smoke test of CCAR 25.853(d) and the toxicity test of D6-36075.

2.4 Force and Strength Analysis

The structural forces of the seat under severe load condition (forward overload) is analyzed and the load on the seat is distributed.

For seats without special requirements, the ultimate total load in all directions is determined as follows:

$$P=(W_{seat}+W_{passenger})\times n_u$$

Where P-the ultimate total load; W_{seat}-the weight of seat; $W_{passenger}$-the weight of passenger; n_u- ultimate load factor.

The weight of each passenger is 750N (77kg) and the ultimate load factor is selected according to regulations. For strength calculations, the total seat load is divided into loads for elements such as shoulder belts, seat belts, and seat bases. At present, various specification manuals only specify the total limit load for aircraft seats, and there are no details. The following is the method of redistributing the seat load.

Passenger seats are generally not fitted with shoulder straps. Therefore, the distributed load is also the seat belt load and the seat base load. The analysis is shown in Figure 2.8.

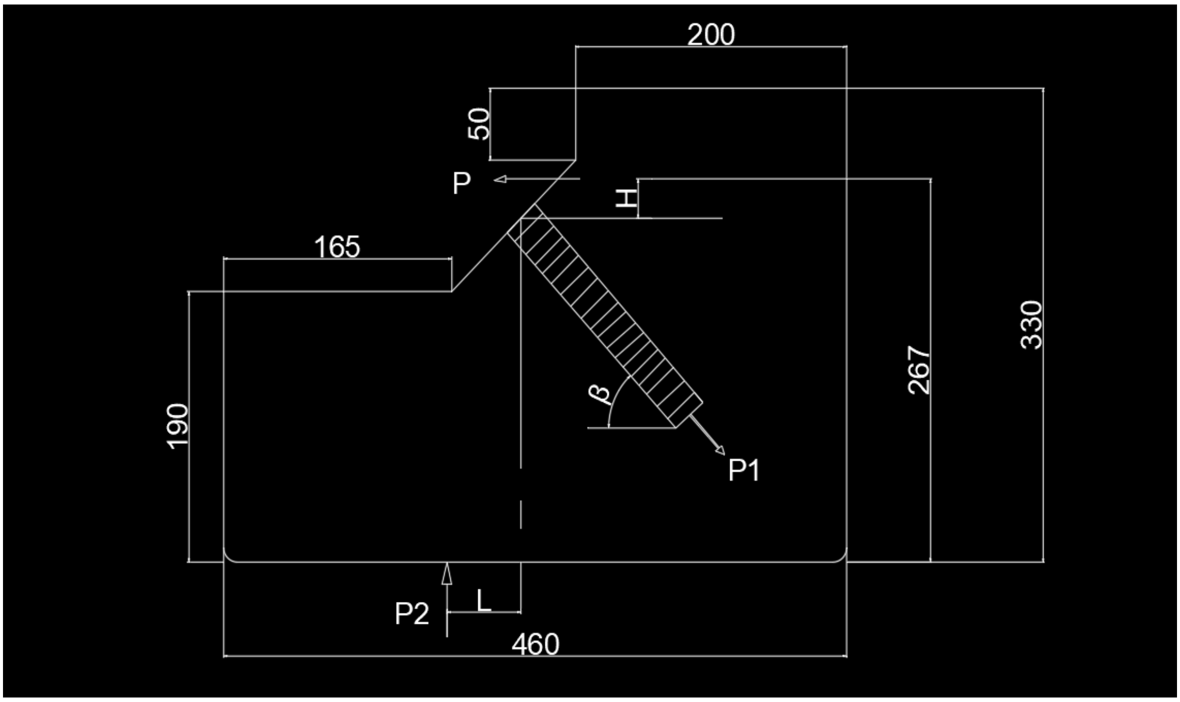

Figure 2.8. seat force analysis module.

It is assumed that the seat belt is rigidly attached to the simulated human body module. Then there is the following equilibrium equation:

$$2 \times P_1 \times \cos\beta = P$$

$$2 \times P_1 \times \sin\beta - P_2 = 0$$

Where P- the ultimate total load of seat; P_1- the one-sided seat belt load; P_2- the seat base load; β- the angle between the seat belt and the horizontal line.

