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НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Кафедра конструкції літальних апаратів

**ДОПУСТИТИ ДО ЗАХИСТУ**
Завідувач кафедри
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« _____»___________________ 2021 р.

# ДИПЛОМНА РОБОТА

**(ПОЯСНЮВАЛЬНА ЗАПИСКА)**
ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ

**«БАКАЛАВР»**

**Тема: «Аванпроект дальньомагістрального літака пасажиромісткістю 158 осіб»**

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**Київ 2021**

**MINISRY OF EDUCATION AND SCIENCE OF UKRAINE**

**NATIONAL AVIATION UNIVERSITY**
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Professor, Dr. of Sc.
_________S.R. Ignatovych
«___» _______ 2021

# DIPLOMA WORK

**(EXPLANATORY NOTE)**
OF ACADEMIC DEGREE
**«BACHELOR»**

**Theme: «Preliminary design of a long-range aircraft with 158 passenger capacity»**

**Performed by:** ___________ **Qiu Wenkai**

**Supervisor: PhD, associate professor** ___________ **T.P. Maslak**

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**Kyiv 2021**

**NATIOONAL AVIATION UNIVERSITY**

Aerospace Faculty

Aircraft Design Department

Academic degree «Bachelor»

Speciality 134 "Aviation and Space Rocket Technology"

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«___» _______ 2021

**TASK**

**for bachelor diploma work**

QIU WENKAI

1. Topic: **«Preliminary design of a long-ranger aircraft with 158 passenger capacity»** confirmed by Rector's order № 815/ст from 21.05.21 to 20.06.21
2. Thesis term: from 24.05.2021 to 20.06.2021
3. Initial data: maximum passenger capacity 158 people; flight range with maximum payload 6200 km; cruise speed 830 km/h at operating altitude 10500 m; landing speed 240 km/hour.
4. Content (list of topics to be developed): selection of design parameters; choice and substantiations of the airplane scheme; calculation of aircraft masses; determination of basic geometrical parameters; aircraft layout; center of gravity position calculation; determination of basic flight performance; description of the aircraft design; engine selection; conceptual design of the skycouch.
5. Required materials:
   – general view of the airplane (A1×1);
   – layout of the airplane (A1×1);
   – assembly drawing of the skycouch passenger's seats (A1×1).
   – Graphical materials are performed in AUTOCAD and CATIA.

6. Thesis schedule:

| Task | Time limits | Done |
|---|---|---|
| Task receiving, processing of statistical data | 24.05.2021–30.05.2021 | |
| Aircraft geometry calculation | 30.05.2021–02.06.2021 | |
| Aircraft layout calculation | 02.06.2021–03.06.2021 | |
| Aircraft center of gravity determination | 03.06.2021-04.06.2021 | |
| Preliminary design of the aircraft: drawings of the general view, aircraft layout, assembly drawing of the block of seats | 04.06.2021-06.06.2021 | |
| Preliminary defence | 6.06.2020–7.06.2020 | |
| Completion of the explanation note | 7.06.2020–15.06.2020 | |

7. Date: 24.05.2021

Supervisor ____________ T.P. Maslak

Student ____________ Qiu Wenkai

# ABSTRACT

Bachelor degree thesis **«Preliminary design of a long-ranger aircraft with 158 passenger capacity»** contains:

62 sheets, 21 figures, 10 tables, 11 references and 3 drawings

Object of the design is development of a long-range passenger aircraft with passenger capacity 158.

Subject of the design – the conceptual design of the skycouch passenger seat.

Aim of the diploma work is the preliminary design of the passenger aircraft with the implementation of the new passenger seats in a cabin layout, the estimation of the geometrical parameters of the main parts of the aircraft.

The methods for the aircraft design are analysis of the prototypes and selections of the most advanced technical decisions, the analysis of the engines which could be installed at the designing aircraft, the choice of tires for the landing gear according to the initial data of the aircraft.

The diploma work contains drawings of the long-range passenger aircraft with a carrying capacity of 158 passengers, calculations and drawings of the aircraft layout, conceptual design of the skycouch type block of seats, calculations and drawing.

**AIRCRAFT, PRELIMININARY DESIGN, LAYOUT, CENTER OF GRAVITY POSITION, PASSENGER CABIN, BLOCK OF SEATS, SKYCOUCH**

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# INTRODUCTION

Air transportaion plays an important role in international exchange and cooperation. It transports passengers and cargo from one place to another. Nowadays, there are a total of approximately 30000 planes in the world. Among them, the mid-range narrow-body airliner is the most popular model of the world fleet. According to the data presented in the fig.1, there are 14199 narrow-body airliners in the world fleet in 2021. According to the forecast, the number of narrowbody airliners will increase to 19664 in 2026 and 23712 in 2031. That is why the task of my diploma work is the preliminary design of the narrowbody aircraft for the 158 passengers for the range of flight at 6200 km.

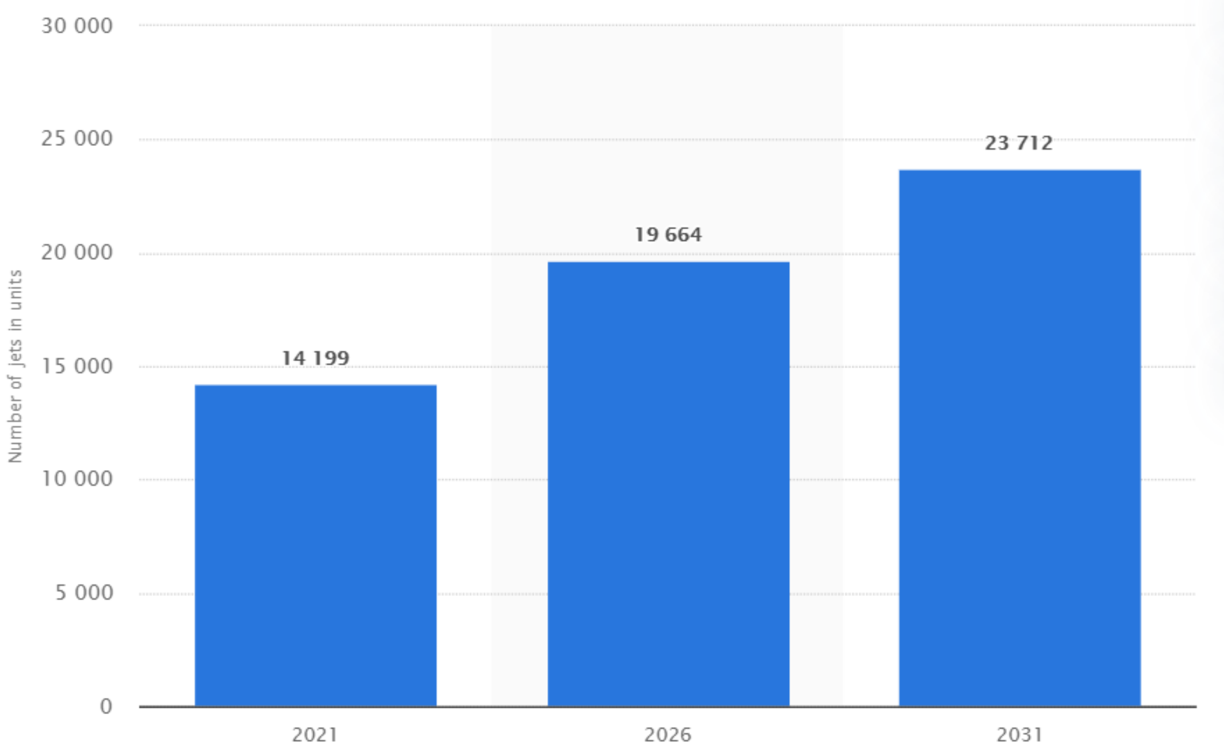


Figure 1 - World fleet size of aircraft

In addition, under the influence of the COVID-19, the air transport industry has suffered a lot since 2020, with a significant drop in air traffic and a significant decrease in the number of passengers taking international flights.

Since March 2020, as the epidemic has spread globally, the center of the epidemic has shifted to Europe and the Americas, global air travel demand has declined, and flights have continued to decrease. A lot of heavy airplanes such as Boeing 777, Boeing 787, Airbus A330 and Airbus A350, etc. are suspended. Therefore, an aircraft with a relatively small passenger capacity and a midle-long flight range will be more popular in the market.

The aim of this project is to design a new aircraft intend for the carriage of 158 passengers and baggage on long distance routes. The plane should have a good profitability and meet the requirements of the international organization of air transport. Also, in the special part, I will design a skycouch type of the seats. It is a passenger seat type, which can be transformed into a couch during flight. This can improve passenger comfort. Comfortable service is the core competitiveness of airlines for passengers. This equipment can significantly improve airlines' competitiveness and thus increase profitability.

# 1 PRELIMINARY DESIGN OF THE AIRCRAFT

## 1.1 Analysis of prototypes

The prototype of the aircraft is an aircraft with a passenger capacity of 150-170 seats. In this market segment, the most popular and best selling model are Airbus A320 and Boeing 737. And there is also a newly designed aircraft, that is Comac C919, which is designed by Commercial Aircraft Corporation of China.

The statistical data of above three airplanes are presented in table 1.1

Table 1.1 - Operational-technical data of prototypes

| model / parameter | A320-200 | B737-800 | C919 |
|---|---|---|---|
| The purpose of airplane | passenger | passenger | passenger |
| Fuselage length, m | 37.57 | 40 | 38.9 |
| Wing span, m | 35.8 | 35.79 | 35.8 |
| MTOW, kg | 78000 | 66361 | 72500 |
| Maximum pay-load, kg | 19900 | 20540 | 20400 |
| Number of passenger seat | 150 | 160 | 158 |
| The height of the flight, m | 12000 | 12500 | 12100 |
| Cruise speed, km/h | 829 | 838 | 834 |
| Range, km | 6112 | 5665 | 4075 |
| Take off distance, m | 2100 | 2450 | 2000 |
| Type of engines | CFM56-5B | CFM56-7 | CFM LEAP-1C |
| Number of engines | 2 | 2 | 2 |
| Fineness ratio of the fuselage | 9.5 | 9.7 | 10.5 |
| Sweepback on 1/4 chord, ° | 25 | 25.02 | 25 |

## 1.2 Brief description of the main parts of the newly designed aircraft

The designing aircraft is designed to transport 158 passengers at an altitude of 10,500 meters at a cruising speed of 830 km/h, with a maximum range of 6200 kilometers.

The aircraft is a low-wing aircraft, and equipped with a conventional tail unit which contains a single vertical stabilizer and rudder that equipped with aerodynamic balance. The width of the cabin is 3.75m, and the fuselage width is 3.95 m, which is a relatively large diameter in narrow-body aircraft. There are two turbofan engines installed under the wing to provide thrust for the aircraft. And the designing aircraft is equipped with a retractable tricycle landing gear system.

A 27° sweep back wing with a high aspect ratio, which is based on new supercritical airfoil is installed on the fuselage. On the wing tip, a winglet is installed to reduce drag. The cross section of the fuselage is a circular shape and the fuselage is mostly made of composite materials and aluminium alloys to save weight and to improve fuel efficiency.

The fuselage is the mainly part of the aircraft. Its main function is to fix the wing, tail, landing gear and other parts to make it into a whole. At the same time, it is also used to carry personnel (crew and passengers), cargo, fuel and various equipment. According to the initial data, the fuselage length of the designed aircraft is 37.57 m, and it has a circular cross section of 3.75 meters cabin width and a 3.95m outside diameter. The fineness ratio of the fuselage is 9.5. For forward fuselage part and after fuselage part, the fineness ratio are 1.6 and 3.45 respectively.

The structure of the fuselage a semi-monocoque construction. The simi-monocoque fuselage includes a substructure of bulkheads and formers, along with stringers, to support flight loads and stresses imposed on the fuselage. Which is the most commonly used type of fuselage. The bulkheads, frames, stringers, and longerons are the idea structure for designing and constructing a streamlined fuselage that is rigid and strong. Skin is stifened by longitudinal elements such as siffeners, stringers and longerons. Stringers are also increase the stability of the skin.

