МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Кафедра конструкції літальних апаратів

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
д-р техн. наук, проф.
_____________ С. Р. Ігнатович
«_____» ___________ 2021 р.

ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)
ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ
"БАКАЛАВР"

Тема: «Аванпроект середньомагістрального літака пасажиромісткістю 162 осіб»

Виконав: ___________ **Хань Вей**

Керівник: канд.техн.наук, доцент ___________ **Т.П. Маслак**

Нормоконтролер: канд.техн.наук, доцент ___________ **С.В. Хижняк**

Київ 2021

MINISRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

Department of Aircraft Design

AGREED
Head of the Department
Professor, Dr. of Sc.
_________S.R. Ignatovych
«___» _______ 2021 y.

DIPLOMA WORK

(EXPLANATORY NOTE)
OF ACADEMIC DEGREE
«BACHELOR»

Theme: «Preliminary design of a mid-range aircraft with 162 passenger capacity»

Performed by: __________ **Han Wei**

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

Standard controller: PhD, associate professor __________ **S.V. Khizhnyak**

Kyiv 2021

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty

Department of Aircraft Design

Academic Degree «Bachelor»

Speciality: 134 "Aviation and Space Rocket Technology"

APPROVED
Head of the Department
Professor, Dr. of Sc.
_________S.R. Ignatovych
«___» _______ 2021 year

TASK

for bachelor diploma work

HAN WEI

1. Theme: **«Preliminary design of a mid-range aircraft with 162 passenger capacity»** confirmed by Rector's order from 21.05.2021 year № 815/ст

2. Period of work execution: from 24.05.2021 year to 20.06.2021 year.

3. Work initial data: cruise speed V_{cr}=828 km/h, flight range L=5460 km, operating altitude H_{op}=11 km, 162 passengers.

4. Explanation note argument (list of topics to be developed): choice and substantiations of the airplane scheme, choice of initial data; engine selection, aircraft layout, center of gravity position calculation, designing of massage device for passenger seat.

5. List of the graphical materials: general view of the airplane (A1×1); layout of the airplane (A1×1); massage device assembly drawing (A1×1).

Graphical materials are performed in AutoCAD, SOLIDWORKS, CATIA.

6. Calendar Plan

Task	Execution period	Signature
Task receiving, processing of statistical data	24.05.2021–28.05.2021	
Aircraft geometry calculation	28.05.2021–31.05.2021	
Aircraft layout	31.05.2021–03.06.2021	
Aircraft centering	03.06.2021–05.06.2021	
Graphical design of the parts	05.06.2021–12.06.2021	
Preliminary defence	12.06.2021–14.06.2021	
Completion of the explanation note	14.06.2021–20.06.2021	

7. Task issuance date: 24.05.2021 year

Supervisor of diploma work ___________ T.P. Maslak

Task for execution is given for ___________ Han Wei

ABSTRACT

Explanatory note to the diploma work «Preliminary design of a mid-range aircraft with 162 passenger capacity» contains:

pages, figures, tables, references and 4 drawings

Object of the design is a mid-range aircraft with 162 passenger capacity.

Subject of the design – the conceptual design of the massage device for passenger's seat with performance of stress-strain analysis.

Aim of the diploma work is the preliminary design of the mid-range passenger aircraft based on the prototypes with the layout of the passenger cabin, conceptual design of the massage device assembly.

The design methods are analysis of prototypes, selection of the most suitable parameters for designing aircraft, estimation of the geometrical characteristics based on statistic data recommendations, calculation of the centre of gravity of the designing aircraft, 3D modeling of the message device, stress-strain analysis of the massage device.

The actual realization of these results is defined as: the designing of the mid-range aircraft with 162 passenger capacity, calculations and drawings of the aircraft layout and conceptual design of the massage device.

The materials of the diploma work could be recommended for the students of aviation specialties, for the aircraft operational companies, etc.

AIRCRAFT, PRELIMININARY DESIGN, CABIN LAYOUT, CENTER OF GRAVITY POSITION, MASSAGE DEVICE

INTRODUCTION

In the past ten years, the global air passenger demand has increased by an average of 5.5% every year. Although air passenger transport industry was hit by COVID-19 in recent two years, air passenger demand will quickly return to normal as the epidemic subsided.

Air passenger transport has become an indispensable way for people to travel. People can reach anywhere in the world easily and quickly by plane, and traveling around the world is no longer an unreachable dream for ordinary people. Economic globalization is the general trend in the world. With the continuous development of air passenger transport, the economic cost of air travel is getting lower and lower. With the rise of some developing countries, the demand for medium-range aircraft will increase in the coming decades. Air travel will continue to develop and become one of the most important ways of travel.

Compared with passenger aircraft and cargo aircraft, for developing countries, the future demand for passenger aircraft may be greater than cargo aircraft. Take China as an example, as people's income level continues to improve, people pay more attention to entertainment, they will choose a faster aircraft rather than a train for traveling. As for the cargo transportation, road, train, or ship transportation, it has a more economic advantage than aircraft, especially to the transportation of many large or cheap goods. So I think the demand for domestic passenger flights in China will increase rapidly in the coming decades.

A passenger aircraft is designed to carry passengers and their luggage instead of cargo only, passenger aircraft have features which separate them from cargo aircraft. The passenger aircraft is more concerned about the comfort and safety of passengers, rather than pursuing large capacity. There are few features, first is narrow fuselage cross section, a low-wing to allow the high flexibility and safety during emergency situations such as ditching, quieter and more fuel-efficient engines are used to provide a comfort environment for passengers.

Considering the type of aircraft allows transporting about 160 passengers and at a distance close to 5000 km without refueling, which can meets all requirements whatever in distance or passenger capacity for domestic passenger flights, short flights and mid-range flights.

After analyzing of the several popular aircraft on the market, I chose Boeing 737-800, COMAC-C919 and Airbus A320 as prototypes for the designed aircraft. They have similar characteristics in flight range, passenger capacity and so on.

The purpose of my work is the preliminary design of a mid-range aircraft with 162 passenger capacity. It will be suitable for mid-range flight and even for domestic passenger flights in case of a big country. The aircraft will be economical and comfortable, making sure passengers and airlines will be happy to accept it. To achieve these goals, I will combine the advantages of these three prototypes and will use the most appropriate technical characteristics of each of them. The special task in mu work is devoted to the design of massage device for passengers to make sure that they can have a better experience to take this aircraft.

CONTENT

1. PRELIMINARY DESIGN OF A MID-RANGE AIRCRAFT

1.1 Prototypes analysis and description of aircraft design

In order to form a concept of aircraft preliminary design, we must first choose the optimal design parameters. The selecting of the optimal design parameters of the aircraft is the multidimensional optimization task. Its configuration means the whole complex flight-technical, weight, geometrical, aerodynamic and economic characteristics.

My task in this stage of diploma work is analysis of various prototypes according to initial data. After putting my approximate data that I gathered from different resources into the computer program, I received more accurate initial data to begin my project. My task is choosing a passenger aircraft with capacity of 162 passengers under a given payload at a maximum range of 5200 km.

On the table 1.1 and 1.2, we have operational – technical and geometric parameters of three different transport aircraft, which have similar characteristics and parameters to our desired aircraft. Prototypes which were chosen for comparison are as following:

Table 1.1 - Technical data of aircraft prototypes

Name and dimensions	Boeing 737-800	C 919	Airbus A320
The purpose of airplane	Passenger	Passenger	Passenger
Crew/flight attend, numbers	2/6	2/5	2/4
Passenger's seat	168	156	117
Maximum take-off weight, m_{tow}, kg	79010	72500	68000
Max payload, kg	20540	20500	19500
The form of the cross-section fuselage	circular	circular	circular
Flight Range with MTOW, km	5460	4075	6150
Cruise speed, km/h	828	960	828

Table 1.1 - Technical data of aircraft prototypes (continued)

Cruise altitude, km	11	10.7	11
Number and type of engines	2 (CFMI CFM56-7B)	2 (CFM International LEAP-1C)	2 (CFM56-5B)
Take off run at MTOW, m	2550	2000	2090
Landing distance, m	1190	1600	1230
Landing speed, km/h	220	250	250
Field length for takeoff, m	1940	1800	1500
Thrust (each engine), KN	117	130	120
Degree bypass ratio	5.9	11	5.9

Table 1.2 - Geometrical parameters of prototypes

Name and dimensions	Boeing 737-800	COMAC C919	Airbus A320
Length of the fuselage, m	38.1	38.9	37.6
Wingspan, m	34.32	33.6	34.1
Wing area, m^2	124.6	129.15	122.6
Aspect ratio	9.45	8.74	9.50
Sweepback angle, degree	25	25	25
Height at tail, m	12.57	11.952	11.76
Fuselage diameter, m	3.76	3.96	3.95
Fineness ratio of the fuselage	10.5	9.82	9.5
Fineness ratio the nose and tail unit part	2.86	3.64	2.95
Wing taper ratio, m	0.286	0.25	0.327
Mean geometric chord, m	4.48	4.23	4.19

The first step to develop this project is to choose the aircraft that is going to be analyzed as a prototype. The first general idea was to choose representative and successful aircraft, because the success of these planes embodies the wisdom and hard work of countless aircraft engineers, a successful aircraft must have its unique advantages, it can better reflect the needs of the modern aviation market, and it is worth studying.

Airbus A320 is one of the best-selling aircraft in the history of civil aviation and has great study value, another reason is it is similar to COMAC C919 which is the first large-scale trunk passenger aircraft of China, so that I can compare them and take their advantage. However, the number of passengers that A320 can carry doesn't meet my design in my project.