After solving the equation, the following results are obtained:

$$P_1 = P/2\cos\beta$$

$$P_2 = P\tan\beta$$

So we can get the final load distribution result below：

$$P_1 = (W_{seat} + W_{passenger}) \times n_u / 2\cos\beta$$

$$P_2 = (W_{seat} + W_{passenger}) \times n_u \tan\beta$$

Where L is less than 55mm, and H=Ltanβ.

In order to further ensure occupant safety and design quality, in addition to checking the strength of the seat belt according to the above-distributed load, it should also meet the following requirements: the ultimate load (tensile) seat belt webbing is not less than 10050N, and the seat belt assembly The ultimate load (tensile) is not less than 6700N. This rule applies to all seats on the aircraft.

Generally speaking, the load distributed by the seat belt should be less than 6700N, otherwise the design of the seat belt hook position is unreasonable. For the local structure connected with the seat belt, it should also be designed according to 6700N, and the joint coefficient should be considered at the same time.

In order to further determine the load condition of the designed seat frame, a strength analysis was performed after modeling with SolidWorks software. The conditions of the analysis are a load factor of 1 during normal flight and a vertical load factor of 2.5 in the case of an emergency heavy landing. The average passenger weight is 77 kg for the analysis. The material of the frame chosen for the simulation is carbon fiber composite. The load analysis results of the seat frame under the two operating conditions are shown in Figures 2.9~2.14.

Under normal flight conditions:

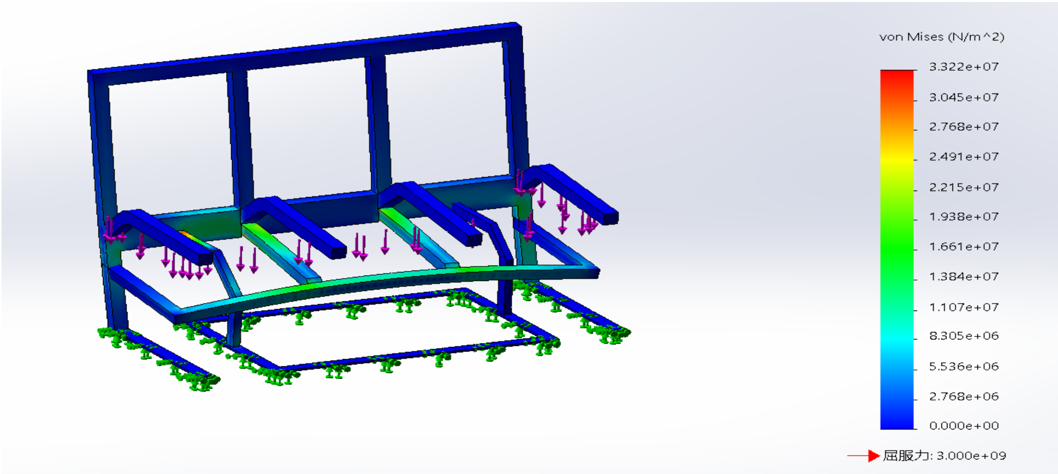

Figure 2.9 Stress diagram

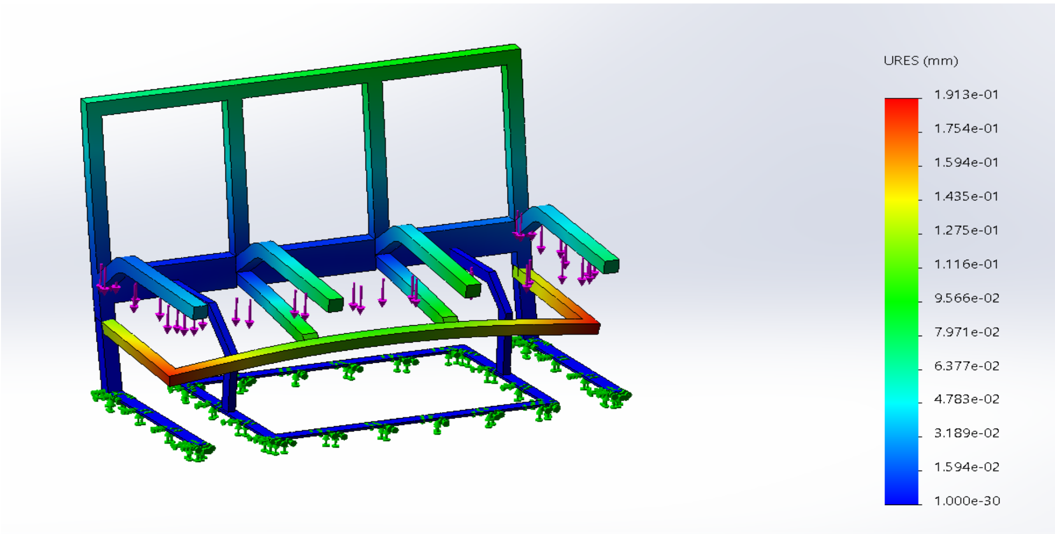

Figure 2.10 Displacement diagram

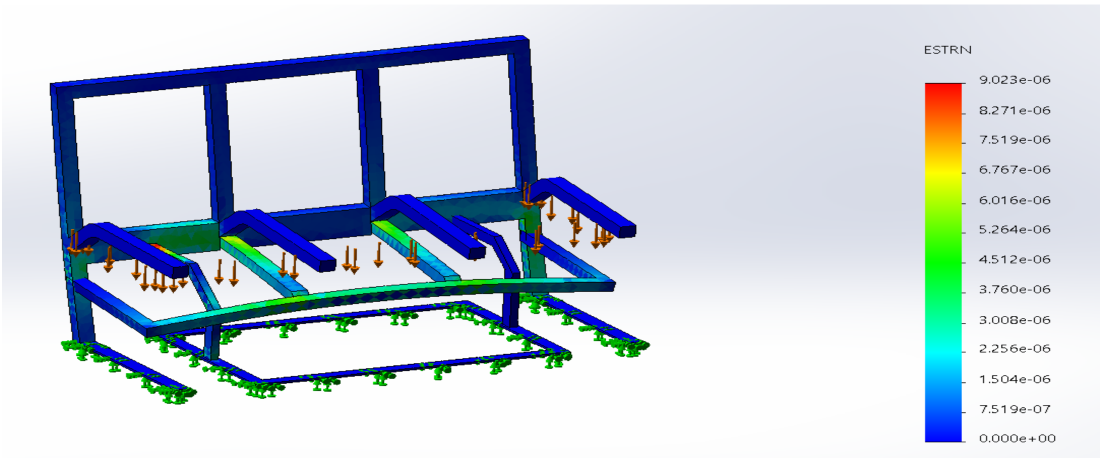

Figure 2.11 Deformation diagram

In the event of a heavy landing:

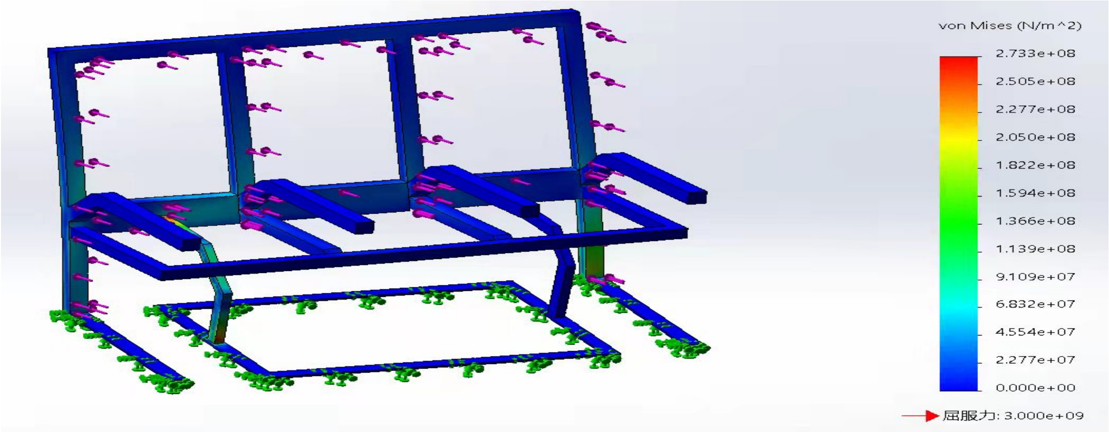

Figure 2.12 Stress diagram

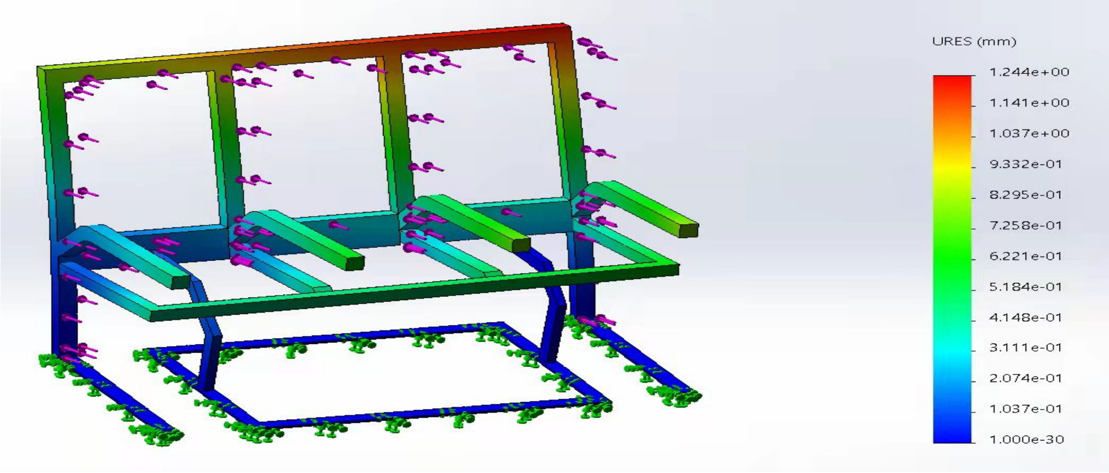

Figure 2.13 Displacement diagram

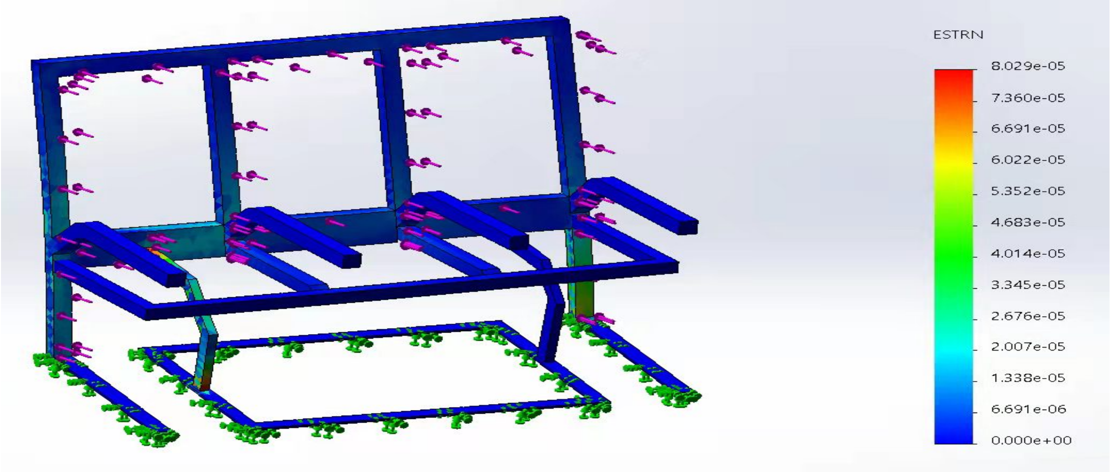

Figure 2.14 Deformation diagram

According to the analysis of the simulation analysis results, the maximum stress acting on it in flight and emergency landing conditions is equal to 33.2 MPa and 273 MPa, respectively, which are both less than the ultimate stress of the material, which is 1600 Mpa, and the frame structure can still be kept intact even during a strong landing, so the use of carbon fiber composite materials as the frame of the seat meets the strength requirements.

Conclusions to the special part

The following tasks are completed in this part:

- The lightweight economy class passenger seat is designed, and the seat functions are kept complete, and the passenger activity space is also increased, which improves the comfort of the passengers.

-The carbon fiber composite material is selected as the material of the seat frame, and the advantages and disadvantages of this design are analyzed. There are also methods of attaching and securing the material.