The fuselage is mostly made of composite materials and aluminium alloy, which is lighter and stronger. In the high temperature area, for example, outlet of auxiliary power unit (APU), because aluminum alloy and composite materials can not withstand high temperature, they cannot meet the requirements in these areas. Therefore, those with high temperature resistant materials such as steel and titanium are used in this area.

The wing is also one of the main parts of an aircraft. In addition to generate lift force for the aircraft, it also has many functions, such as hanging the engine, storing fuel. Wing provide lateral stability of the aircraft and provide roll control of the aircraft.

The designed aircraft has a swept wing with a sweep back angle of 27°. The wing is installed in the lower part of the fuselage, and it is made of composite material and metal structure. Basically, the wing is a framework composed mainly of skin, spars, ribs, and stringers. Spars are the main beams of the wing. They extend along the lengthwise of the wing (perpendicular to the fuselage). All the loads carried by the wing is ultimately taken by the spars. In flight, the aerodynamic forces act on the skin. From the skin, these forces are transmitted to the ribs and then to the spars. There are two spars, the front spar and the rear spar. The front spar is located near the leading edge and the rear spar is close to the trailing edge.

The ribs are the transverse structural elements of a wing which support the skin, prevent buckling of the stringers with skin and provide the shape of airfoil.

In order to offer lateral stability to the aircraft, the wings are cocked upwards from the fuselage towards the wingtips. This is known as the dihedral angle of the wing. The dihedral angle of the designed wing is 6°.

At the leading edge of the wing, it is equipped with an hot air  heating and an electroheating anti-icing device. The warm air and electricity are generated by engines. Structually, there is slats installed on the leading edge. It can be extended when taking off and landing. The main function of it is to guide the airflow from the lower surface of the wing to the upper surface, dissipate the vortex generated at the trailing edge of the wing due to the increase of the angle of attack or the extending of the flaps, and to ensure that the wing can provide enough lift to prevent from stall.

On the upper surface, spoilers are installed. The spoiler system consists of flight and ground spoilers. In flight, the 8 sections of the flight spoilers are extended as speed brakes or are extended to help ailerons to provide roll control during turns at high speed. Roll augmentation by the spoilers is automatically provided when the pilot input a turning signal. In addition, the 4 section of spoilers like ground airbrakes will extend when the flight computer detects that the landing gear is compressed. The spoiler is hydraulically controlled. When the spoiler is extended, the airflow through the wing is changed, removing the lift, increasing the drag at the same time, helping the aircraft to slow down when it is landing.

On the trailing edge of the wing, the flaps are mounted. The extended flaps increase the area of the wing, resulting in a greater lift to ensure sufficient lift during takeoff and landing.

On the outside of the trailing edge of the wing, there is a small wing surface that can swing up and down, which is the aileron. The aileron is the main operating surface of the aircraft. The rolling moment generated by the pilot's differential deflection of the left and right ailerons can make the aircraft roll.

On the tip of the wing, there is a sharklet installed. When the aircraft is flying at a high speed, due to the pressure difference, the air on the lower surface of the wing will move to the upper surface, forming a strong vortex, which will increase the resistance and fuel consumption. The sharklet can obstructs the air flow around the upper and lower surfaces, thereby reducing the strength of the vortex, and effectively reducing the resistance and fuel consumption during flight.

There is a torsion box structure in the middle of the wing, which is the fuel tank of the aircraft.

The aspect ratio and taper ratio of the designed wing are 10.3 and 4.08 respectively.

The tail unit is conventional configuration, consisting of vertical and horizontal stabilizer.

The horizontal tail is arranged symmetrically on the tail of the aircraft. The front half of the wing is a fixed horizontal stabilizer. The rear half is an elevator hinged behind the stabilizer. The elevator can be steered up and down to deflect, and the trailing edge is also equipped with an adjustment piece. In order to improve the balance ability of the flat tail, the horizontal stabilizer can slowly change the installation angle during flight. In the trailing edge of the elevator, there are servo tabs installed for balance. The horizontal tail is also swept with a sweep back angle of 33°. Its dihedral angle is 8°.

The vertical tail is arranged on the upper part of the aircraft axis. Like the horizontal tail, the front half of the vertical tail surface is a fixed stabilizer, and the rear half is a rudder hinged on the rear of the stabilizer, which can be steered and deflected. The function of the vertical tail is to keep the turning in a state of no sideslip; to keep the nose aligned with the runway when landing with crosswind; and to balance the asymmetric yaw moment during flight (for example, the yaw caused by the fail of one engine in multiple engines). The rudder control system is equipped with a damper to prevent the yaw phenomenon of the aircraft in high-altitude and high-speed flight. The vertial tail is also swept with a sweep back angle of 40°.

For the flight control system, the designed aircraft is equipped with ‘fly-by-wire’ (FBW) system. It replaced the conventional physical flight control system. The ‘fly-by wire’ system controls the aircraft through the flight computer. The pilot's manipulation input is converted into an electrical signal through a converter, processed by the onboard computer, and then transmitted to the actuator through a cable.

The flight control system can be divided into primary flight control system and secondary flight control system. The primary flight control system are ailerons, rudder and elevator. The secondary flight control system are flaps, slats, spoilers, and trim system.

## 1.3 Geometry calculations for the main parts of the aircraft

### 1.3.1 Wing geometry calculation

The initial data of the wing parameters of designing aircraft are presented in the table 1.2.

Table 1.2. – Initial data of the wing parameters

| | |
|---|---|
| Aspect ratio, $\lambda$ | 10.3 |
| Taper ratio, $\eta$ | 4.08 |
| Sweep back angle on 1/4 chord, $\chi_{1/4}$ | $27^{\circ}$ |
| Relative load on the wing, $P_0$ [Pa] | 5887 |
| Maximum takeoff mass, $m_0$ [kg] | 84284 |

Geometrical characteristics of the wing are determined from the maximum takeoff mass and relative load on a wing. For the designed aircraft, maximum takeoff weight is 84284 kg, and the relative load on the wing is 5887 Pa.

The full wing area can be calculated as:

$$S_w = \frac{m_0 \cdot g}{P_0} = \frac{84284 \times 9.8}{5887} = 140.31 m^2$$

Aspect ratio is an important characteristic for the wing. The greater the aspect ratio is, the smaller the induced drag. For the designed aircraft, the aspect ratio is 10.3.

Then, wing span can be calculated as:

$$l_w = \sqrt{S_w \cdot \lambda} = \sqrt{140.31 \times 10.3} = 38.02 m$$

Chord of root:

$$b_{root} = \frac{2 \cdot S_w \cdot \eta}{l_w \cdot (1+\eta)} = \frac{2 \times 140.31 \times 4.08}{38.02 \times (1+4.08)} = 5.93m$$

Chord of tip can be calculated through taper ratio:

$$b_{tip} = \frac{b_{root}}{\eta} = \frac{5.93}{4.08} = 1.45m$$

Where: $\eta$ – taper ratio.

Onboard chord can be defined as:

$$b_{ob} = b_{root} \cdot \left(1 - \frac{(\eta-1) \cdot D_{fuselage}}{\eta \cdot l_w}\right) = 5.93 \times \left(1 - \frac{(4.08-1) \times 3.95}{4.08 \times 38.02}\right) = 5.46m.$$

After determination of the geometrical characteristics of the wing, we come to the estimation of the geometry of the ailerons and high lift devices.

Aileron span:

$$l_{ail} = 0.375 \cdot \frac{l_w}{2} = 0.375 \times \frac{38.02}{2} = 7.12875m$$

Aileron area:

$$S_{ail} = 0.065 \cdot \frac{S_w}{2} = 0.065 \times \frac{140.31}{2} = 4.560075m^2$$

Aileron chord:

$$b_{ail} = 0.44 \cdot b_{tip} = 0.44 \times 1.45 = 0.638m$$

Range of aileron deflection for upward $\delta_{up} = 25°$; for downward $\delta_{down} = 15°$.

The sketch of the wing is shown as figure 1.1. As shown, the length of mean aerodynamic chord $b_{MAC} = 4.14326m$.

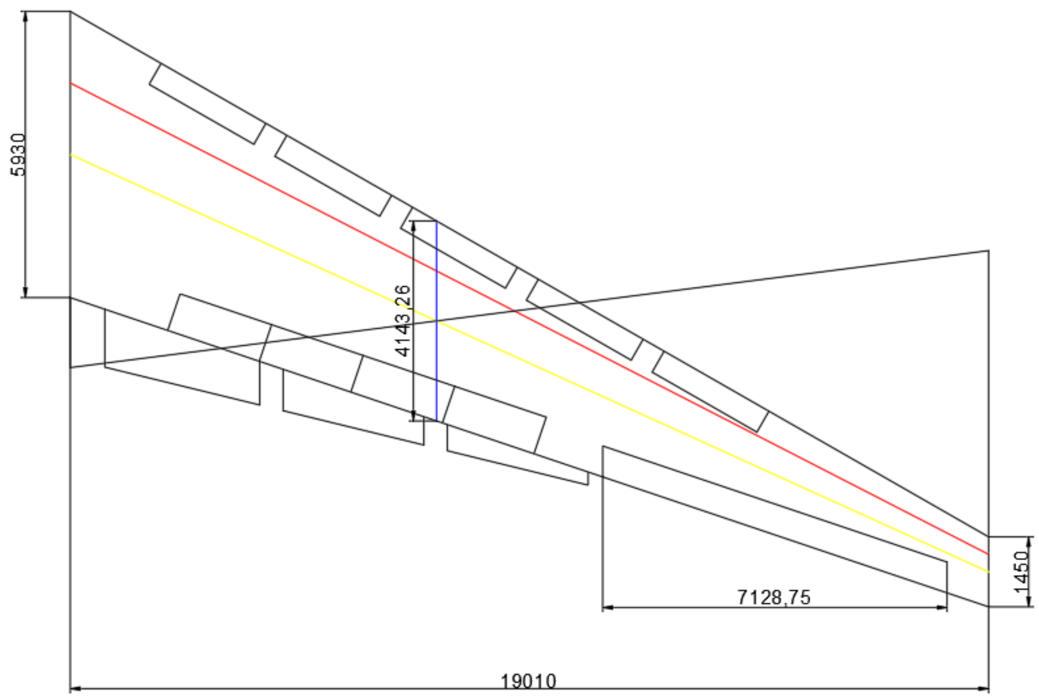


Figure 1.1 – Geometry of the wing and mean aerodynamic chord estimation

### 1.3.2 Fuselage layout

The preliminary design of the fuselage is based on the prototypes, especialy for the pilot cabin layout, position of the seats in it and accommodation of passengers. All calculations will be performed according to the requirements for cabin and geometrical dimensions of the seats, aisles, and necessary volume for the lavatories and gallays.

In the cockpit, there are 2 seats for the pilots. Behind the pilot seats, there is an additonal seat for the engineer or a backup pilot. In front of the pilot seat, instrument panels are installed. A side-stick is installed on each side of the cockpit for 2 pilots to control the elevator and ailerons, and in the front of the two pilots' seat, there are pedals for braking and controlling rudder. Six independent windshields are distributed in the front and sides of the cockpit. The windshields are strong enough to withstand bird-strike up to 648.2km/h. Each side of the windows can be opened manually and used as emergency exit for the pilots to evacuate under the emergency situation.

In the passenger cabin, there are windows on both sides, and also emergency exits are arranged on the both side of the cabin. In the upper part of the cabin, there are luggage racks for accommodating passengers' personal belongings. At the bottom of the shelves are installed service panels with individual ventilation nozzles, lights, buttons for switching on individual lighting, the call button of the flight attendant and the numbering of the seats.

The passenger furnishing of the plane provides necessary convenience on board. It includes adjustable chairs for pilot, flight attendant seats and passenger seats. Some of the passenger seats are equipped with a legrest. It can be stretched to form a plane with the seat cushion. And it also can stop at an arbitrary position to provide a more comfortable experience for passengers. Of course, this special seat will be equipped with a special seat belt to ensure the safety of passengers when lying on the seat. There is a display on the back of each seat for passenger entertainment. Except that, light-protective blinds, lavatories and kitchen are equipped in the cabin.

Emergency equipment is necessary onboard. The ropes, oxygen masks, fire extinguishers, first-aid kits, an ax, emergency lighting, life jackets and life rafts are placed in the specific locations. Moreover, there is light marking of evacuation routine on the floor to guide passengers to evcuate. There is also a noticeboard "EXIT" near each emergency exit to indicate the location of emergency exits.