COMAC C919 is the first large-scale trunk passenger aircraft developed from COMAC. It is of great significance to the Chinese people, but the flight range with MTOW is a little bit less than what I want to design which can fully meet the needs of any domestic air routes and mid-range flights.

Next, the aircraft that can cover the designed range perfectly with consideration of passenger capacity is Boeing 737-800. After considering various parameters, Boeing 737-800 is the prototype that best suits my project.

The aircraft considered to design in this project is mid-range passenger aircraft. The fuselage is designed as a semi-monocoque type with a circular cross section. It has low-wing, two engines it is able to carry 162 passengers and has a maximum payload up to 20000 kg, cruising speed is 0.8 Ma at altitude of 11km, which flight range with MTOW is 5200 km. The designed aircraft fuselage is narrow-body type with length in 39.48 m.

The wing is one of the most important part for aircraft which generates lift force, provides aircraft control and spaces for fuel storage. In our case, we have low-wing with sweep-back and high aspect ratio which gives slightly more lift and enable sustained and endurance flight. Low-wing aircraft has good performance in emergency ditching and high maintainability. The main function of tail unit is to control aircraft in pitching or yawing during flight which consists of vertical stabilizer with rudder and horizontal stabilizer with elevator.

1.2 Aircraft geometry calculations and fuselage layout

The layout of the aircraft includes the relative disposition of the main units, the construction elements, the number of passengers and so on.

The main task is to select the aircraft parameters and solutions that best meet the operational requirements.

1.2.1 Wing geometry calculation

The first step in the preliminary design of the aircraft is to find the geometric parameters of aircraft main part. The first iteration includes the statistical data of prototypes and the statistical coefficient for the aircraft. The calculated initial data which from the department's computer program is presented in the Appendix A.

According to the initial data:

Take off Lift Coefficient (at Stall Speed): $C_{Lmax} = 1.993$;

Optimal Lift Coefficient in the Design Cruising Flight Point: $C_y = 0.45761$;

High-lift Device Coefficient: $C_{HLD} = 1.1$;

The aircraft has a triple slotted flap, and the triple slotted flap generates an ΔCl of 1.1 when deflected 60 degrees.

$$C_{lmax} = C_{lmax_{gross}} - C_{lmax_{HLD}} = \frac{1.993}{0.9 * 0.95} - 1.1 = 1.23;$$

So that I need to look for NACA airfoil sections that yield an ideal lift coefficient of 0.45761 and a net maximum lift coefficient of 1.23 (flaps up).

After comparing these coefficients, I choose (b737b-il) BOEING 737 MIDSPAN AIRFOIL as my designed aircraft airfoil. Figure 1.1 is a drawing of this airfoil.

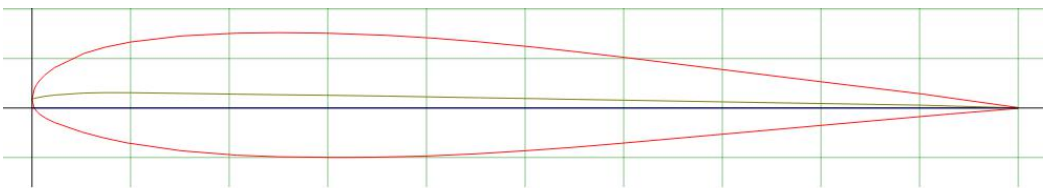


Figure 1.1 - Airfoil b737b-il

The wing structure of this aircraft is mid-span airfoil which can produce enough lift to carry useful payload. Wing root is approximately 16.5 % of the fuselage length. Max thickness 12.5% at 29.7% chord. Max camber 0.8% at 10% chord. The twist angle of the root is 4 degrees and there is no twist at the tip of the wing [1].

Wing loading explain the ratio of the aircraft's takeoff weight to the wing area. We can take maximum take off weight m0 and specific wing load P0 of our designing plane from the Appendix A , so the wing area is:

$$S_{wfull} = \frac{m_o * g}{P_o} = \frac{83551 * 9.8}{5334} = 153.5\ [m^2];$$

According to the statistic data of prototypes and on the base of aircraft designers experience we could decrease the area of a wing to 142.3 m^2.

Then we could find wing span through the aspect ratio equal to 9.45:

$$l = \sqrt{S_w * \lambda_w} = \sqrt{142.3 * 9.45} = 36.7\ [m];$$

Root chord of the wing equal:

$$b_o = \frac{2S_w * \eta_w}{(1 + \eta_w) * l} = \frac{2 * 142.3 * 3.5}{(1 + 3.5) * 36.7} = 6.03\ [m];$$

Tip chord equal:

$$b_t = \frac{b_o}{\eta_w} = \frac{6.03}{3.5} = 1.72\ [m];$$

Board chord equal:

$$b_{ob} = b_o * \left(1 - \frac{(\eta_w - 1) * D_f}{\eta_w * l_w}\right) = 5.59\ [m];$$

The construction of the designing wing is semi-monocoque, and there are two spars placed at the 25% and 65% chord away from the leading edge. According to the method guide the position of the spars from the leading edge of the wing are located:

$$\overline{x}_i = \frac{x_i}{b};$$

where x_i – distance between leading edge and i-spars in current cross-section, b – length of wing chord in the current cross section.

For these two spars: $\overline{X_1} = 0.25,\ \overline{X_2} = 0.65$.

The width of the torsion box and the capacity of the fuel tanks are determined by the distance between two spars.

The Mean Aerodynamic Chord (MAC) of wing is determined by geometrical method which is shown on the figure 1.2.

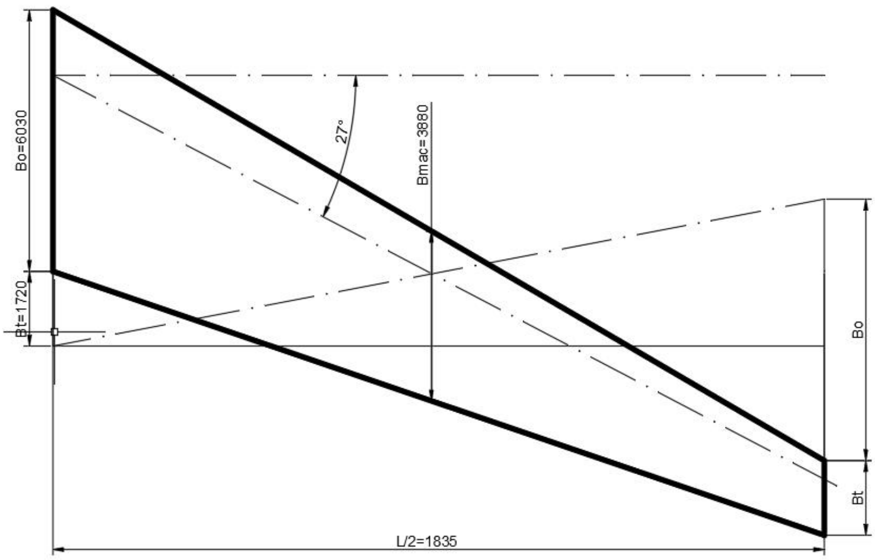


Figure 1.2 - Geometrical method of a mean aerodynamic chord determination

So we can obtain the length of the mean aerodynamic chord, which is equal to b_{mac} = 3.88 m.

After determining the geometric characteristics of the wing, we began to estimate the geometric characteristics of the aileron and configure the high-lift device.We have double slotted flaps according to the prototype and initial data.

The geometric parameters of the ailerons span are:

$$l_{ail} = 0.35\frac{l_w}{2} = 0.35 * \frac{36.7}{2} = 6.42\ [m];$$

Calculating the ailerons chord based on statistic data recommendations, where bi – is the current chord length in the cross section where our aileron is located:

$$b_{ail} = (0.22...0.26) * b_i;$$

$$b_{ail_{root}} = 0.25b_i = 0.25 * 3.34 = 0.835\ [m];$$

$$b_{ail_{tip}} = 0.25b_i = 0.25 * 1.87 = 0.4675\ [m];$$

Aileron's area could be found:

$$S_{ail} = \frac{(0.835 + 0.4675) * 6.42}{2} = 4.181\ [m^2];$$

The total area of the aerodynamic balance devices is:

$$S_{ailerons\ bal} \leq (0.25...0.28)\ S_{ail} = 0.26*4.181=1.087\ [m^2];$$

The deflection range of the aileron is: upward $\delta'ail \geq 25^\circ$; downward $\delta''ail \geq 10^\circ$. According to the preliminary calculations of the wing geometrical parameters we can design the wing layout. At the fig. 1.3 there is the top view of a wing with presented position of spars, high lift devices, spoilers, ailerons and winglets.