-The strength calculation and strength strain analysis of the designed seat are carried out, and the reliability and strength of the structure under the load of normal flight and emergency landing of the aircraft are proved.

GENERAL CONCLUSIONS

The preliminary design and fuselage layout design of the aircraft in this design work have obtained the basic parameters of the aircraft. The position of the center of gravity of the aircraft is within a reasonable range that satisfies the stability and maneuverability of the aircraft. requirements in flight and on the ground. Aircraft design is complex and we need to take into account many other factors as far as possible considering manufacturing, market, cost, rationality, etc. The aircraft is a narrow-body single-aisle layout and can accommodate 220 passengers. The main prototype is the A321-neo, with new engines and other advanced technologies. This design work is only a small part of aircraft design, and the detailed design is often the most complex. Only by taking every step of the design road can the design be successfully applied in practice.

In the design of the economy class seat, three plane views were drawn and the seat frame model was established, and a new material - carbon fiber composite material was chosen as the material of the seat frame, and the safety standards were met in both calculation and simulation strength, although the cost will be higher, but it has the advantages of light weight, high strength and lower maintenance costs. For long-range airliners and long flight times, this is undoubtedly more beneficial than detrimental.

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Appendix

Appendix A

INITIAL DATA AND SELECTED PARAMETERS

Passenger Number	220
Flight Crew Number	2
Flight Attendant or Load Master Number	6
Mass of Operational Items	2162.06 kg
Payload Mass	20050.80kg
Cruising Speed	850.0 km/h
Cruising Mach Number	0.7966
Design Altitude	11.00 km
Flight Range with Maximum Payload	7200 km
Runway Length for the Base Aerodrome	2.95 km
Engine Number	2
Thrust-to-weight Ratio in N/kg	3.1000
Pressure Ratio	30.00
Accepted Bypass Ratio	6.00
Optimal Bypass Ratio	6.00
Fuel-to-weight Ratio	0.1700
Aspect Ratio	9.40
Taper Ratio	4.11
Mean Thickness Ratio	0.120
Wing Sweepback at Quarter of Chord	25.0°
High-lift Device Coefficient	1.160
Relative Area of Wing Extensions	0.050
Wing Airfoil Type	supercritical
Winglets	no
Spoilers	yes
Fuselage Diameter	3.95m
Fineness Ratio of the fuselage	11.26
Horizontal Tail Sweep Angle	29.0°
Vertical Tail Sweep Angle	34.0°

CALCULATION RESULTS

Optimal Lift Coefficient in the Design Cruising Flight Point	Cy=0.45135
Induce Drag Coefficient	Cx = 0.00911
ESTIMATION OF THE COEFFICIENT	Dm = Mcritical - Mcruise
Cruising Mach Number	0.79660
Wave Drag Mach Number	0.80698
Calculated Parameter Dm	0.01038
Wing Loading in kPa (for Gross Wing Area):	
At Takeoff	5.557
At Middle of Cruising Flight	4.562
At the Beginning of Cruising Flight	5.352

Drag Coefficient of the Fuselage and Nacelles	0.00847
Drag Coefficient of the Wing and Tail Unit	0.00915
Drag Coefficient of the Airplane:	
At the Beginning of Cruising Flight	0.02927
At Middle of Cruising Flight	0.02769
Mean Lift Coefficient for the Ceiling Flight	0.45135
Mean Lift-to-drag Ratio	16.29968
Landing Lift Coefficient	1.623
Landing Lift Coefficient (at Stall Speed)	2.435
Takeoff Lift Coefficient (at Stall Speed)	1.984
Lift-off Lift Coefficient	1.448
Thrust-to-weight Ratio at the Beginning of Cruising Flight	0.553
Start Thrust-to-weight Ratio for Cruising Flight	2.342
Start Thrust-to-weight Ratio for Safe Takeoff	2.847
Design Thrust-to-weight Ratio Ro	2.989
Ratio Dr = R_{cruise} / $R_{takeoff}$ Dr	0.823
SPECIFIC FUEL CONSUMPTIONS (in kg/kN*h):	
Takeoff	34.8856
Cruising Flight	57.8883
Mean cruising for Given Range	63.2099
FUEL WEIGHT FRACTIONS:	
Fuel Reserve	0.03490
Block Fuel	0.30804
WEIGHT FRACTIONS FOR PRINCIPAL ITEMS:	
Wing	0.09100
Horizontal Tail	0.00941
Vertical Tail	0.00934
Landing Gear	0.03995
Power Plant	0.09195
Fuselage	0.09802
Equipment and Flight Control	0.11679
Additional Equipment	0.00986
Operational Items	0.01857
Fuel	0.34294
Payload	0.17223
Airplane Takeoff Weight	M =116442kg
Takeoff Thrust Required of the Engine	173.99kN
Air Conditioning and Anti-icing Equipment Weight Fraction	0.0201
Passenger Equipment Weight Fraction (or Cargo Cabin Equipment)	0.0129
Interior Panels and Thermal/Acoustic Blanketing Weight Fraction	0.0058
Furnishing Equipment Weight Fraction	0.0117