Under the floor of cabin, the following compartments are located: landing gear bay, front cargo compartment, rear cargo compartment and electronic compartment. The front and rear cargo compartment are separated, each of them has a hatch on the side and equipped with a container locking system.

For the layout of the cabin, the cabin is divided into to area – business class and economy class. In the business class, there are 2 rows of seats and 8 seats in total. The layout of the seat is 2+2. The seats in the business class are more comfortable and spacious, and there is a more spacious aisle. In the economy class, there are 25 rows seat and the layout is 3+3. The economy class will be equipped with a new type of seat, which is called skycouch. It can provide a better comfort for the passengers.

The cross section of the economy class and business class is shown as following figure 1.2.

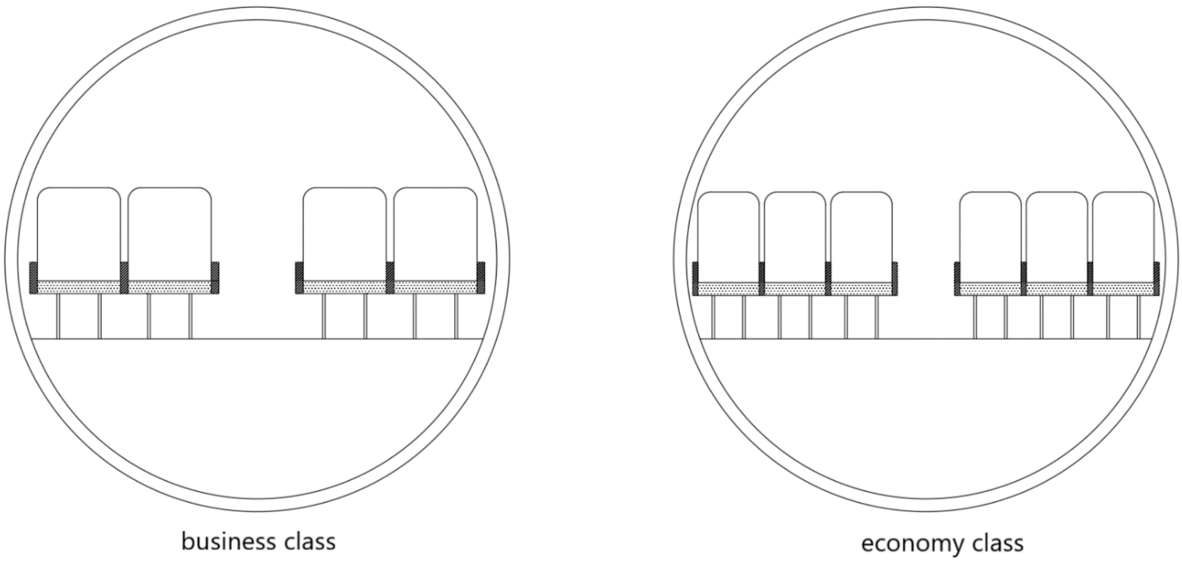


Figure 1.2 – Cross section of economy class and business class

For an aircraft with a passenger capacity 158, it can be designed to have only one aisle. A three-seat block will be installed on each side of the aisle in economy class, and in the business class, a two-seat block will be installed on the each side. More details of the seat dimensions and the cabin arrangement is presented in the table 1.3

Width of fuselage should enough to accomodate the seat and a aisle which is wide enough both in economy class and business class. The width of the cabin can be calculated as follow:

Table 1.3 Data of cabin arrangement

| Name, size | Passenger saloon type | |
|---|---|---|
| | Business class | Economy class |
| Number of passenger seats | 8 | 144 |
| Distance between the armrests [mm] | 650 | 480 |
| Arm-rest width [mm] | 80 | 60 |
| Height of the seat cushion above the flour [mm] | 455 | 440 |
| Height of armrests above floor | 600 | 600 |
| Height of the seat [mm] | 1216 | 1200 |
| Seat pitch, t [mm] | 860 | 750 |
| Angle of the chair back deflection [˚] | 36 | 25 |
| Seat width [mm] | 650 | 450 |
| Width of the block from two chairs [mm] | 1300 | - |
| Width of the block from three chairs [mm] | - | 1350 |
| Width of the aisle [mm] | 570 | 470 |
| Mass of one chair [kg] | 9 | 6 |
| Mass of the block from two chairs [kg] | 18 | - |
| Mass of the block from three chairs [kg] | - | 18 |
| distance between internal armrests to the decorative panels [mm] | 95 | 50 |
| width of the wall [mm] | 100 | 100 |

Width of cabin in business class:

$$B_{cabin} = 2\delta + n_{block} \cdot b_{block} + n_{aisle} \cdot b_{aisle} + n_{armrest} \cdot b_{armrest}$$
$$= 2 \times 50 + 2 \times 1300 + 1 \times 570 + 6 \times 80 = 3750mm$$

Width of cabin in economy class:

$$B_{cabin} = 2\delta + n_{block} \cdot b_{block} + n_{aisle} \cdot b_{aisle} + n_{armrest} \cdot b_{armrest}$$
$$= 2 \times 50 + 2 \times 1350 + 1 \times 470 + 8 \times 60 = 3750mm$$

Where:

$\delta$ – distance between external armrests to the decorative panels

Width of cabin can be calculated as follow:

$$B_{cabin} = B_{fuselage} - 2\delta_{wall} = 3950 - 2 \times 100 = 3750mm$$

Where:

$\delta_{wall}$ – width of the wall

According to the result, the width of the cabin is suitable for the arrangment.

Height of cabin can be calculated as follow:

$$H_{cabin} = 1.48 + 0.17 \cdot B_{cabin} = 1.48 + 0.17 \times 3.75 = 2.1175m$$

Next, we come to discuss the fusulage length and cabin length. The fuselage length can be defined as fineness ratio multiplied by fuselage diameter. And cabin length is determined by seat pitch.

$$L_{fuselage} = FR \cdot D_{fuselage} = 9.5 \times 3.95 = 37.525m$$

$$L_{nose} = FR_{nose} \cdot D_{fuselage} = 1.6 \times 3.95 = 6.32m$$

$$L_{rear} = FR_{rear} \cdot D_{fuselage} = 3.45 \times 3.95 = 13.6275m$$

$$L_{cabin} = L_1 + (N-1) \cdot L_{seat\ pitch} + L_2$$

Where:

FR – fineness ratio, which can be find in the initial data;

$L_1$ – distance between the wall to the back of the seat in the first row;

$L_2$ – distance between the back of the seat in the last row to the wall;

N – number of rows.

Length of business class:

$$L_{business} = 1200 + (2 - 1) \times 860 + 250 = 2310mm$$

Length for economy class:

$$L_{economy} = 1200 + (25 - 1) \times 750 + 250 + 2 \times 300 = 20050mm$$

Then total length of cabin:

$$L_{cabin} = L_{business} + L_{economy} = 2.31 + 20.05 = 22.36m$$

**1.3.3 Luggage compartment**

The unit load on the floor $K = 732kg/m^2$.

The area of cargo compartment is defined as:

$$S_{cargo} = \frac{M_{bag}}{0.4K} + \frac{M_{cargo\&mail}}{0.6K} = \frac{20 \times 152}{0.4 \times 732} + \frac{15 \times 152}{0.6 \times 732} = 15.57m^2$$

Cargo compartment volume is:

$$V_{cargo} = \nu \cdot n_{passenger} = 0.2 \times 158 = 31.6m^3$$

Luggage compartment design similar to the prototype

**1.3.4 Galleys and lavatories**

Volume of galleys(buffets):

$$V_{galley} = 0.1 \cdot N_{passenger} = 0.1 \times 158 = 15.8m^3$$

Area of galleys(buffets):

$$S_{galley} = \frac{V_{galley}}{H_{cabin}} = \frac{15.8}{2.1175} = 7.46m^2$$

Weight of meals for each passenger is 1.0kg, tea and water are 0.6kg. So, the total weight of meals and water is 252.8kg.

Galley design is similar to prototype. It is equipped with cabinet door components, garbage collection bins, carts, storage cabine, water heaters, ovens, and related water system piping and electrical system wiring, etc.

Flight time duration can be calculated as:

$$t = \frac{flight\ range}{cruise\ speed} + 0.5 = \frac{6200}{829} + 0.5 = 7.97h$$

Number of toilets is determined by the number of passengers and flight duration: if t > 4h, then 1 toilet for 40 passengers.

So, number of toilets is defined as:

$$N_{toilet} = \frac{158}{40} = 3.95$$

Then it should be 4. But most of the 150-seat aircraft currently in service have three toilets, therefore, we set it to be 3.

**1.3.5 Layout and calculation of basic parameters of tail unit**

Span of horizontal tail unit and vertical tail unit can be calculated as:

$$l_{HTU} = (0.32 \ldots 0.5) \cdot L_w = 0.4 \times 38.02 = 15.208m$$

$$h_{VTU} = (0.14 \ldots 0.2) \cdot L_w = 0.18 \times 38.02 = 6.8436m$$

The area of horizontal tail unit and vertical tail unit can be calculated as:

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

$$S_{VTU} = \frac{A_{VTU} \cdot S_w \cdot b_{MAC}}{L_{VTU}}$$

Where:

$A_{HTU}, A_{VTU}$ --- statistic coefficient of horizontal tail unit and vertical tail unit;

$L_{HTU}, L_{VTU}$ --- arms from horizontal tail unit and vertical tail unit to the gravity center.

$A_{HTU} = 0.65 \ldots 0.8$, we take it as 0.7;

$L_{HTU} = 19.5m.$

$A_{VTU} = 0.08 \ldots 0.12$, we take it as 0.10;

$L_{VTU} = 18.5m.$

As a result,

$$S_{HTU} = \frac{A_{HTU} \cdot S_w \cdot b_{MAC}}{L_{HTU}} = \frac{0.7 \times 140.31 \times 4.14326}{19.5} = 20.86m^2$$

$$S_{VTU} = \frac{A_{VTU} \cdot l_w \cdot S_w}{L_{VTU}} = \frac{0.1 \times 38.02 \times 140.31}{18.5} = 28.84m^2$$

Next step we come to the determination of elevator and rudder:

$$S_{elevator} = (0.3 \ldots 0.4) \cdot S_{HTU} = 0.35 \times 20.86 = 7.301m^2$$

$$S_{rudder} = (0.35 \ldots 0.45) \cdot S_{VTU} = 0.4 \times 28.84 = 11.536m^2$$

For aerodynamic balance, its area can be defined as:

$$S_{aero\ ele} = (0.15 \ldots 0.23) \cdot S_{elecator} = 0.2 \times 7.301 = 1.4602m^2$$

$$S_{aero\ rud} = (0.15 \ldots 0.23) \cdot S_{rudder} = 0.2 \times 11.536 = 2.3072m^2$$

Area of trim tabs on elevator:

$$S_{tbe} = (0.08 \ldots 0.12) \cdot S_{elevator} = 0.10 \times 7.301 = 0.7301m^2$$

Area of trim tab on rudder:

$$S_{tbr} = (0.04 \ldots 0.06) \cdot S_{rudder} = 0.05 \times 11.536 = 0.5768m^2$$

Next, we come to the determination of geometry of horizontal tail unit and vertical tail unit. The taper ratio of horizontal tail unit is known as 3.62, and which of vertical tail unit is 3.78.