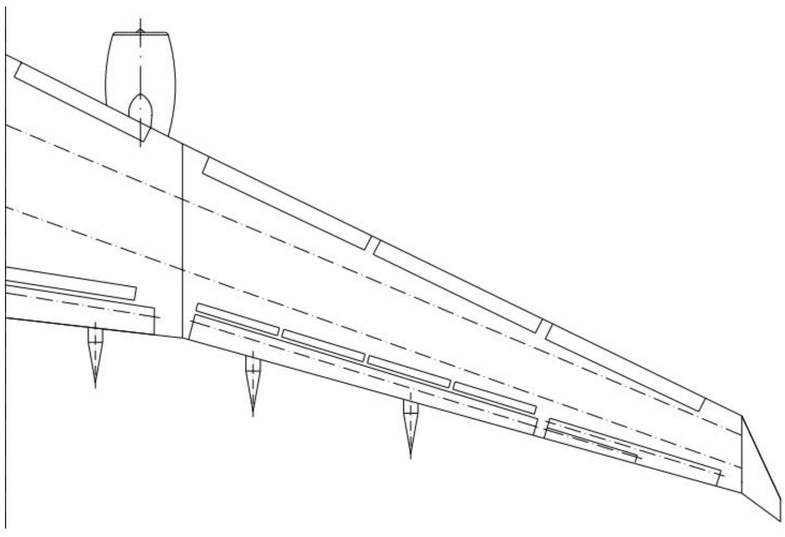


Figure 1.3 - Preliminary design of the wing

1.2.2 Fuselage layout

In my diploma work, layout of the aircraft consists of a structural body which allows space to carry passengers, baggage, and other useful loads. The fuselage structure consists of bulkheads, formers, stringers and longerons and skin. Bulkhead and formers give the shape to the aircraft' s skin. Formers are installed parallel to each other and are connected by side members along the entire perimeter of the surface. Technologically the fuselage is divided into three parts: front (cockpit), middle (passenger compartment), rear (tail unit), and the preliminary design of aircraft layout are shown in Figure 1.4.

The front part is the cockpit, the space under the cockpit accommodates many electrical instruments and other devices and the landing gear's front wheel. The tail of the fuselage consists of smaller forms, spars and stringers. As the formers are smaller but their thickness is constant, they are more rigid so that there are no structural problems to support both the horizontal and vertical stabilizers. The APU (auxiliary power unit) is usually placed at the tail.

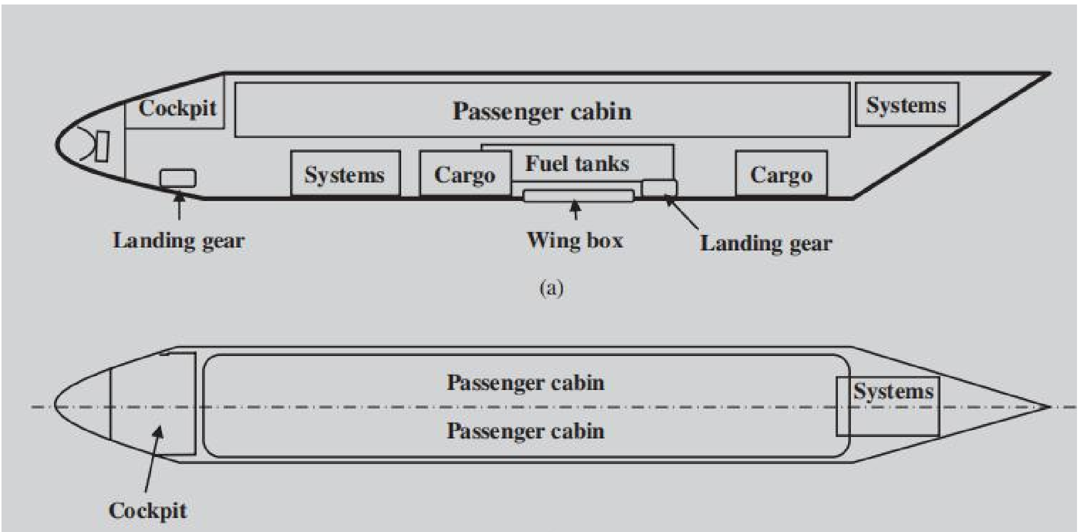


Figure 1.4 - Preliminary design of aircraft layout

In selecting the fuselage parameters, we need to take into account the aerodynamic requirements of the streamline and cross section.

The circular cross-section of fuselage is the most efficient because it provides the minimum weight and maximum strength, meeting strength requirements and reducing weight are important for aircraft design .

We also concentrate on the geometrical parameters, such as: fuselage diameter, length of fuselage, aspect ratio of fuselage, nose part and tail unit. We design the length of the aircraft fuselage by considering the aircraft plan, layout, and characteristics of the aircraft's center of gravity position and the landing angle of attack.

Length of aircraft fuselage:

$$l_f = \lambda_f * D_f = 10.5 * 3.76 = 39.48 \text{ [m]};$$

Length of aircraft fuselage nose part:

$$l_{np} = \lambda_{np} * D_f = 1.27 * 3.76 = 4.76 \text{ [m]};$$

Length of the fuselage tail unit:

$$l_{tu} = \lambda_{tu} * D_f = 1.6 * 3.76 = 6.02 \text{ [m]};$$

For passenger aircraft fuselage, the size of passenger cabin is important. Height of the passenger cabin plays an important role in the size of passenger cabin mid-section.

Cabin height is :

$$H_{cab} = 1.48 + 0.17B_{cab} = 1.48 + 0.17 * 3.76 = 2.12 \text{ [m]}$$

Windows are placed in one row on each side of the fuselage. The shape of windows are rectangular with rounded corners. Because aircraft windows are easily leading to stress concentration, the corners of the windows are rounded. The windows located between two bulkhead and in my design, the distance between two windows is about 550 mm.

For the economic class cabin, I design the passenger seat as 3 + 3 each row.

The appropriate width of economic class cabin:

$$B_{cab} = n_3 * b_3 + n_{aisle} b_{aisle} + 2\delta + 2\delta_{wall};$$

$$B_{cab} = 2 * 1450 + 1 * 460 + 2 * 50 + 2 * 100 = 3660 \text{ [mm]};$$

For business class, I design the passenger seat as 2 + 2 each row.

The appropriate width of business class cabin:

$$B_{cab} = n_2 * b_2 + n_{aisle} b_{aisle} + 2\delta + 2\delta_{wall};$$

$$B_{cab} = 2 * 1340 + 1 * 600 + 2 * 90 + 2 * 100 = 3660 \text{ [mm]};$$

The length of economic passenger cabin:

$$L_{econ} = L_1 + (N - 1) L_{seatpitch} + L2,$$

$$L_{econ} = 1200 + (23 - 1) * 800 + 300 = 19100 \text{ [mm]};$$

The length of business passenger cabin is equal:

$$L_{busi} = L_1 + (N - 1) L_{seatpitch} + L2,$$

$$L_{busi} = 1200 + (6 - 1) * 860 + 300 = 5880 \text{ [mm]};$$

Cargo cabins are placed under the floor of passenger cabin. Cargo placement is important in the flight which will influence gravity center of the aircraft. Incorrect placement of cargo and passengers, can lead to emergency situations in flight, that is why we have to calculate exactly cargo placement and limit their weight.

Maximum area load for Boeing 737-800, K_{max}=732 kg/m^2.

The total weight of mail and luggage that can be taken on board is: 8409 kg.

The volume of cargo compartment is equal: 44 m^3

The design of cargo compartment is refer to the prototype design.

1.2.3 Galleys and lavatories design

Next, we are going to design galleys and lavatories on board. According to international standards, the volume of the galleys should be about 0.1 cubic meter per passenger, in my case the volume of galley should be:

$$V_{galley} = 0.1 * n_{passenger} = 0.1 * 162 = 16.2\ [m^3];$$

The total area of galley floor:

$$S_{galley} = \frac{V_{galley}}{H_{cab}} = \frac{16.2}{2.12} = 7.64\ [m^2];$$

Number of meals per passenger breakfast, lunch and dinner – 0.8 kg; tea and water – 0.4 kg, the total weight of food for passenger and crew number is about 210 kg.

Number of lavatories on the aircraft depends on the number of passengers and flight time. In my situation, flight time is more than 4 hours, so one toilet for 40 passengers.

$$t = \frac{S_{flight}}{V_{cruise}} + 0.5 = \frac{5200}{828} + 0.5 = 6.78\ [h],$$

$$N_{lavatory} = \frac{N_{passenger}}{40} = \frac{162}{40} > 4;$$

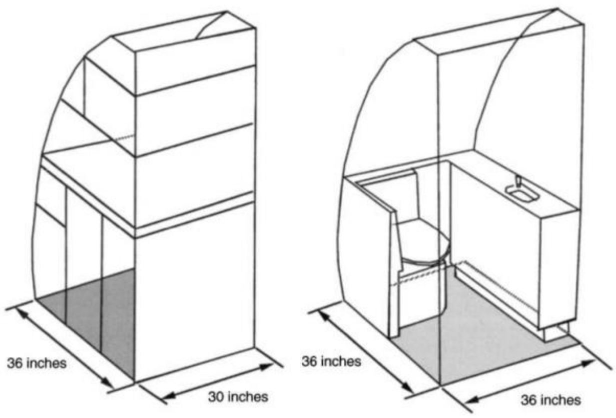


Figure 1.5 - Design of galley and toilet

On my aircraft, 2 galleys and 5 lavatories are designed. Galley and lavatory design are similar to the prototype, galley and lavatory layout are shown in Figure 1.5. And preliminary design of aircraft layout is shown in Figure 1.6.

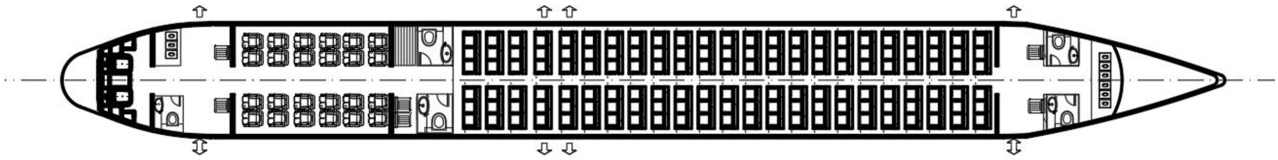


Figure 1.6 - Preliminary design of aircraft layout

1.2.4 Tail unit design

In the following steps, we will consider designing the aerodynamic layout of the tail unit, including parameters of fin and horizontal tail and the tail unit arms. The area of the tail and the arms provide aerodynamic moments for the stability and control aircraft in longitudinal direction.