Flight Control Weight Fraction	0.0051
Hydraulic System Weight Fraction	0.0146
Electrical Equipment Weight Fraction	0.0307
Radar Weight Fraction	0.0029
Navigation Equipment Weight Fraction	0.0043
Radio Communication Equipment Weight Fraction	0.0022
Instrument Equipment Weight Fraction	0.0050
Fuel System Weight Fraction	0.0103

Additional Equipment:

Equipment for Container Loading	0.0064
No typical Equipment Weight Fraction (Build-in Test Equipment for Fault Diagnosis, Additional Equipment of Passenger Cabin)	0.0035

TAKEOFF DISTANCE PARAMETERS

Airplane Lift-off Speed	281.95km/h
Acceleration during Takeoff Run	2.33m/s^2
Airplane Takeoff Run Distance	1311m
Airborne Takeoff Distance	578m
Takeoff Distance	1890m

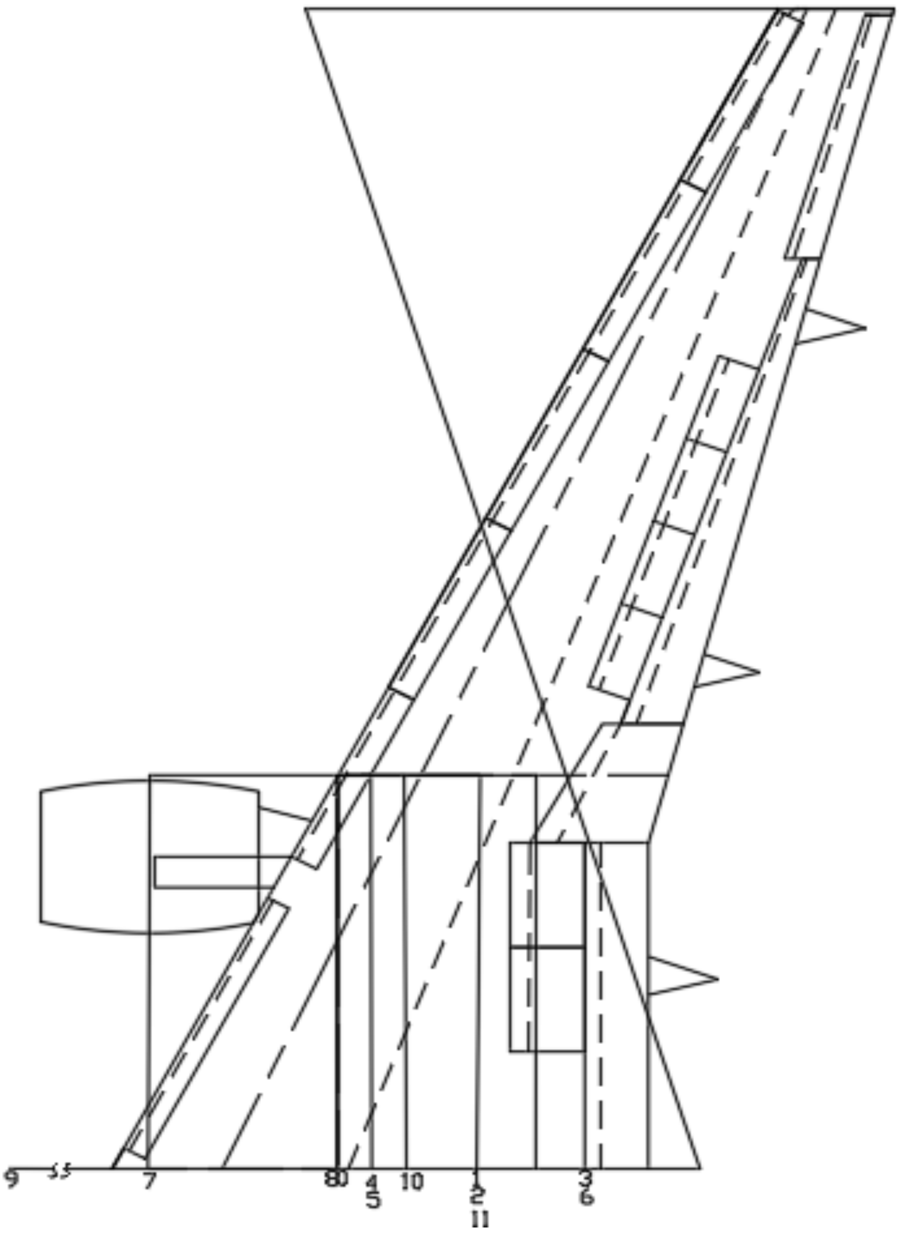
CONTINUED TAKEOFF DISTANCE PARAMETERS