$$b_{tip\ HTU} = \frac{2S_{HTU}}{(\eta_{HTU} + 1) \cdot l_{HTU}} = \frac{2 \times 20.86}{(3.62 + 1) \times 15.208} = 0.76m$$

$$b_{root\ HTU} = \eta_{HTU} \cdot b_{tip\ HTU} = 3.62 \times 0.76 = 2.7512m$$

The sketch of horizontal tail unit is shown as figure 1.3. We can get the value of mean aerodynamic chord of horizontal tail unit

$$b_{MAC\ HTU} = 1.94082m$$

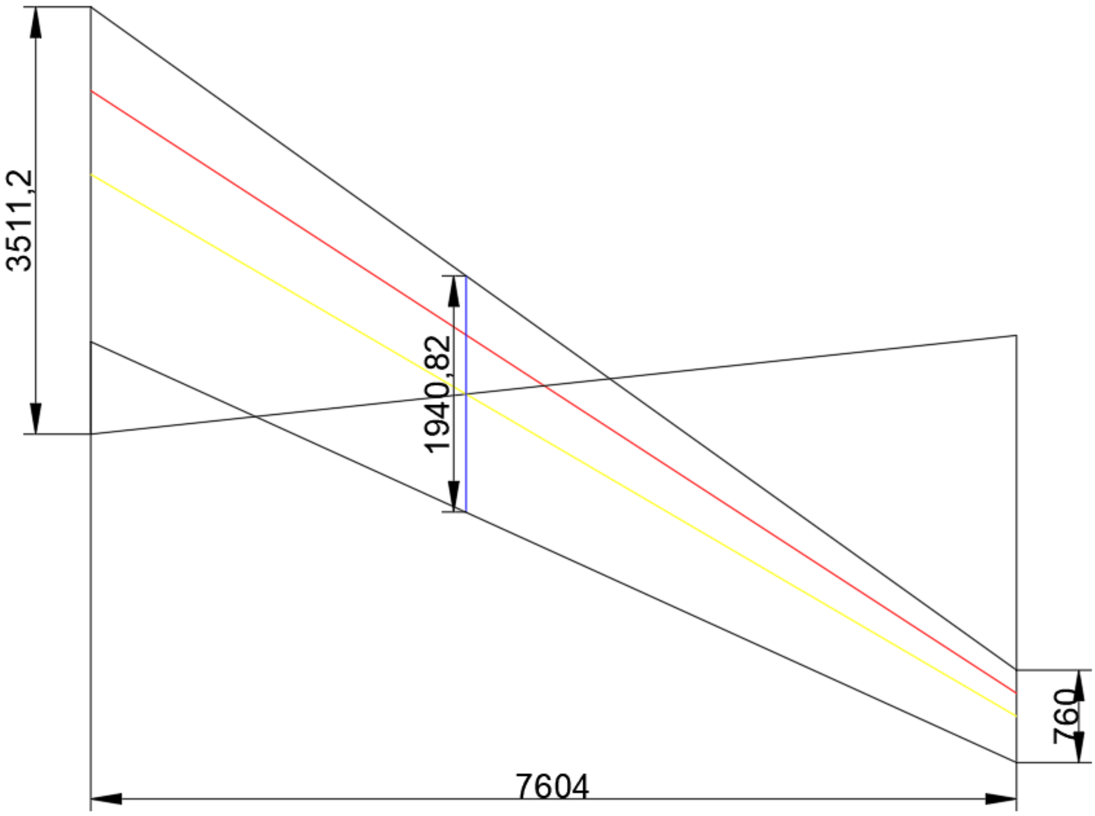


Figure 1.3 – Geometry of horizontal tail unit

$$b_{tip\ VTU} = \frac{2S_{VTU}}{(\eta_{VTU}+1)\cdot h_{VTU}} = \frac{2\times 28.84}{(3.78+1)\times 6.8436} = 1.76m$$

$$b_{root\ VTU} = \eta_{VTU}\cdot b_{tip\ VTU} = 3.78\times 1.76 = 6.6528m$$

The sketch of vertical tail unit is shown as figure 1.4. We can get the value of mean aerodynamic chord of vertical tail unit

$$b_{MAC\ VTU} = 4.68067m$$

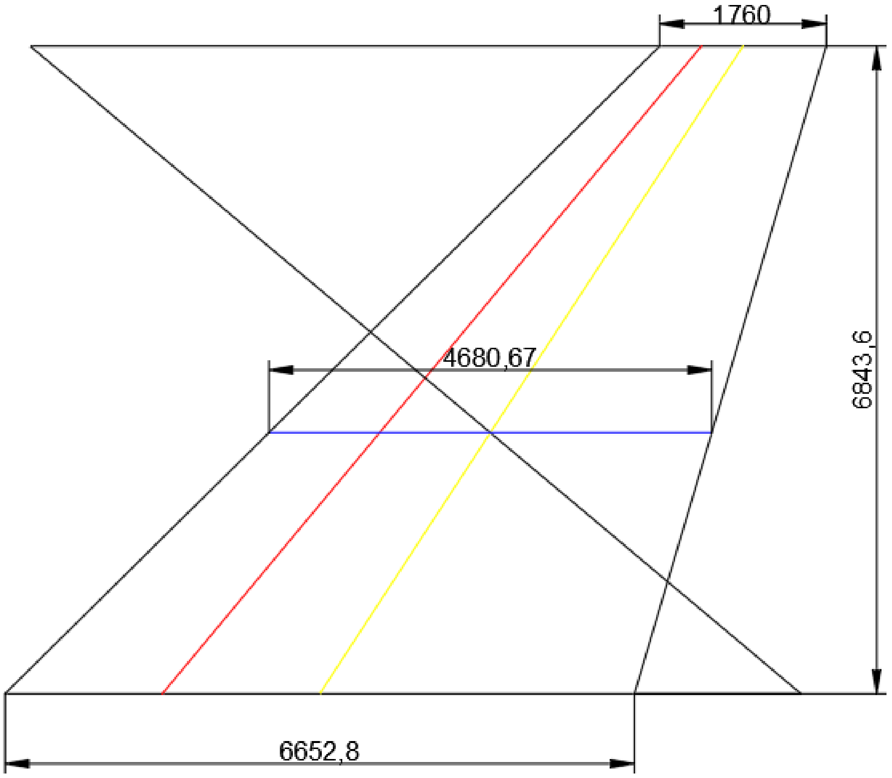


Figure 1.4 - Geometry of vertical tail unit

Relative thickness ratio of stabilizer is determined form the next formular:

$$c_{HTU} = 0.8 \cdot c_{wing} = 0.8 \times 0.14 = 0.112$$

**1.3.6 Landing gear design**

The distance between nose landing gear and main landing gear is defined as wheel base. The position of the main landing gear behind the center of gravity, so as to maintain the balance of the aircraft. And the main landing gear bears the main load, so it should be stronger.

The distance from center of gravity to main landing gear is calculated as:

$$B_m = (0.15 \dots 0.2) \cdot b_{MAC} = 0.18 \times 4.00589 = 0.7210602m$$

The wheel base can be calculated by the formular:

$$B = (0.3 \dots 0.4) \cdot L_f = 0.35 \times 37.525 = 13.13375m$$

The distance from center of gravity to nose landing gear is calculated as:

$$B_n = B - B_m = 13.13375 - 0.7210602 = 12.4126898m$$

Wheel track can be defined as:

$$T = (0.7 \dots 1.2) \cdot B = 0.7 \times 13.1495 = 9.193625m$$

Wheels for the landing gear is chosen by the size and load on it, for the front support we consider dynamic loading also.

Next, we come to the determination of load on wheels. We need to choose different tires for the landing gear according to the load during takeoff. Dynamic coefficient($k_g$) is 1.75.

Nose wheel load:

$$P_{NLG} = \frac{9.81 \cdot B_m \cdot k_g \cdot m_0}{B \cdot n \cdot z} = \frac{9.81 \times 0.7210602 \times 1.75 \times 84284}{13.13375 \times 1 \times 2} = 39719.71N$$

Main wheel load:

$$P_{MLG} = \frac{9.81 \cdot B_n \cdot m_0}{B \cdot n \cdot z} = \frac{9.81 \times 12.4126898 \times 84284}{13.13375 \times 2 \times 4} = 97679.02N$$

Table 1.4 – Aviation tires for designing aircraft

| Nose landing gear | | Main landing gear | |
|---|---|---|---|
| Tire size | Ply rating | Tire size | Ply rating |
| 30×8.8 | 16 | 46×16 | 30 |

The designed aircraft is equipped with a tricycle landing gear, including two inward retractable main landing gear and one forward retractable nose landing gear. The nose gear is placed in front of the center of gravity and the main gears are located behind the center of gravity, which keeps the aircraft stable. The main landing gear is mounted on the wing, it can retract to the bottom of the fuselage. Both the landing gear and the hatch are electrically controlled and hydraulically operated. When the hydraulic system of the aircraft fails and the landing gear cannot be lowered by the hydraulic system, it can also be lowered through gravity drop. Once the landing gear is dropped to the proper position, it will be automatically locked to ensure the safety of landing.

The lower end of the landing gear is equipped with wheels with pneumatic tires. Brakes or automatic braking devices are installed on the wheels. Brake is achieved by disc brakes. The disc brakes have good performance, they are lighter, and easier to maintain. The purpose of the brake system is to reduce the landing distance after touch down.

Structurally, the landing gear is equipped with a shock absoborber to absorb the landing shocks during landing operation; torque link to keep the piston and wheels aligned; shimmy damper to prevent rapid movement of the landing gear without interfering with slower operations.

In addition, the steering system is installed on the nose gear, which greatly improved the maneuverability of the aircraft when taxiing.

### 1.3.7 Choice and description of power plant

The aircraft will powered by 2 CFM56-5B turbofan engines, which is a high-bypass ratio turbofan engine. The bypass ratio of this engine is 5.9. It is a two-shaft engine, which means that there are two rotating shafts, one high-pressure and another one low-pressure. Each of the engines can provide maximum 100kN thrust. Compared with other engines, the CFM56-5B has a double annular combustion chamber that can reduce the emission of nitrogen oxides and other pollutants, a new fan, a longer fan housing and a new fourth-stage low-pressure compressor

The engines are equipped with anti-icing system, generator, fuel supply system, oil system, fire extinguishing system and thrust reversal.

The engines are wing mounted, such a layout provides a more convenient maintenance service, and the gravity of engine can compensate the aerodynamic forces acting on the wing during flight.

There are some variants of and CFM56-5 series and their parameters shown in the following table 1.5.

Table 1.5 – Some data of the CFM56 models

| Model | Thrust | Bypass ratio | Dry weight |
|---|---|---|---|
| CFM56-5A1 | 111kN | 6.0 | 2270kg |
| CFM56-5B6 | 100kN | 5.9 | 2380kg |
| CFM56-5C3 | 145kN | 6.5 | 3990kg |

### 1.4 Determination of the aircraft center of gravity position

When an airplane is flying, the position of the aircraft will move as the consume of fuel. the position of center of gravity has a significant influence on the attitude of the airplane. During the flight, the center of gravity of the aircraft should be located in a fairly small predetermined area. If the center of gravity is in front of this area, it will inevitably turn the elevator greatly, which increases the difficulty of take-off and landing. If the center of gravity is located behind this area, the aircraft cannot fly stably. It can be seen that the position of the center of gravity of the aircraft largely determines the flight status of the aircraft-the balance, stability and maneuverability of the aircraft.

### 1.4.1 Determination of centering of the equipped wing

The equipped wing masses include the masses of the equipment which are installed on the wing.

The equipped wing masses of the designing aircraft are shown in the table 1.6.

Table 1.6 - Trim sheet of equipped wing masses

| Trim sheet of equipped wing masses | | | | | |
|---|---|---|---|---|---|
| N | Object name | Mass | | C.G coordinates Xi, m | Moment of mass |
| | | Units | Total mass m(i) | | |
| 1 | Wing | 0.11688 | 9851.11392 | 1.7401692 | 17142.60503 |
| 2 | Fuel system | 0.0093 | 783.8412 | 1.7401692 | 1364.016314 |
| 3 | Flight control system, 30% | 0.00174 | 146.65416 | 2.485956 | 364.575789 |
| 4 | Electrical equipment, 10% | 0.00321 | 270.55164 | 0.414326 | 112.0965788 |
| 5 | Anti-ice system, 50% | 0.0106 | 893.4104 | 0.414326 | 370.1631574 |
| 6 | Hydraulic systems, 70% | 0.01127 | 949.88068 | 2.485956 | 2361.361576 |
| 7 | Engines (without fuel system) | 0.08155 | 6873.3602 | -1.5 | -10310.0403 |
| **8** | **Total (without landing gear and fuel)** | **0.23455** | **19768.8122** | **0.576907607** | **11404.77814** |
| 9 | Main landing gear, 80%-90% | 0.0319515 | 2693.000226 | 1.864467 | 5021.010052 |
| 10 | Nose landing gear, 10%-15% | 0.0056385 | 475.235334 | -11.269283 | -5355.56147 |
| 11 | Fuel | 0.31451 | 26508.16084 | 1.7401692 | 46128.68504 |
| **12** | **Total** | **0.58665** | **49445.2086** | **1.156814045** | **57198.91177** |

The position of the center of equipped wing can be calculated by the following formular:

$$X_w = \frac{\sum m_i \cdot x_i}{\sum m_i} = \frac{87198.91177}{49445.2086} = 1.156814045\ m$$

Where:

$m_i$ – mass of each object installed on the wing

$x_i$ – center of gravity coordinates of each object installed on the wing.