In order to approximate the geometry of the tail unit, we can refer to the statistics of the aircraft.

The area of vertical tail unit is:

$$S_{VTU} = (0.12...0.20)S_w;$$

The area of horizontal tail unit is:

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

And the are also could be calculated:

$$S_{HTU} = \frac{A_{HTU} * S_w * b_{MAC}}{L_{HTU}} = 32.78\ [m^2];$$

$$S_{VTU} = \frac{A_{VTU} * S_w * L_w}{L_{VTU}} = 26.44\ [m^2];$$

Values Lhtu and Lvtu are affected by the length of the fuselage nose and tail part, sweep angle and wing position, as well as aircraft stability and control conditions. We could take Lhtu ≈ Lvtu = 14.35 m.

Determination of the elevator area:

$$S_{\text{elevator}} = 0.35 * S_{\text{HTU}} = 11.47\ [\text{m}^2];$$

Rudder area:

$$S_{\text{rudder}} = 0.4 * S_{\text{VTU}} = 10.58\ [\text{m}^2];$$

The area of altitude elevator trim tab:

$$S_{\text{trim tab of ele}} = (0.08..0.12)S_{\text{ele}} = 0.1 * 6.55 = 0.655\ [\text{m}^2];$$

Area of rudder trim tab is equal:

$$S_{\text{trim tab of rud}} = (0.04..0.06)S_{\text{rud}} = 0.05 * 5.22 = 0.261\ [\text{m}^2];$$

Span of horizontal tail unit:

$$L_{\text{HTU}} = (0.32..0.5)L_{\text{wing}} = 0.4 * 36.7 = 14.68\ [\text{m}];$$

Span of vertical tail unit:

$$L_{\text{VTU}} = (0.14..0.2)L_{\text{wing}} = 0.18 * 36.7 = 6.61\ [\text{m}];$$

Aerodynamic balance area:

$$S_{\text{aero banlance}} = (0.15..0.23),$$

$$S_{\text{control surface}} = 0.2 * 15.89 = 3.178\ [\text{m}^2];$$

Rudder area (for aircraft with two engines):

$$S_{\text{tr}} = 0.05 \cdot S_{\text{rud}} = 0.05 \cdot 30.8 = 1.54\ [\text{m}^2];$$

The height of the vertical tail:

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

Refer to my prototype, tapper ratio of horizontal and vertical tail unit: ηhtu = 4.93; ηvtu = 3.69. Tail unit aspect ratio: λvtu = 1.91; λhtu = 6.16.

The tip chord of horizontal tail unit:

$$b_{htip} = \frac{2S_{HTU}}{(\eta_{HTU} + 1)l_{HTU}} = \frac{2 * 32.78}{(4.93 + 1) * 14.35} = 0.77 \text{ [m]};$$

Root chord of horizontal stabilizer:

$$b_{hroot} = b_{htip} * \eta_{HTU} = 0.77 * 4.93 = 3.80 \text{ [m]};$$

Tip chord of vertical tail unit:

$$b_{vtip} = \frac{2S_{VTU}}{(\eta_{VTU} + 1)l_{VTU}} = \frac{2 * 26.44}{(3.69 + 1) * 14.35} = 0.79 \text{ [m]};$$

Root chord of vertical tail unit:

$$b_{vroot} = b_{vtip} * \eta_{VTU} = 0.79 * 3.69 = 2.92 \text{ [m]};$$

Mean aerodynamic chord of horizontal tail unit:

$$b_{MAChtu} = 0.66 * \frac{\eta_{HTU}{}^2 + \eta_{HTU} + 1}{\eta_{HTU} + 1} * b_{htip} = 2.59 \text{ [m]};$$

Mean aerodynamic chord of vertical tail unit:

$$b_{MACvtu} = 0.66 * \frac{\eta_{VTU}{}^2 + \eta_{VTU} + 1}{\eta_{VTU} + 1} * b_{vtip} = 2.04 \text{ [m]};$$

Tail unit sweptback:

The horizontal stabilizer sweptback is taken as 30°, and the vertical stabilizer sweptback is taken as 35°, preliminary design of horizontal stabilizer is shown in Figure 1.7 .

The height of vertical stabilizer is 7.6 m, preliminary design of vertical stabilizer is shown in Figure 1.8.

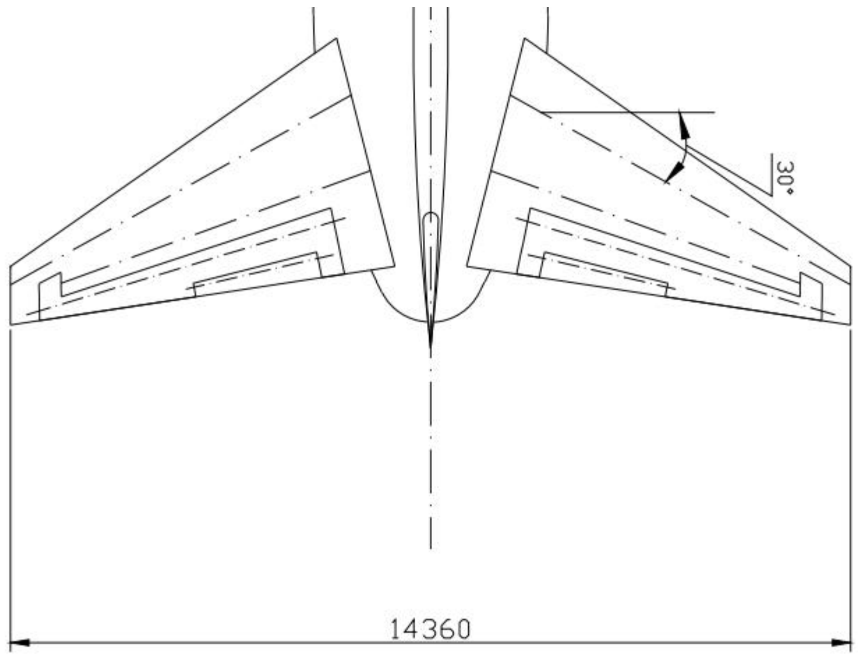


Figure 1.7 - Preliminary design of horizontal stabilizer

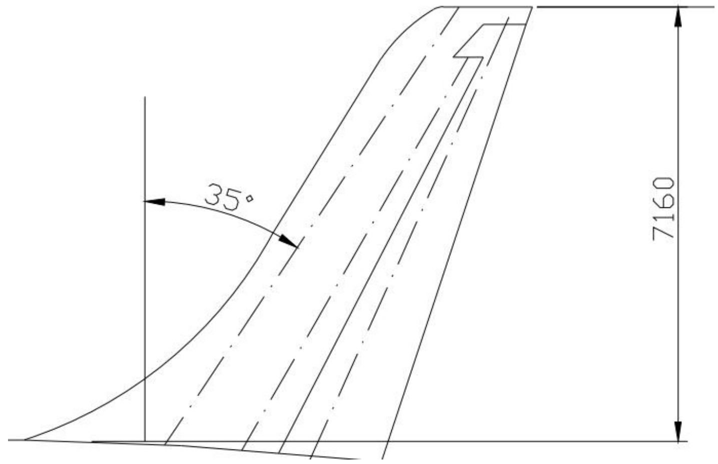


Figure 1.8 - Preliminary design of vertical stabilizer

1.2.5 Landing gear design

In the initial stage of design, when only determining the position of the center of gravity of the aircraft without the overall view of the aircraft, only part of the landing gear parameters can be determined. In this part, I also refer to my prototype at beginning.

The wheelbase is the distance between the main landing gear and the nose gear. Main gear is more close to the aircraft center of gravity. During the landing operation, the main wheel first touches the ground, while the takeoff operation, the main wheel left the ground at last. Additionally, main wheels carry most of the loads of an aircraft when it landed. Schematic diagram of landing gear layout is shown in Figure 1.9.

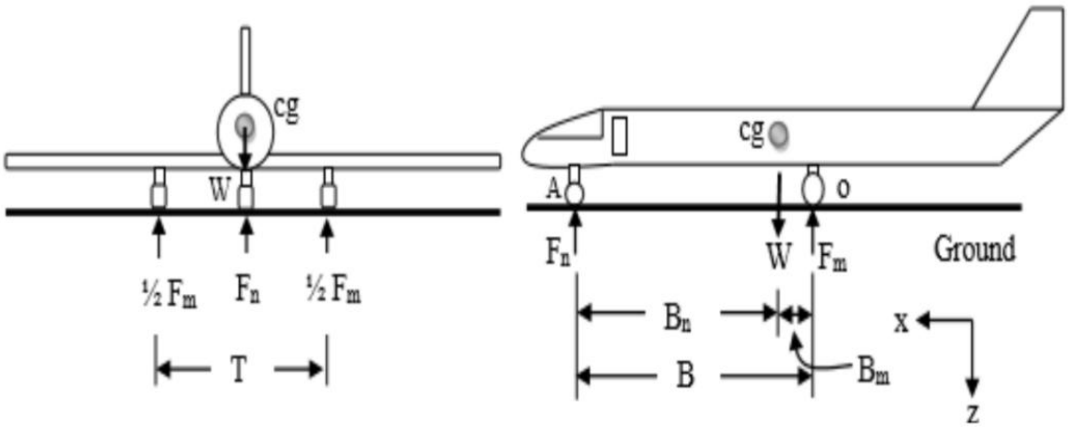


Figure 1.9 - Landing gear layout

Main wheel axel offset:

$$B_m = 15.6 * 0.05 = 0.78\ [m];$$

Wheel base (the ratio refers to prototype):

$$B = 0.425 * L_f = 0.425 * 36.7 = 15.6\ [m];$$

Based on the experience of previous designers, nose landing gear carries no more than 15% of aircraft weight.