Decision Speed	267.85 km/h
Mean Acceleration for Continued Takeoff on Wet Runway	0.30m/s2
Takeoff Run Distance for Continued Takeoff on Wet Runway	2149.39m
Continued Takeoff Distance	2727.77m
Runway Length Required for Rejected Takeoff	2826.12m

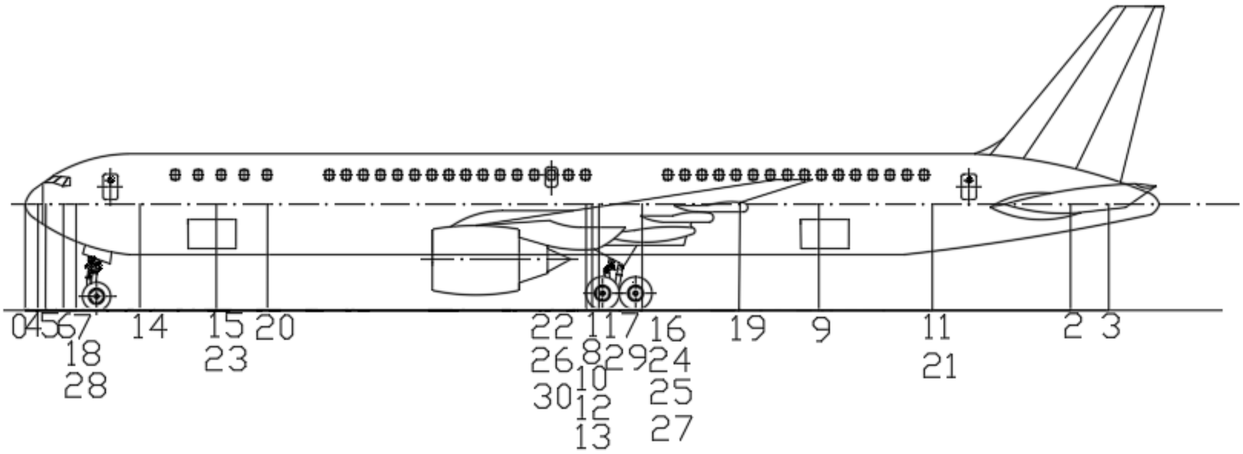
LANDING DISTANCE PARAMETERS

Airplane Maximum Landing Weight	86041kg
Time for Descent from Flight Level till Aerodrome Traffic Circuit Flight	21.8min
Descent Distance	51.38km
Approach Speed	246.19km
Mean Vertical Speed	1.99m/s
Airborne Landing Distance	515m
Landing Speed	231.19km/h
Landing run distance	714m
Landing Distance	1230m
Runway Length Required for Regular Aerodrome	2053m
Runway Length Required for Alternate Aerodrome	1746m

Appendix B



Appendix C



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