### 1.4.2 Determination of the centering of the equipped fuselage

The equipped fuselage masses include the masses of the equipment which are installed on the fuselage. The origin of the coordinate is the nose of the fuselage.

The equipped fuselage masses of the designing aircraft are shown in the table 1.7.

Table – 1.7 Trim sheet of equipped fuselage masses

| Trim sheet of equipped fuselage masses | | | | | |
|---|---|---|---|---|---|
| N | Objects names | Mass | | C.G coordinates Xi, м | Moment of mass |
| | | units | total mass | | |
| 1 | fuselage | 0.08049 | 6784.01916 | 18.7625 | 127285.1595 |
| 2 | horizontal tail | 0.00931 | 784.68404 | 33.260795 | 26099.21499 |
| 3 | vertical tail | 0.00936 | 788.89824 | 34.113636 | 26912.1874 |
| 4 | navigation equipment | 0.0046 | 387.7064 | 2 | 775.4128 |
| 5 | radio equipment | 0.0023 | 193.8532 | 1 | 193.8532 |
| 6 | radar | 0.0031 | 261.2804 | 0.74 | 193.347496 |
| 7 | instrument panel | 0.0054 | 455.1336 | 2.5 | 1137.834 |
| 8 | Flight control system 70% | 0.00406 | 342.19304 | 18.7625 | 6420.396913 |
| 9 | hydraulic system 30% | 0.00483 | 407.09172 | 22.515 | 9165.670076 |
| 10 | anti ice system, 25% | 0.0053 | 446.7052 | 11.2575 | 5028.783789 |
| | airconditioning system, 25% | 0.0053 | 446.7052 | 18.7625 | 8381.306315 |
| 11 | electrical equipment, 90% | 0.02889 | 2434.96476 | 18.7625 | 45686.02631 |

Continuation of the table1.7

| | | | | | |
|---|---|---|---|---|---|
| 12 | lining and insulation | 0.0062 | 522.5608 | 18.7625 | 9804.54701 |
| 13 | Load devices equipment | 0 | 0 | 0 | 0 |
| 14 | Not typical equipment | 0.0031 | 261.2804 | 15 | 3919.206 |
| 15 | Additional equipment (emergency equipment) | 0.0071 | 598.4164 | 5 | 2992.082 |
| 16 | Operational items | 0.02024 | 1705.90816 | 15 | 25588.6224 |
| 17 | Furnishing: | | | | |
| | lavatory1,2, 20% | 0.00228 | 192.16752 | 5.8043526 | 1115.408044 |
| | lavatory3,4, 20% | 0.00228 | 192.16752 | 30.2985472 | 5822.396675 |
| | galley 1, 30% | 0.00342 | 288.25128 | 33.3766855 | 9620.872318 |
| | galley 2, 30% | 0.00342 | 288.25128 | 33.3766855 | 9620.872318 |
| 18 | Passenger equipment: | | | | |
| | passenger seats (economy class) | 0.010251056 | 864 | 20.8235478 | 17991.5453 |
| | passenger seats (business class) | 0.000854255 | 72 | 9.832352 | 707.929344 |
| | seats of flight attendances | 0.000237293 | 20 | 9.8823519 | 197.647038 |
| | seats of pilots | 0.000355939 | 30 | 2.315921 | 69.47763 |
| 19 | equipped fuselage without payload | 0.222678543 | 18768.23832 | 18.3677228 | 344729.7989 |
| 20 | on board meal | 0.002999383 | 252.8 | 33.3766855 | 8437.626094 |
| 21 | Baggage, cargo, mail | 0.056238432 | 4740 | 18.7625 | 88934.25 |
| 22 | Passengers | 0.121849936 | 10270 | 18.6341082 | 191372.2912 |
| 23 | crew | 0.005398415 | 455 | 10 | 4550 |
| 24 | equipped fuselage with payload | 0.409164709 | 34486.03832 | 17.75893589 | 612435.3438 |

The position of the center of equipped fuselage can be calculated by the following formular:

$$X_f = \frac{\sum m_i \cdot x_i}{\sum m_i} = \frac{612435.3438}{34486.03832} = 17.75893589\ m$$

Where:

$m_i$ – mass of each object installed on the fuselage

$x_i$ – center of gravity coordinates of each object installed on the fuselage.

The position of mean aerodynamic chord can be calculated by the formula:

$$X_{MAC} = \frac{m_f x_f + m_{wing} x_{wing} + m_0 C}{b_{MAC}} = 17.07519m$$

Where:

$m_0$ – aircraft takeoff mass, kg;

$m_f$ – mass of equipped fuselage, kg;

$m_{wing}$ – mass of equipped wing, kg;

$C$ – distance from MAC leading edge to the C.G. point, determined by the designer. For low wing aircraft $C = (0.22 \dots 0.25) b_{MAC}$.

### 1.4.3 Calculation of center of gravity positioning variants

The center of gravity of the airplane positioning variants can be calculated and shown in the following table 1.8.

Table 1.8 – Calculation of the C.G. positioning variants

| Calculation of the C.G. positioning variants | | | | |
|---|---|---|---|---|
| N | Objects name | Mass, Kg mi | Coordinate C.G., m | Mass moment, kg*m |
| 1 | equipped wing (without fuel and landing gear) | 19768.8122 | 17.59265115 | 347785.8167 |
| 2 | Nose landing gear (extended) | 475.235334 | 4.85625 | 2307.861591 |
| 3 | main landing gear (extended) | 2693.000226 | 17.99 | 48447.07407 |
| 4 | fuel | 26508.16084 | 18.939 | 502038.0581 |
| 5 | equipped fuselage (without payload) | 18768.23832 | 18.3677228 | 344729.7989 |
| 6 | passengers of economy class | 8820 | 20.8235478 | 183663.6916 |
| 7 | passengers of business class | 1680 | 9.832352 | 16518.35136 |
| 8 | baggage | 3160 | 18.7625 | 59289.5 |
| 9 | cargo, mail | 1580 | 18.7625 | 29644.75 |
| 10 | crew | 455 | 10 | 4550 |
| 11 | nose landing gear (retracted) | 475.235334 | 3.35625 | 1595.00859 |
| 12 | main landing gear (retracted) | 2693.000226 | 17.99 | 48447.07407 |
| 13 | reserve fuel | 3005.56744 | 20 | 60111.3488 |

The table 1.8 shows mass, coordinate of center of gravity and mass moment of each object. Based on these results, we can calculate the centering of each position variant by the formular:

$$X_c = \frac{x_{c\ mass} - X_{MAC}}{b_{MAC}},$$

where:

$x_{c\ mass}$ – center of mass.

The results are shown in the table 1.9

Table 1.9 – Centering of positioning variants

| Airplanes C.G. positioning variants | | | | | |
|---|---|---|---|---|---|
| N | Variants of the loading | Mass, kg | Moment of the mass, kg*m | Center of mass, m | Centering |
| 1 | take off mass (L.G. extended) | 84284 | 1538974.902 | 18.25939564 | 0.300162698 |
| 2 | take off mass (L.G. retracted) | 84284 | 1538262.049 | 18.25093789 | 0.29812137 |
| 3 | landing weight (LG extended) | 60405.85352 | 1097048.193 | 18.1612895 | 0.276484206 |
| 4 | ferry version | 68668.44692 | 1249145.756 | 18.19097143 | 0.283648115 |
| 5 | parking version | 41705.28608 | 743270.5512 | 17.82197465 | 0.194588586 |

**Conclusion to the part**

In the part of the diploma work we have selected Airbus 320, Boeing 737, Comac C919 aircraft as prototypes. We introduced the main parts of the designing aircraft, including wing structure, fuselage structure, tail unit, landing gear design, and engine selection. Cabin furnishing and cockpit layout are also introduced in the first part of the work. The engine model CFM 56  has also been determined as well. After finishing above tasks, we calculated the geometry of the wing, tail unit, cabin layout and landing gear. In the second part of the project, we have finished the calculation of the center of gravity of equipped wing and equipped fuselage. And finally we determined the position of the center of gravity – the most forward position is 0.19 from the leading edge of mean aerodynamic chord and most aft position is 0.3.

Analyzing the calculation results, the position of center of gravity is in a reasonable range. And the parameters of the main parts are meet the requirements. The designed aircraft is an excellent long-range narrow-body airliner. It can meet the requirements of the modern passenger transport market.

## 2 CONCENPTUAL DESIGN OF THE SKYCOUCH

### 2.1 General requirements for passenger seat design

Passenger seat is an indispensible device in the cabin. It is not only an important part of the interior decoration of passenger aircraft, providing passengers with a comfortable ride, but also playing an important role in protecting passengers in emergency situations.

The safety of civil aircraft includes two aspects: airworthiness and fallability. Passenger seats will not affect the key systems of the aircraft, so it will not affect the airworthiness. Therefore, the main requirements to the seat is fallability.

For the passenger seat, there are three main aspects to meet the requirements of the fallability:

1) strength;
2) flame retardancy;
3) installation.

At present, all contemporary planes are equipped with 16G seats. In 1988, the US Federal Aviation Administration issued regulations requiring all new aircraft to be equipped with "16G" seats. These seats are only used to transport catagory aircraft and meet the 9G requirements of the Federal Aviation Regulations Sec. 25.561 and the dynamic requirements of Sec. 25.562.

Due to the large number of passengers carried by the aircraft, and the risk of fire is high and it is not easy to evacuate. Therefore, there is a high flame retardancy standard on the materials used in the cabin. According to the requirements of the FAR Sec. 25.853(a), all the part and materials of the seat including coating, glue and foam must meet the applicable test criteria prescribed in part I of appendix F of this part, or other approved equivalent methods, regardless of the passenger capacity of the airplane.

The installation of seats should meet the requirements in FAR Sec. 25.561 and Sec. 25.562. In addition, it has to meet the requirements in Sec. 25.807 Emergency exit, Sec. 25.812 Emergency lighting, Sec. 25.813 Emergency exit access, Sec. 25.815 Width of aisle and Sec. 25.817 Maximum number of seat abreast.

### 2.2 General description to the Skycouch

The skycouch refers to the three adjacent seats in the same row that can be easily converted into a sofa with a flat surface, which can be used for couples and family passengers to rest and relax during long-distance flights. Like the traditional seat, it is equipped with an adjustable seatback, adjustable armrests, headrest, seat cushion and entertainment equipment. The special feature of the skycouch is that it has an adjustable legrest. As shown in figure 2.1, which is the couch seat installed in the airplane of ANA (All Nippon Airways, Japan).

Figure 2.1 – The couch seat of ANA

The main idea of my project is to create the conceptual design of skycouch with screw rod and sleeve which is driven by an electric motor. The developed seats also have the standart part like armrest, which provides passenger’s comfort, and it is operated manually. The armrests of the designed seat assembly can rotate 90 degrees around the axis of rotation. If you want to retract the armrest, hold it and lift it up. As shown in figure 2.2, the armrests are retracted to the seatback. In addition, there are three buttons on the armrest, as shown in figure 2.3. One of them is used to adjust the seatback, like the convention passenger seats. The rest two are used to control the electric motor which installed under the seat cushion to drive the legrest up and down.