Nose wheel axial offset will be:

$$B_n = B - B_m = 15.6 - 0.776 = 14.824 \text{ [m]};$$

Wheel track:

$$T = 0.37 * B = 5.76 \text{ [m]};$$

To prevent the side nose-over, the value T should be more than two times of the distance from runway to the center of gravity. [2] So I take the distance H of landing gear as 2. 5 m, where H<5. 76/2=2. 88 m.

For the low wing CG is placed relatively lower:

$$Y_{CG} = (0.18..0.2)D_f = 0.19 * 3.76 = 0.7144 \text{ [m]};$$

Wheels for the landing gear are chosen by the size and the static and dynamic loads acts on it.

The load on the wheel is determined:

Nose wheel load:

$$P_{nose} = \frac{B_m * m_0 * g * K_g}{B * z} = \frac{0.776 * 79010 * 9.81 * 1.75}{15.6 * 2} = 33.74 \text{ [KN]};$$

Where - Kg = 1. 5. . . 2. 0 – dynamics coefficient.

Static load on main wheel:

$$P_{main} = \frac{B_n * m_0 * g}{B * n * z} = \frac{14.824 * 79010 * 9.81}{15.6 * 2 * 2} = 184.13 \text{ [KN]};$$

We choose tires by considering the maximum load on the wheels and the speed of the aircraft during take-off and landing, and we also refer some parameters from prototype, the tires we choose shown in the table 1.3. The Main landing gear of prototype Boeing 737-800 is shown in Figure 1.10.

Figure 1.10 - Main landing gear of Boeing 737-800

Table 1.3 – Landing gear tires for designing aircraft

Main gear		Nose gear	
Tire size	Ply rating	Tire size	Ply rating
Width: 36. 83cm Diameter: 113. 03cm	28	Width:19. 685cm Diameter :68. 58cm	12

1.2.6 Engine description

The power plant of my designed aircraft includes two CFM56-7B high by-pass turbofan engines and auxiliary power unit (APU) which are made by CFM international. This is an axial flow, high bypass turbofan with dual shafts, its compressor consist of a fan, three stages low pressure and nine stages high pressure compressors, and the turbine includes a high pressure stage and three low pressure stages. The compression ratio of this engine is 5.1:1 in cruise mode. The take off thrust of the engine in the range from 92 to 121 kN. The length of the engine is equal to 250.8 cm and the diameter of the fan is equal to 155 cm.

The application examples of CFM56 turbofan engine shown in a Table 1.4.

And the CFM56-7B engine model cutaway is shown Figure 1.11.

Table 1.4 - Application examples of CFM56 turbofan engine [3]

Model	Thrust (kN)	Bypass ratio	Length (m)	Dry weight (kg)	Applications
CFM56-5B	137	5.5:1	2.60	2500	Airbus A320 family
CFM56-5C	145	6.4:1	2.62	2544	Airbus 340-200/300
CFM56-7B	117	5.1:1	2.51	2400	Boeing 747 NG

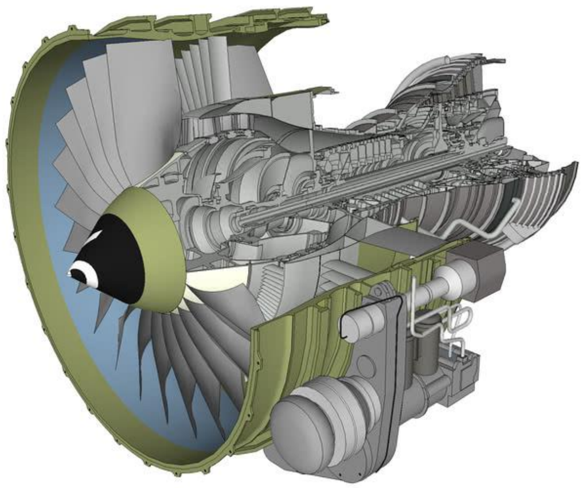


Figure 1.11 - CFM56-7B engine

According to the manufacturer data, the CFM56-7 first ran on 21 April 1995, compared to the CFM56-3, it's more durable, fuel combustion performance increased by 8% , and maintenance costs decreased by 15%. The engine ' s improvements also include the use of new materials, such as single crystal turbine blades used in high-pressure turbines [4] .

1.3 Aircraft centre of gravity calculation

There are many factors could affect the center of gravity on board, not only mass but the mass displacement will change the center of gravity. During flight, the center of gravity of the aircraft will always change because of fuel consumption. To calculate the center of gravity, we should firstly find the mass displacement, we divided the mass as two parts: equipped wing masses and equipped fuselage masses.

1.3.1 Trim sheet of equipped wing

Many factors, such as structural quality, fuel quality, landing gear quality and the quality of equipment placed in the wing, will affect the total mass of the equipped wing. The all masses of the wing for designed aircraft are represented in Table 1.5.

Table 1.5 - Trim sheet of equipped wing:

N	Object name	Mass		C.G. coordinates Xi , m	Mass moment
		units	total mass m(w)		
1	Wing (structure)	0.117710	9834.78821	1.6296	16026.77087
2	Fuel system	0.008300	693.4733	1.6296	1130.08409
3	Airplane control, 30%	0.001800	150.3918	2.328	350.1121104
4	Electrical equipment, 30%	0.009660	807.10266	0.388	313.1558321
5	Anti-ice system , 70%	0.015330	1280.83683	0.388	496.96469
6	Hydraulic systems , 70%	0.011550	965.01405	2.328	2246.552708
7	Engine	0.086830	7254.73333	0.64	4643.029331
	Equipped wing without landing gear and fuel	0.251180	20986.34018		25206.66963
8	Nose landing gear	0.002424	202.5072718	-11.72	-2373.385226
9	Main landing gear	0.036556	3054.310708	1.94	5925.362774
10	Fuel	0.275210	22994.07071	1.6296	37471.13763
	Total	0.565370	47237.22887	1.1808	66229.78481

1.3.2 Trim sheet of equipped fuselage

The origin of the center of gravity coordinate is located on the projection of the nose part to the horizontal axis for the calculation of the equipped fuselage.

The list of equipped fuselage masses is shown in table 1.6.

We use the following formula to calculate the center of gravity coordinates:

$$X_f = \frac{\sum m_i^{'} X_i^{'}}{\sum m_i^{'}} ;$$

After determining the equipped wing and the fuselage's center of gravity , then we should to establish a moment balance equation relative to the fuselage nose:

$$m_f x_f + m_w(x_{MAC} + x_w^{'}) = m_0(x_{MAC} + C)\ ;$$

Table 1.6 - Trim sheet of equipped fuselage masses

N	Objects names	Mass		C.G coordinates Xi, м	Mass moment
		units	total mass m(f)		
1	Fuselage	0.09448	7893.89848	19.74	155825.556
2	Horizontal tail	0.0104	868.9304	34.42656	29914.28455
3	Vertical tail	0.01026	857.23326	34.42656	29511.59226
4	Navigation equipment	0.0047	392.6897	4.69812	
5	Radar	0.0031	259.0081	4.69812	1216.851135
6	Radio equipment	0.0023	192.1673	4.69812	902.8250355
7	Instrument panel	0.0054	451.1754	4.69812	2119.67617
8	Aircraft control system 70%	0.0042	350.9142	19.74	6927.046308
9	Hydro-pneumatic system 30%	0.00495	413.57745	27.636	11429.62641
10	Anti ice system	0.01095	914.88345	31.584	28895.67888
11	Air-conditioning system	0.01095	914.88345	19.74	18059.7993
12	Electrical equipment 70%	0.02254	1883.23954	19.74	37175.14852
13	Lining and insulation	0.0071	593.2121	19.74	11710.00685
14	Atypical equipment	0.0033	275.7183	19.74	5442.679242
15	Additional equipment	0.00326	272.37626	19.74	5376.707372
16	Operational items	0.001965	164.177715	19.74	3240.868094
17	Furnishing:	0.0115	960.8365		19460.05224
	Lavatory1, galley 1	0.0023	192.1673	4.935	948.3456255
	Lavatory2，3； galley 2，3	0.0046	384.3346	12.6336	4855.529603
	Lavatory4，5； galley 4，5	0.0046	384.3346	35.532	13656.17701
18	Passenger equipment	0.013883736	1230.18284		24712.39421
	Passenger seats (business class)	0.002872497	240	9.87	2368.8

Table 1.6 - Trim sheet of equipped fuselage masses (continued)

	Passenger seats (economic class)	0.011011239	920	23.688	21792.96
	Seats of flight attendance	0.00037	30.91387	11.844	366.1438763
	Seats of pilot	0.00047	39.26897	4.69812	184.4903333
	Equipped fuselage without payload	0.226078736	18889.10445		304205.7366
19	On board meal	0.002527797	211.2	19.74	4169.088
20	Baggage,cargo, mail	0.04844945	4048	19.74	79907.52
21	Crew/attendant	0.007181243	600	11.844	7106.4
22	Passenger (business class)	0.02692966	2250	8.2908	18654.3
23	Passenger (economic class)	0.123876435	10350	23.688	245170.8
	TOTAL	0.43504332	36348.30445	18.13602738	659213.8446
	TOTAL fraction	1.00041332	83585.53332		720800.6

After determining the location of the wing relative to the fuselage,we should connect the wing with the fuselage. And after that we calculate the location of the center of gravity for all equipment with a new origin in the nose of fuselage (table 1.7).