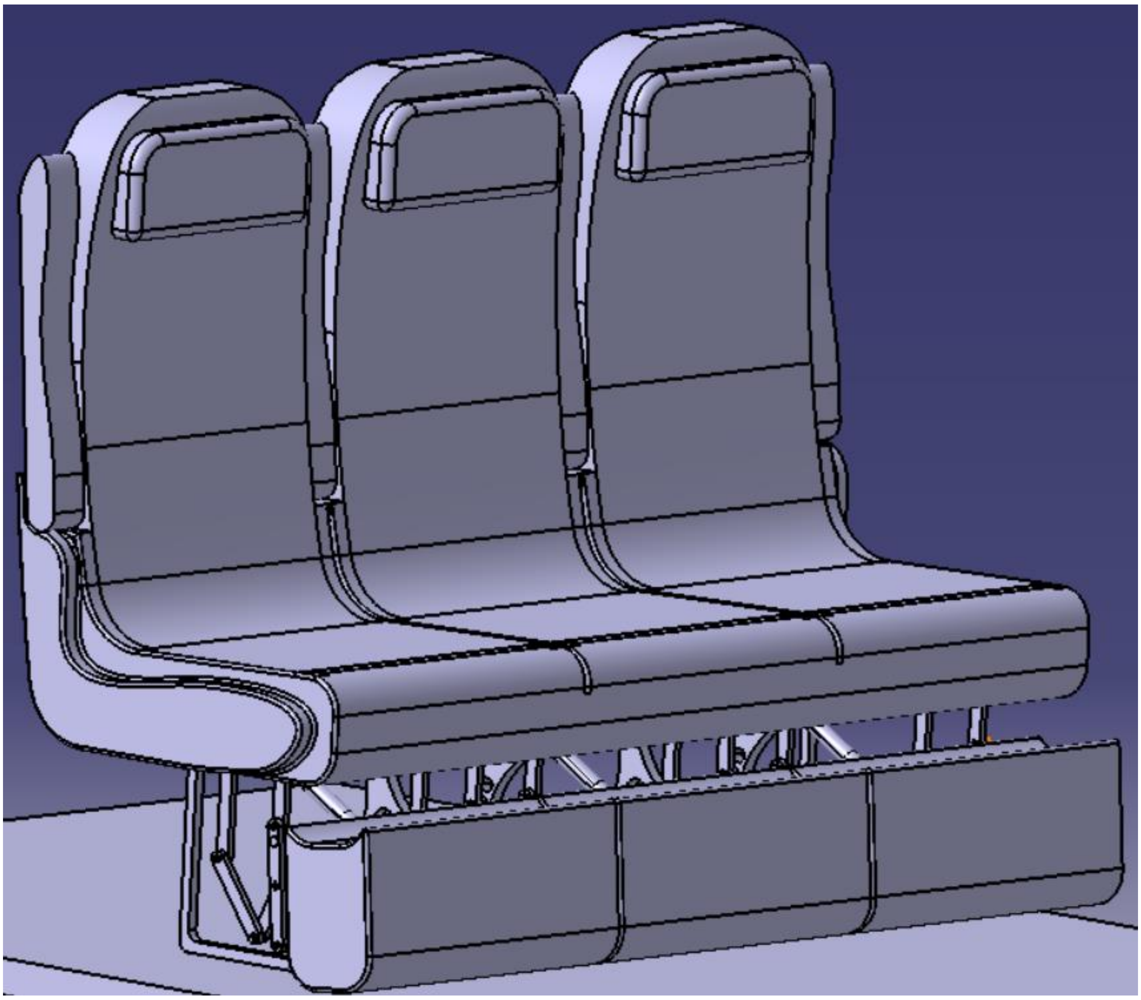

Figure 2.2 – Armrests retracted

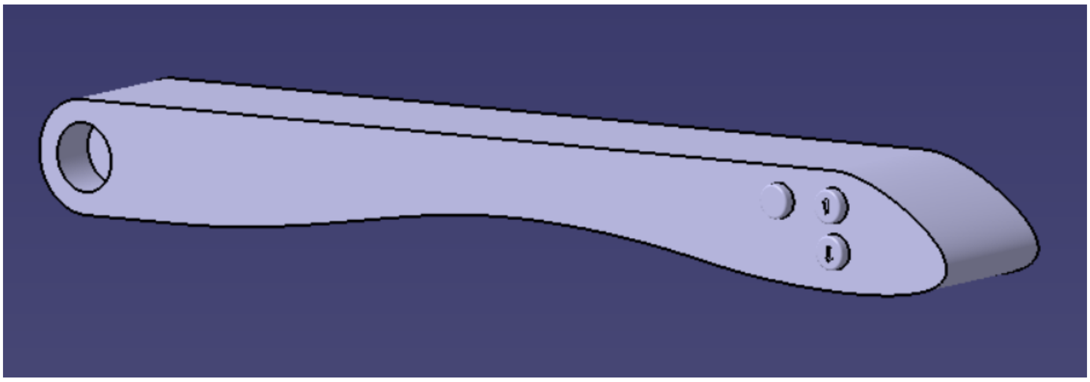

Figure 2.3 – Buttons on the armrests

To recline the seatback, push the inside button and hold it while move your body back untill the seatback is in the correct position, then release the button. The seatback can be adjusted approximately 15 degrees. To returen the seatback to the vertical position, lean forward while pushing the button, the seatback will return to the set initial position under the action of the spring.

The critical part of the skycouch is the legrest. The legrest can be stretched to be flush with the seat cushion to form a flat bed. Passengers can lie on the cushion during a long flight. It can provide passengers with great comfort

To extend the legrest, push the upward button, the legrest will lift up automatically under the driven of the electric motor and vice versa.

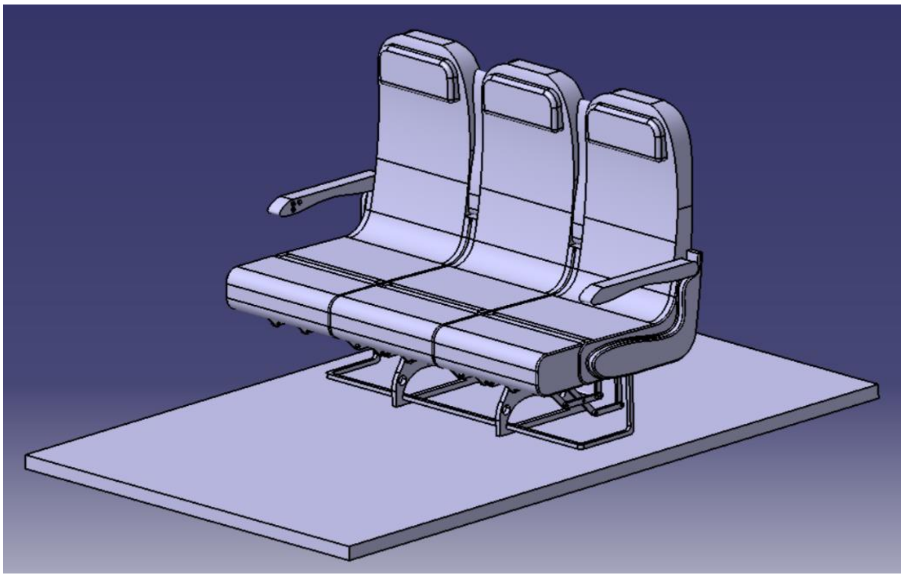

Figure 2.4 – The legrests extended into a flat bed

The legrest is driven by a linkage mechanism containing a screw rod, sleeve and a electrical motor. The mechanism is shown as following figure.

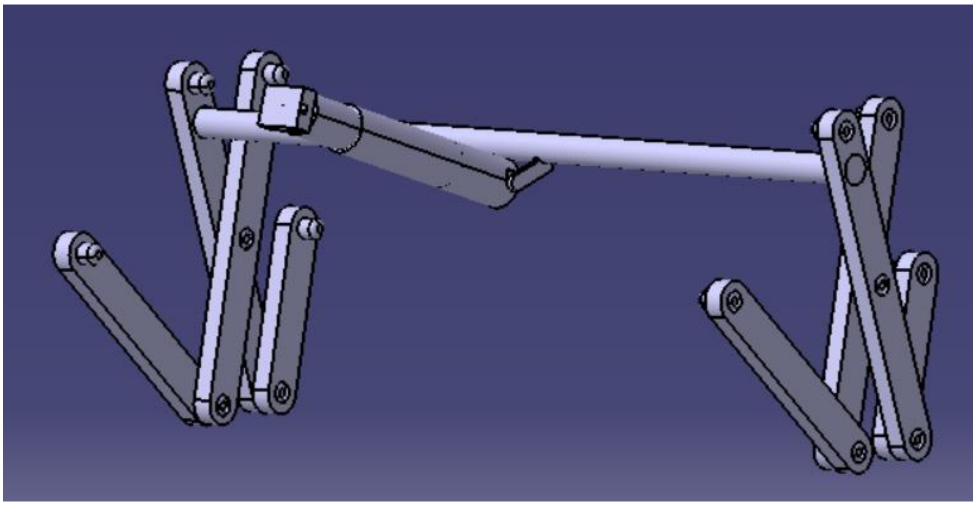

Figure 2.5 - Link system

The screw rod is an ideal mechanism that converts rotary motion into linear motion. The outer surface of the screw rod is threaded, and the inner surface of the sleeve is also threaded. They fit with each other. The electrical motor drives the screw rod to rotate, and the sleeve is pushed forward. The rod connecting the left and right link mechanisms rotates under the drive of the sleeve, driving the link mechanisms on both sides to lift the legrest.

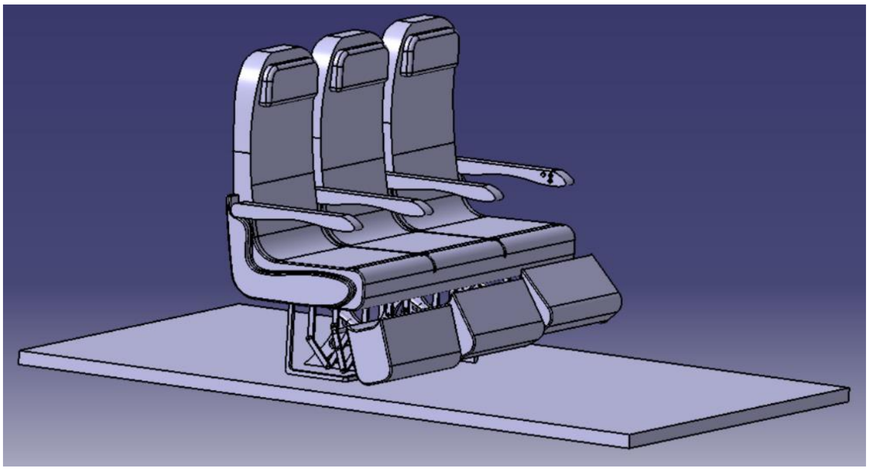

Figure 2.6 – The legrests stop at an arbitary position

As shown in figure 2.6, the legrest can be stopped at any position  to provide a better comfort. That is because the screw rod and sleev are self-locking mechanism. If there is no external force input (here it refers the electrical motor does not start), the mechanism will be locked even there is a very big external force. It gives passengers more choices and riding positions

The passenger seat is fixed on the rail which is installed on the floor. It can be easily realized through the guide rail if the users want to move the seat. The rail is shown in figure 2.7.

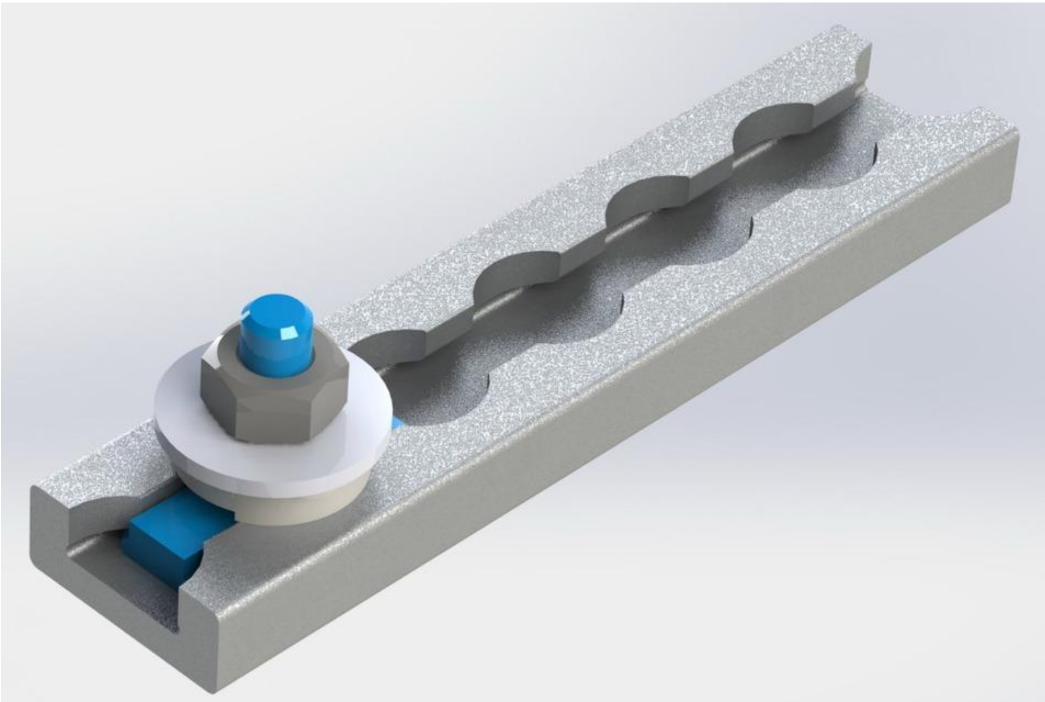

Figure 2.7 – Model of seat rail

**2.3 Strength calculation of the skycouch**

The designed passenger seat should meet the following requirements:

- provide comfort to passengers
- meet the flame retardancy requirements in the airworthiness regulations
- meet the requirements of static loads in airworthiness regulations
- meet the requirements of dynamic loads in airworthiness regulations

According to the FAR Sec 25.561 (the requirements for static conditions). When the passengers experience the following inertial forces acting on the surrounding structures, the structure must be designed to give each occupant possibility to escape from a serious injury in a  minor crash landing: upward, 3.0g, forward, 9.0g, sideward, 3.0g on the airframe; and 4.0g on the seats and their attachments, downward, 6.0g, rearward, 1.5g.

In addition, the designed seat should meet the requirements for emergency landing dynamic conditions. Under the specified conditions, the seat material will not fail because the tensile strength of the material is greater than the maximum stress which is caused by this situation. This is usually verified by dynamic test. The test is conducted with an occupant simulated by a 170-pound anthropomorphic test dummy, as defined by 49 CFR Part 572, Subpart B, or its equivalent, sitting in the normal upright position.

The requirements for emergency landing dynamic conditions are:

1) Downward (The angle deviates from perpendicular to the horizontal plane up to 30 degrees) - 14g
2) Forward (If the plane deviates from the flight direction by 10 degrees) - 16g

Head injury is the deadliest injury. Therefore, there are special criteria to evaluate the severity of the passenger's head injury. In the FAR Part 25.562, the Head Injury Criterion (HIC) is introduced:

$$HIC = \left\{(t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\}_{max} < 1000$$

Where:

$t_1$ is the initial integration time

$t_2$ is the final integration time

a(t) is the total acceleration vs. time curve for the head strike, and where (t) is in seconds, and (a) is in units of gravity (g).

The seat rail should meet the above requirements.

The legrest is supported by the srew rod and sleeve. They should strong enough to support the weight of the passenger and prevent passenger falling from the seat due to strength failure.

Strength calculation for screw rod when the legrest is fully extended:

The sideview of the linkage machanism is shown as following figure 2.8.

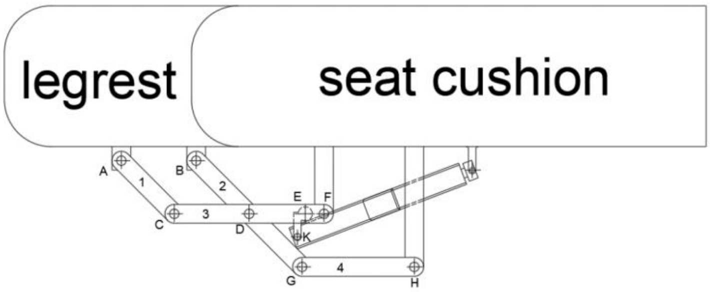


Figure 2.8 – Side view of the linkage mechanism

When an object is in a state of equilibrium, the resultant external force and the resultant external moment of it are both zero, otherwise it cannot be in a balanced state. Expressed by the equation as:

$$\begin{cases} \sum F_{xi} = 0 \\ \sum F_{yi} = 0 \\ \sum M_i = 0 \end{cases}$$

First, we consider forces act on the legrest.

Weight of each passenger: $W_p = 78kg$

Weight of the legrest: $W_l = 1kg$

All the rods are lightweight rod, their weights are negligible.

Total force act on the legrest is:

$$G_t = (\frac{1}{2}W_p + W_l) \cdot g = (\frac{1}{2} \times 78 + 1) \times 9.8 = 392N$$

For each side, the linkage mechanism bear a half of total force.

The force analysis of the legrest is shown in figure 2.9.

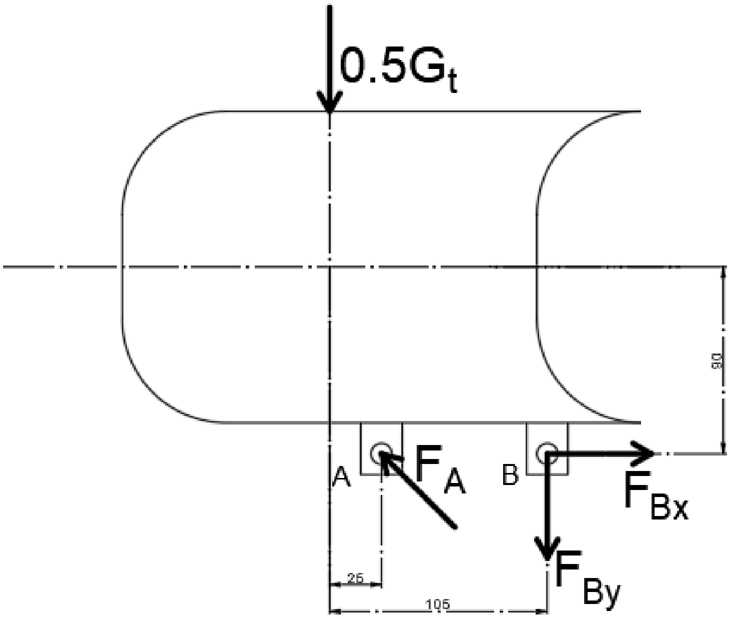


Figure 2.9 - Force field analysis of legrest

According to mechanical equilibrium:

$$\begin{cases} F_A \cos 45° - \frac{1}{2}G_t - F_{By} = 0 \\ F_{Bx} - F_A \sin 45° = 0 \\ 105 \times \frac{1}{2}G_t - 80 \cdot \sin 45° \cdot F_A = 0 \end{cases}$$

Solve the above three equations, we can get the solution of the system of equations:

$$\begin{cases} F_A = 363.8\ N \\ F_{Bx} = 257.25\ N \\ F_{By} = 61.25\ N \end{cases}$$

After the determination the forces that act on the legrest, we come to consider the rod 2. It’s force field analysis is shown as follow:

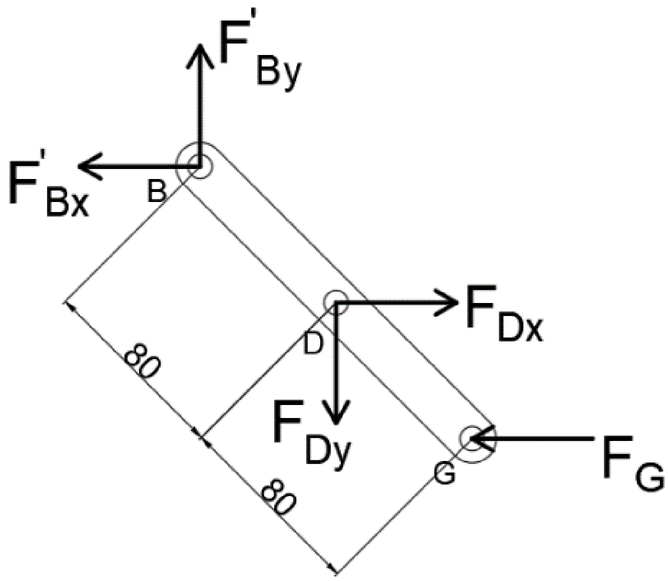


Figure 2.10 - Force field analysis of rod 2

According to mechanical equilibrium:

$$\begin{cases} -F_G + F_{Dx} - F'_{Bx} = 0 \\ -F_{Dy} + F'_{By} = 0 \\ -F_G \cdot 80 \cdot \sin 45° + F'_{Bx} \cdot 80 \cdot \sin 45° - F'_{By} \cdot 80 \cdot \cos 45° = 0 \end{cases}$$

Solve the above three equations, we can get the solutions of the system of equations:

$$\begin{cases} F_{Dx} = 453.25\ N \\ F_{Dy} = 61.25\ N \\ F_G = 196\ N \end{cases}$$

Third, we focus on the rod 3. It's force field analysis is shown as follow:

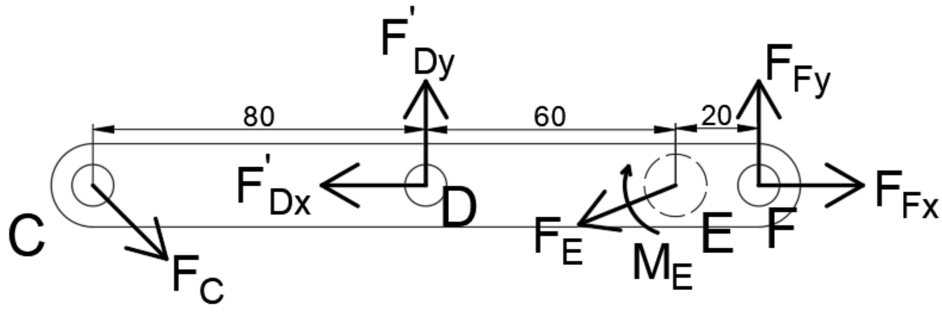


Figure 2.11 - Force field analysis of rod 3

Where $M_E = 30 \times F_E \cos 22° - 10 \times F_E \sin 22°$

According to mechanical equilibrium:

$$\begin{cases} F_{Fx} - F'_{Dx} + F_C \cos 45° - F_E \cos 22° = 0 \\ -F_C \sin 45° + F'_{Dy} + F_{Fy} - F_E \sin 22° = 0 \\ 160F_C \sin 45° - 80F'_{Dy} - M_E + 20F_E \sin 22° = 0 \end{cases}$$

Solve the above three equations, we can get:

$$\begin{cases} F_{Fx} = 2223.7\ N \\ F_{Fy} = 1015.2\ N \\ F_E = 2186.9\ N \end{cases}$$

According to the Newton's Third Law of Motion, the forces act on the sleeve and screw rod respectively are:

$$F_{sl} = F_{sc} = 2F_E = 4373.8\ N$$

The cross section of the sleeve and screw rod are shown as follow:

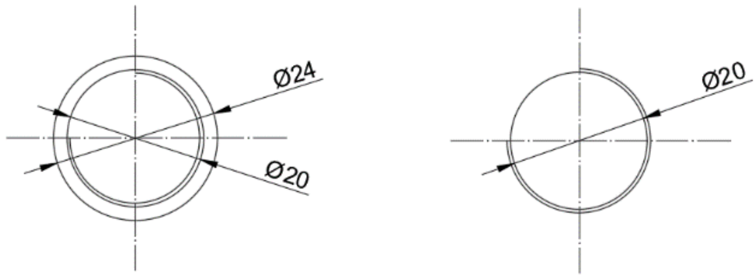


Figure 2.12 – cross section of sleeve (left) and screw rod (right)

The area of the sleeve cross section: $S_{sl} = \pi(\frac{D}{2})^2 - \pi\left(\frac{d}{2}\right)^2 = 138.23 \times 10^{-6}\ m^2$, $S_{sc} = \pi(\frac{d}{2})^2 = 314.16 \times 10^{-6}\ m^2$

The maximum normal stress in the corss section of the sleeve and screw rod respectively are:

$$\sigma_{sl} = \frac{F_{sl}}{S_{sl}} = \frac{4373.8}{138.23 \times 10^{-6}} = 31.64\ MPa$$

$$\sigma_{sc} = \frac{F_{sc}}{S_{sc}} = \frac{8749.2.2}{314.16 \times 10^{-6}} = 13.92\ MPa$$

Under the emergency situations, the maximum normal stress for the sleeve and srew rod are respectively 14 times bigger than previous.

$$\sigma_{sl\,max} = 14\sigma_{sl} = 31.64 \times 14 = 442.96\ MPa$$

$$\sigma_{sc\,max} = 14\sigma_{sc} = 13.92 \times 14 = 194.88\ MPa$$

For the Metal Matrix Composite 2124-25%SiC, its properties are shown as table 2.1.