Table 1.7 - Center of gravity position of the aircraft

N	**Object Name**	**Mass mi,Kg**	**Coordinate Xi, m**	**Mass moment, Kg.m**
1	Equipped wing (without fuel and landing gear)	13731.60685	21.23754071	291625.5595
2	Nose landing gear (extended)	202.5072718	9.02	1826.615592
3	Main landing gear (extended)	3054.310708	21.68	66217.45615
4	Fuel	22994.07071	21.3696	491374.0934
5	Equipped fuselage (without payload)	18889.10445	19.74	372870.9217
6	Passengers of business class	2250	8.2908	18654.3
7	Passengers of economy class	10350	23.688	245170.8

Table 1.7 - Center of gravity position of the aircraft (continued)

8	Baggage, cargo, mail	4048	19.74	79907.52
9	Crew/attendant	600	11.844	7106.4
10	Nose landing gear (retracted)	202.5072718	8.02	1624.10832
11	Main landing gear (retracted)	3054.310708	21.68	66217.45615
12	Reserve fuel	2855.77318	21.3696	61026.73055

After we determined the C.G. of fully equipped wing and fuselage, we determined the wing MAC leading edge position relative to fuselage by above moment balance equation, Xmac equal:

$$x_{MAC} = \frac{m_f x_f + m_w x_w' - m_0 C}{m_0 - m_w};$$

where m0 – aircraft takeoff mass, kg; mf – mass of fully equipped fuselage, kg; mw – 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) BMAC for aircraft with low wing:

$$X_{MAC} = \frac{734729.7 + 66229.8 - 83551 * 0.25 * 3.88}{83551 - 47237.2} = 19.825\ [m];$$

The centering - is the position of the center of gravity of the aircraft relative to the leading edge of the mean aerodynamic chord, expressed as a percentage.

$$\bar{x}_T = \frac{x_T - x_A}{b_A} 100\%;$$

Substitute the corresponding coordinates of the centroid of Table 1.7. The results of the centre of gravity calculation are the positions of aircraft centre of gravity for different operation, shown in the table 1.8.

Table 1.8 - Airplane's centre of gravity position variants

N	**Object name**	**Mass mi Kg**	**Mass moment kg*m**	**Center of masses Xc.g.**	**C.G.point Xc**
1	Take off mass(LG extended)	76119.59999	1579396.696	20.74888328	23.82%
2	Take off mass(LG retracted)	76119.59999	1579194.189	20.7462229	23.75%
3	Landing weight(LG extended)	55981.30246	1149049.333	20.52559127	18.06%
4	Ferry version(without payload, LG retracted)	59471.59999	1235461.569	20.77397563	24.46%
	Parking version(without payload,fuel,crew,LG extended)	35877.52928	737183.5823	20.54722266	18.62%

The center of gravity point will be in this range: 18.06% - 24.46%. The most forward centre of gravity is located on the 18.06% from the leading edge of the mean aerodynamic chord in landing weight with landing gear extended, and the most aft center of gravity on the 24.46% when the aircraft in ferry version.

Conclusions to the part

In this part of my diploma work, the preliminary design of a mid-range aircraft with 162 passenger capacity was developed. I have calculated the geometrical dimensions for the main parts of the aircraft, such as wing, fuselage, tail unit, cabin layout, landing gear and choosing the CFM56-7B engine for my aircraft. Designed aircraft can accommodate up to 162 passengers, their luggage and some mail or cargo, it can fully meet the demands from domestic to mid-range flights of most countries.

The tires for the aircraft are chosen: for the nose landing gear are DR25821T with dimensions 27x7.75-15, for the main landing gear are DR29622T with dimensions H44x16.5-21 for the designed aircraft. The main landing gear tires have ply rating of 28 which can fully meet the requirements for the designed aircraft in each normal operation. In addition, the range of center of gravity is in the specified range for the designed aircraft.

2. CONCEPTUAL DESIGN OF MASSAGE DEVICE FOR PASSENGERS

2.1 Requirements of the passenger seat

The seat design process usually includes the following stages:

- The construction and development of the seats shall meet the geometric parameters and safety requirements;
- Experimental test of static strength of seat and massage device;
- Experimental test of dynamic strength of seat and massage device;
- Experimental test of material flammability and toxic;
- Experimental test of the massage function of the seat;
- Obtain approval documents for the use of such equipment on aircraft samples.

Seat is exposed to two types of loads during the flight. The first is static load, this loads acts on the seat and massage device are not allowed to exceed the yield strength of the material. Under the load below yield strength, all structural members of the structure work in the elastic deformation zone with no plastic deformation after unloading.

The other type of load is the dynamic load. Since the maximum equivalent stress generated by the structure in the design must not exceed the tensile strength of the material, there should be no damage to the material or failure of the structure under dynamic load.

Forward (flight direction deviates up to 10 degrees) 16g [5];

Down (flight direction deviates up to 30 degrees) 14g.

For the chair structure, the chair shall be positioned for acceptable level of head injury criterion (HIC).

In order to evaluate the design of the chair and surrounding interior, special standards presented in regulatory documents were developed. In order to assess head safety levels, HIC criteria were introduced and other damage criteria identified by General Aviation Safety Panel (GASP) are shown in Table 2.1.

To quantify the HIC criterion, the following formula [5] is used:

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

Where t_1 - is the initial time (in seconds) of impact; t_2 - is the final time (in seconds) of impact; a (t) - is the total acceleration of the head during the impact.

Each parts of the seat undergo dynamic load tests and meet the criteria shown in Table 2.1.

Table2. 1 - Injury Pass-Fail Criteria identified by GASP [6]

Parameter	Injury Criteria
Head Injury Criterion (HIC)	1000 units
Shoulder Harness Loads	1750lb (single); 2000lb (dual)
Lumbar load	1500lb
Femur Load	2250lb

2.2 General requirements to the design of massage device

In medium and long-distance flight, many passengers suffer from shoulder, neck and back pain. This not only causes a poor travel experience, but also leads to sub-health status, so increasing massage equipment to enable passengers to reduce fatigue. At the same time, the designed massage equipment not only to serve passengers, it's also possible to serve pilot in further developed version of this device when it could meet the more stringent requirements of Federal Aviation Regulations for pilot seat.

There are several problems need to be solved in the process of massage device designing:

- Design a structure with the function of massage;
- Match the size of the massage device with the seat;
- Provide required strength characteristics;
- Provide security characteristics.

The main requirements [6] of the Federal Aviation Regulations (FAR) to passenger seat are:

- Each seat can provide protection to the passenger during air crash, which requires seats to pass the load factor test: static load factor - 9g; dynamic load factor - 16g.
- Seat material must be flame-retardant which can avoid excess damage to passenger due to seat on fire. And it required to provide guidance material for demonstrating compliance with the Federal Aviation Regulations (FAR) pertaining to flammability of aircraft seat cushion.

2.3 General description of the designing massage device

The designed massage device is an assembly. The cover of this device divided into front (figure 2.1) and back cover (figure 2.2).

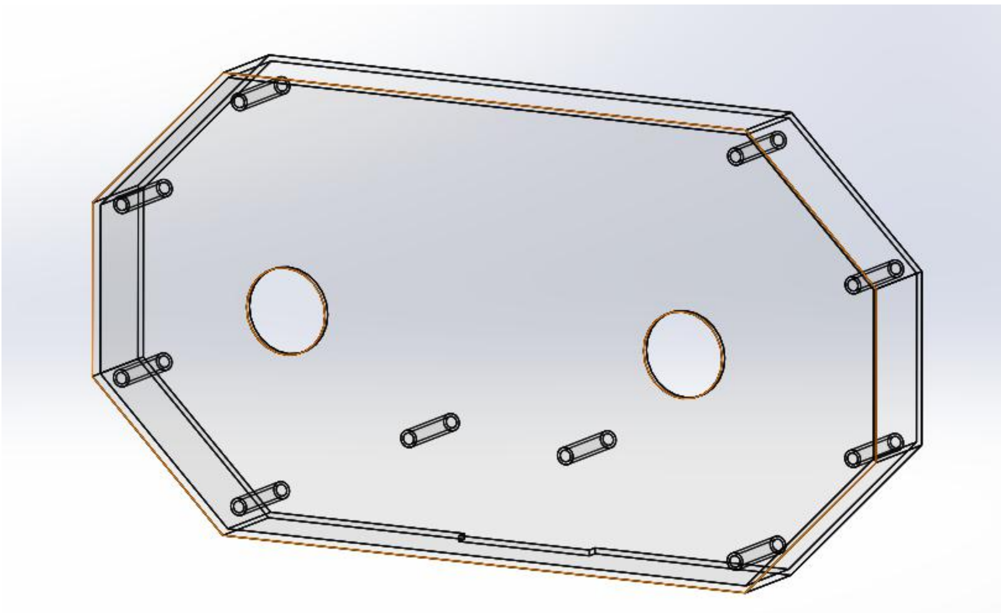


Figure 2.1 - Front cover.

The front cover is designed to fix and protect the internal structure with dimension 300 mm* 160mm. It keeps the internal structure from being affected by dust, and makes the internal structure is not easily damaged. The back cover has many cylinders on it, the bigger cylinders are used to locate the gear mechanism and the smaller cylinders are used to contact and fix with shell. In addition, circuit control panel is built in it.