Table 2.1 – Properties of Metal Matrix Composite 2124-25%SiC

| Metal Matrix Composite 2124-25%SiC | | |
|---|---|---|
| Composition: Aluminum alloy 2124 + 25%SiC particles | | |
| Property | Value in metric unit | Value in US unit |
| Density | $2.88*10^3$ kg/$m^3$ | 180 lb/$ft^3$ |
| Modulus of elasticity | 115 GPa | 16680 ksi |
| Tensile strength | 650 MPa | 94270 psi |
| Yiled strength | 480 Mpa | 69620 psi |

Safety factor for the sleeve and screw rod are:

$$\eta_{sl} = \frac{\sigma_b}{\sigma_{sl\ max}} = \frac{650}{442.96} = 1.47$$

$$\eta_{sc} = \frac{\sigma_b}{\sigma_{sc\ max}} = \frac{650}{194.88} = 3.36$$

The load factor is more than 1. The material can be used for manufacturing the sleeve and screw rod and can be used in a safe condition.

After checking the strength of the sleeve and screw rod, we come to the estimation of the strength of each rod in the linkage mechanism when the legrest is fully extended:

The shape of cross section of each rod are the same, it is shown as figure 2.13.

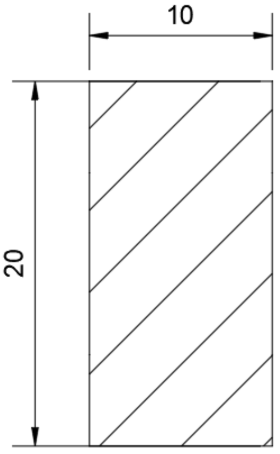


Figure 2.13 – Cross section of each rod

The area of the rod cross section is $S_r = 10 \times 20 = 200\ mm^2$

The rod 1 and rod 4 are two-force members, they only bear compression stress. Therefore, the normal stress calculation for rod 1 and rod 4 are:

$$\sigma_1 = \frac{F_A}{S_r} = \frac{363.8}{200 \times 10^{-6}} = 1.819\ MP$$

$$\sigma_4 = \frac{F_G}{S_r} = \frac{196}{200 \times 10^{-6}} = 0.98\ MPa$$

Obviously, the normal stress of the two rods is much less than the tensile strength of the material we choosed, so the material meets the performance requirements.

Unlike rod 1 and rod 4, rod 2 and rod 3 are not simply subjected to tension or pressure, but under the combined action of tension or compression and bending moment.

Decompose the force on the rod 2 into the direction along the rod and the direction perpendicular to the rod, as shown in figure 2.14. Its bending moment and normal stress are also shown in the figure.

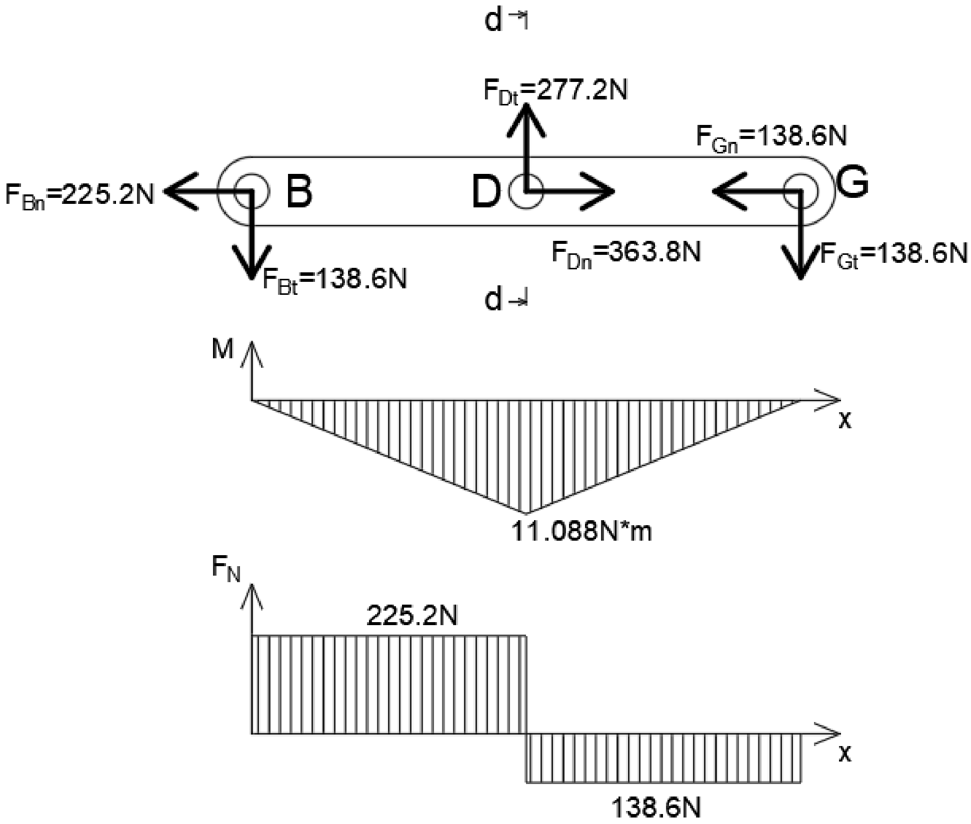


Figure 2.14 - Bending moment and normal stress of rod 2

The shape of cross section of d-d is shown as follow:

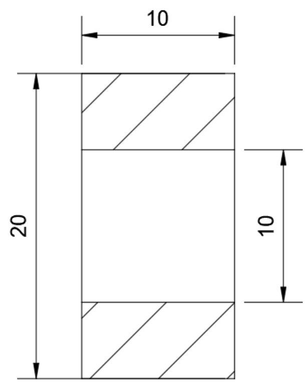


Figure 2.15 - Cross section of d-d

Inertial moment:

$$I_z = \frac{1 \times 2^3}{12} - \frac{1 \times 1^3}{12} = 0.58\ cm^4$$

$$\sigma = \frac{My_{max}}{I_z} = \frac{11.088 \times 0.01}{0.58 \times 10^{-8}} = 19.12\ MPa$$

Normal stress:

$$\sigma_N = \frac{F_N}{S} = \frac{225.2}{2 \times 1 \times 0.5 \times 10^{-4}} = 2.25\ MPa$$

Total normal stress:

$$\sigma_t = \sigma + \sigma_N = 21.37\ MPa$$

Under the emergency situation, the the load can be:

$$\sigma_{max} = 21.37 \times 14 = 299.18\ MPa$$

Load factor for the rod 2:

$$\eta_3 = \frac{\sigma_b}{\sigma_{max}} = \frac{650}{299.18} = 2.17$$

Similarly, decompose the force on the rod 3 into the direction along the rod and the direction perpendicular to the rod, as shown in figure 2.16. Its bending moment and normal stress are also shown in the figure.

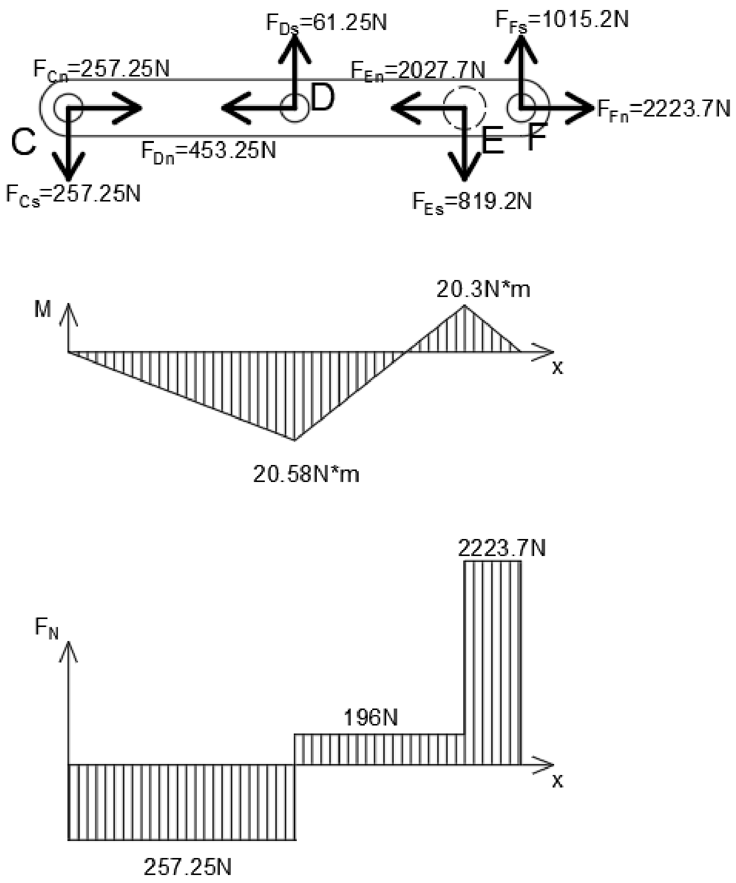


Figure 2.16 - Bending moment and normal stress of rod 3

Inertial moment:

$$I_z = \frac{1 \times 2^3}{12} = 0.66\ cm^4$$

$$\sigma = \frac{My_{max}}{I_z} = \frac{20.3 \times 0.01}{0.66 \times 10^{-8}} = 30.76\ MPa$$

Normal stress:

$$\sigma_N = \frac{F_N}{S} = \frac{2223.7}{2 \times 1 \times 10^{-4}} = 11.11\ MPa$$

Total normal stress:

$$\sigma_t = \sigma + \sigma_N = 41.87\ MPa$$

Under the emergency situation, the the maximum load can be:

$$\sigma_{max} = 41.87 \times 14 = 586.18\ MPa$$

Safety factor for the rod 3:

$$\eta_3 = \frac{\sigma_b}{\sigma_{max}} = \frac{650}{586.18} = 1.11$$

Since the rod three is the maximum loaded rod, the choosed material can meet the requirement of the loads act on the rods.

According to the results from calculation, all calculated safty factors are more than 1. That is the choosed material is strength enough to bear the loads act on the linkage mechanism. It is safe during flight and even in the emergency situations.

**Conclusion to the part**

The main task of this part in my diploma work is to finish the concenptual design of the new type of passenger seat which is called skycouch. The most importment part of the new type of passenger seat is the linkage mechanism which is used for extending and retracting the legrest.

I checked the strength of the linkage mechanism, the screw, the sleeve and all the hinges. The choosed material is wrought aluminum alloy 2024T361. Its tensile strength is 496MPa, and shear stress is 290MPa. According to the calculation resluts, the choosed material can meet the requirements for the mechanism.

# GENERAL CONCLUSION

The aim of the diploma work is to design a single aisle long-range passenger aircraft with a passenger capacity of 158. The initial data is determined by refering to the design of the prototypes. The prototypes are Airbus A320, Boeing 737 and C919.

In the first part of the diploma work, the main parts of the designed aircraft are introduced, including the fuselage, wing, tail unit, landing gear. After the description of the main parts of the designed aircraft, I performed the preliminary design of aircraft according to the calculations of geometrical characteristics. All the geomertrical parameters are calculated in the first iteration. After that, the position of all equipment and concentrated masses in the fuselag and in the wing were defined, so, the final range of the aircraft's center of gravity position is determined. The calculation result shows that the position of center of gravity is in a reasonable range. The designed aircraft has a good stability.

All results of finished above work are demonstrated at the 2 drawings to show the geometry of the aircraft – general view, and the cabin layout.

In the second part of my diploma work, a new type of passenger seat is designed – the skycouch, which has a new design of the mechanism of the legrest deflection. The structure of skycouch and main functions of it are described in the text, the strength calculation of the legrest's linkages are performed. The results show that the Metal Matrix Composite 2124-25%SiC can meet the strength requirement of the seat. The designed seat is in a safe operation.

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