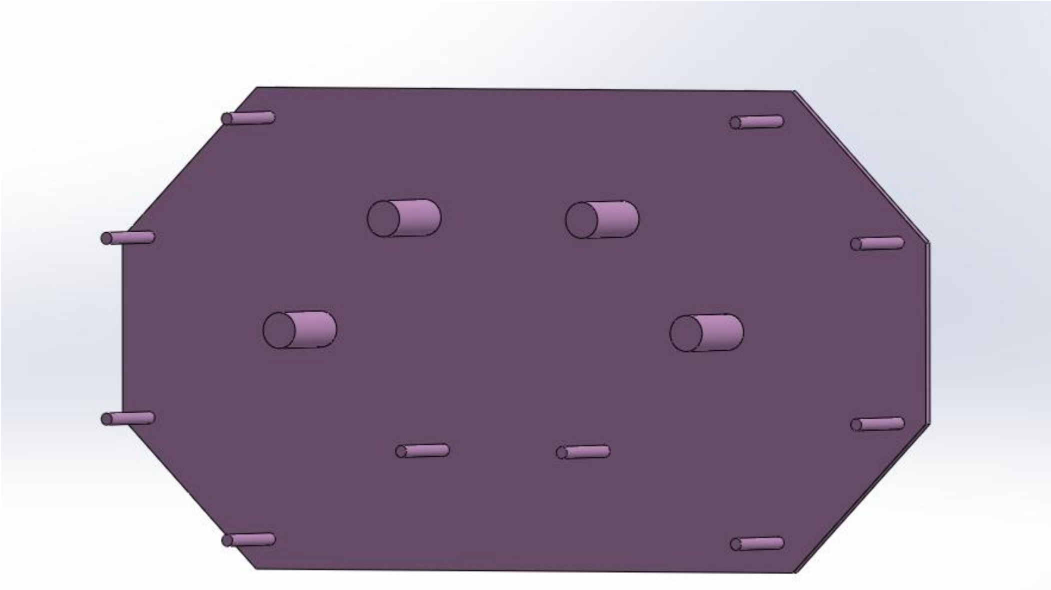


Figure 2.2 - Back cover .

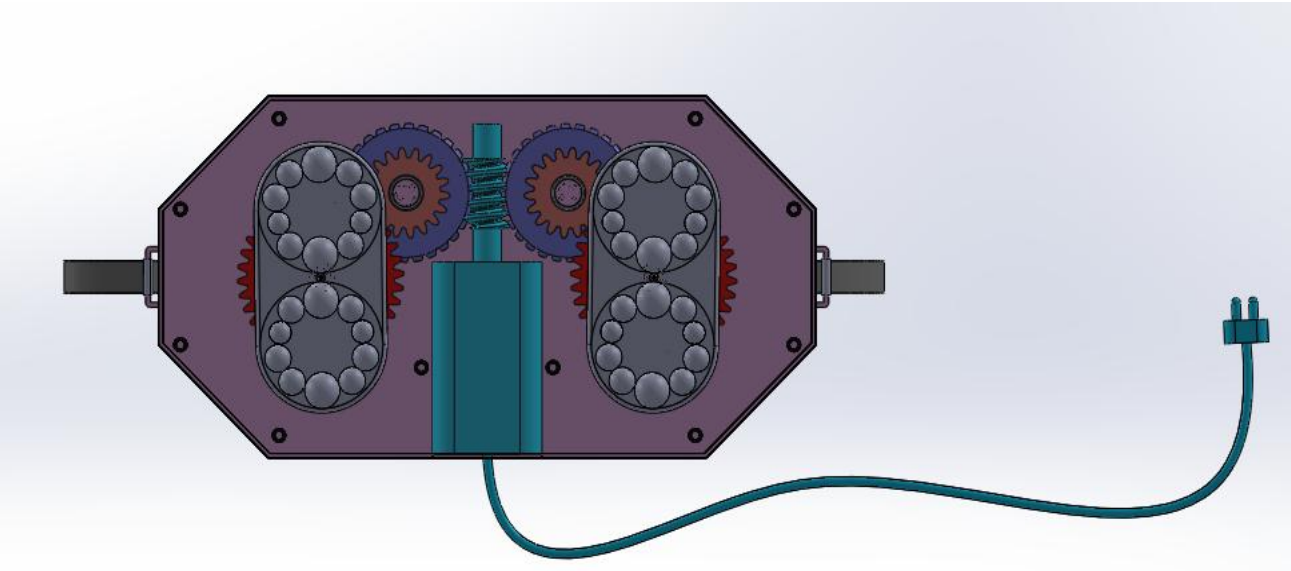
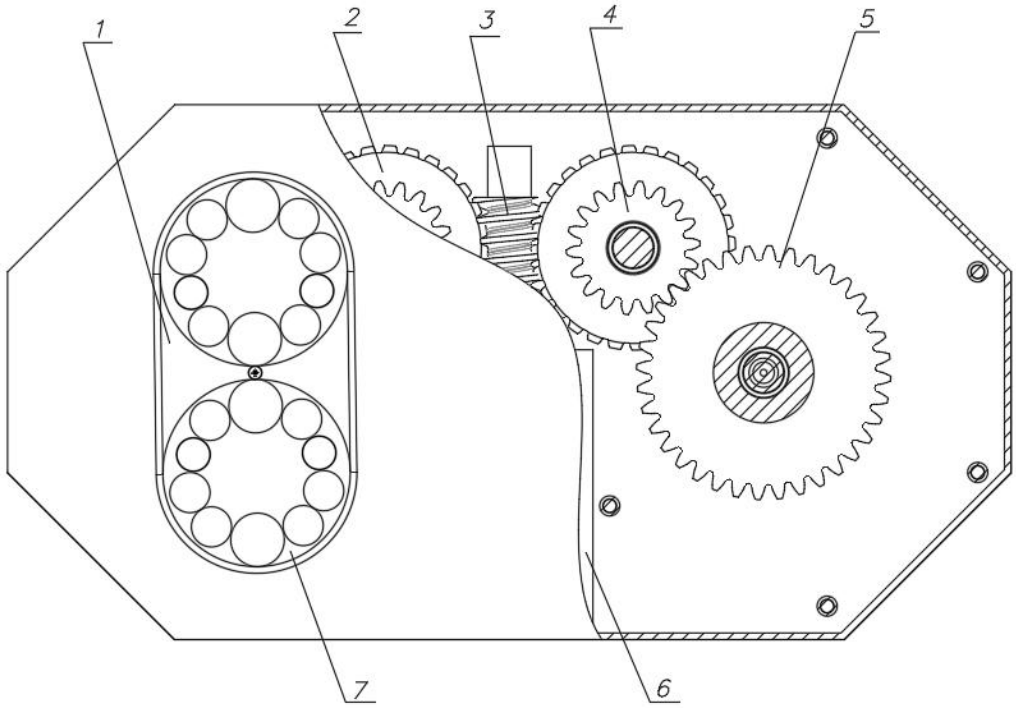


Figure 2.3 - Main structure of massage device.

The 3D-model massage device of main structure is shown in figure 2.3 and the projection of it is shown in figure 2.4. The structure is consist of 4 gears, a worm and 2 worm gears, this device is powered by a motor. By controlling the rotation of the motor, the gears cooperate with each other, and then with the massage head designed behind, the device can achieve the function of massage.



1 - base plate of massage head , 2 - worm gear, 3 - worm, 4 - driving gear, 5 - main gear, 6 - electric motor, 7 - disc on the massage head.

Figure 2.4 - Main structure of massage device

The electric motor (6) drives the worm (3), two worm gears (2) match with worm and worm (3) drives gears (2) to rotate. Driving gear (4) fixed with the worm gear (2) and matches with main gear (5), so driving gear (2) has the same movement trend with worm gear (2) and meanwhile it drives main gear (5). In addition, the main gear (5) fixed with the base plate of massage head (1), so the base plate of massage head (1) rotates with the main gear (5). The electric power is taken from AC generator placed in the seat.

The massage head (figure 2.5) is attached to the main gear. There are many cylinders of different height located on the disks which can simulate the feeling of massage when it rotates. The plate under the disks is attached to the main gear which rotates at the speed of main gear. And there are circuit panel is mounted in the disc which can adjust the rotate speed of disc.

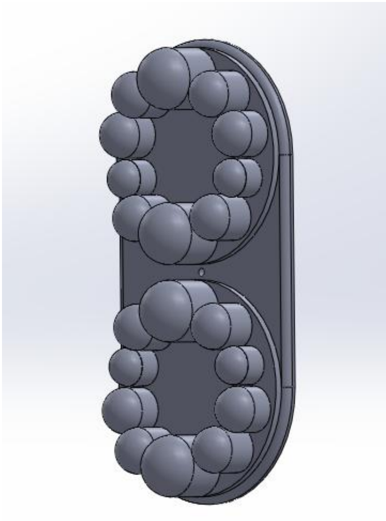


Figure 2.5 - Massage head.

The worm gear and worm (figure 2.6) are a pair of cooperating mechanisms. Worm head number equal 1 and teeth number of worm gear equal 28. Both of their modules equal 2mm and with the pressure angle of 20 degrees.

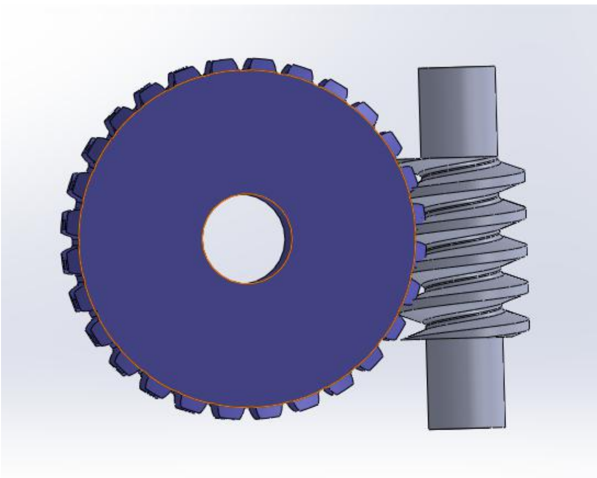


Figure 2.6 - Worm gear and worm.

The secondary gear (figure 2.7) is characterized by modulus of 2 mm, tooth number of 18, pressure angle of 20 degrees and the face width of 10 mm. There is a 16 mm diameter hole in the center of the gear used in conjunction with the ball bearing. The driving gear rotates with worm gear.

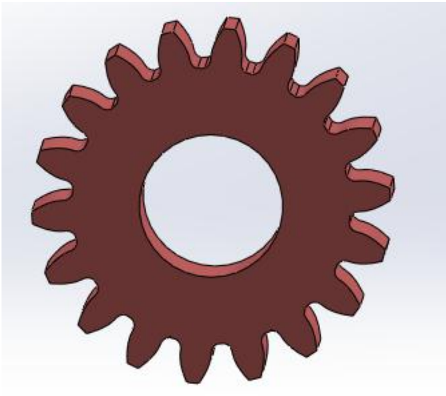


Figure 2.7 - Secondary gear.

Main gear (figure 2.8) is the biggest gear in this device, which characterized by modulus of 2, tooth number of 36, pressure angle of 20 degrees and the face width of 10 mm.The main gear is engaged with the secondary gear, and the main gear is connected with the plate of the massage head, thus driving the massage head to rotate. The main gear connects with massage head by a screw.

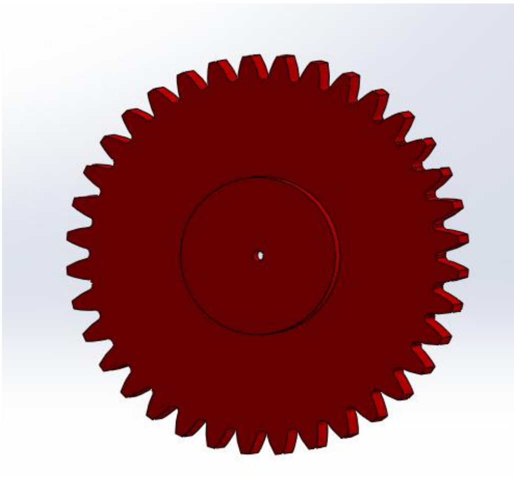


Figure 2.8 - Main gear.

The motor is the power source of the massage device, the rotation of the worm drives the movement of the drive gear and other devices, so that the massage function has been achieved.

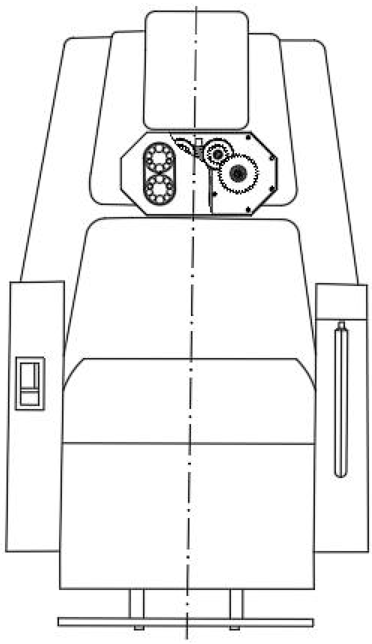


Figure 2.9 -Schematic diagram of passenger seat with massage device.

Figure 2.9 is the preliminary design schematic diagram of passenger seat with massage device, I am more concerned about the massage device so that many details of passenger seat are ignored.

For the designing aircraft, the seat provide a massage choice to the passengers during flight which brings a more comfortable ride experience to passengers. In addition, the other part of seat also designed to make passenger comfortable and safe with lots of adjustment button. The seat is cushioned and adjustable to meet different requirements from passenger.

The follow position also can be adjusted: armrest height and stowage, seat recline (maximum 30 degrees), and headrest position. In my project of special part design, I am more concern about the massage device design, so I won’t go into details about the adjustment buttons here.

2.4 Calculation of the required motor power

The massage device will be used during level-flight, so we should make sure that device can work in normal situation and we should consider that the device will not damage in extreme conditions and cause external damage to the passenger.

The maximum adjustable angle of the seat back α is equal 30 degrees which is shown in figure 2.14, and the massage device will receive maximum force component at this moment. The weight of passenger's upper body derived from the full-scale ATD model is equal 36 kg. And the load factor on back equal 2.5 g is taken from to FAR 25 [5].

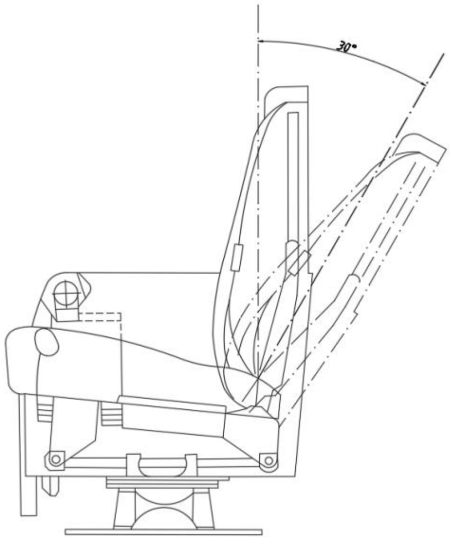


Figure 2.10 - Maximum adjustable angle of the seat back.

So we can calculate the normal stress acts on the massage device during normal situation.

$$F_{normal} = \text{weight} * \sin\alpha * \text{load factor} * \text{safety factor}$$

$$F_{normal} = 36 * 0.5 * 2.5 * 9.81 * 1.5 = 662\ [N];$$

For emergency situation: the load factor in longitudinal direction may reach 16g in 0.09 sec after impact [5]. We should make sure that the massage device will not broke up and hurt human's body in this case.

$$F_{emergency} = weight * \sin\alpha * load\ factor * safety\ factor$$

$$= 36 * 0.5 * 16 * 9.81 * 1.5 = 4238\ [N];$$

The module of main gear equal m=2 mm, the number of gears equal Z=36, so index circle diameter of main gear equal to:

$$d = m * z = 2 * 36 = 72\ [mm];$$

The torque moment required for main gear:

$$T_{main} = F \times r = 662 * 0.036 = 23.8\ [N * m];$$

The gear ratio between main gear and secondary gear equal:

$$i_{ms} = \frac{D_{drive}}{D_{driven}} = \frac{D_{secondary}}{D_{main}} = \frac{0.0072}{0.0036} = 2;$$

The torque moment of secondary gear:

$$T_{output} = T_{input} * i_{ms} * \eta_{ms},$$

$$T_{sec} = T_{input} = \frac{T_{output}}{i_{ms} * \eta_{ms}} = \frac{23.8}{2 * 0.97} = 12.27\ [N * m];$$

Where i_{ms} - gear ratio, η_{ms} - transmission efficiency between main gear and secondary gear.

The torque moment of worm gear:

$$T_{wg} = T_{sec} = 12.27\ [N * m];$$

The transmission efficiency between worm gear ad worm equal 0.86. The gear ratio between worm gear and worm equal 28. And the worm is the driving part, so:

$$P_{wg} = P_w * \eta_{ww} = P_w * 0.86,$$

$$P = \frac{n * T}{9550},$$

$$n_{wg} * T_{wg} = n_w * T_w * 0.86,$$

$$i_{ww} = \frac{n_w}{n_{wg}} = 28;$$

The torque moment of worm:

$$T_w = \frac{n_{wg} * T_{wg}}{n_w * 0.86} = \frac{12.27}{28 * 0.86} = 0.51\ [N * m];$$

Rotation speed calculation of each gear:

After comparison of the massage equipment on the market, and based on the characteristics of my designing equipment, the speed of the massage head is set to 6 rpm. I just consider the preliminary design of the massage device now, the rotation speed of the device could be change in the future upgrade version.

$$n_{head} = n_{\text{main gear}} = 6\ \text{rpm},$$

$$n_{sec} = n_{\text{main gear}} * i_{ms} = 6 * 2 = 12\ \text{rpm},$$

$$n_{\text{worm gear}} = n_{\text{secondary gear}} = 12\ \text{rpm},$$

$$n_{\text{worm}} = n_{\text{worm gear}} * i_{ww} = 12 * 28 = 336\ \text{rpm};$$

Required power of motor:

$$P_r = \frac{n_{\text{worm}} * T_w}{9.55} = \frac{336 * 0.51}{9.55} = 18\ W;$$

The power source is taken from the aircraft interior lighting system with 115V AC voltage [7]. So we choose a motor with a rated power of 20 watts and a rated voltage of 115 volts AC as the power source of the massage device.

2.5 Strength calculation of the massage device

2.5.1 Strength calculation of massage device outer shell

Estimating that the contact area of the massage head and the human body is 0.0032 m^2.

Normal stress:

$$\sigma_{nor} = \frac{F_{normal}}{A} = \frac{662}{0.0032} = 0.21 \text{ MPa};$$

$$\sigma_{eme} = \frac{F_{emergencyl}}{A} = \frac{4238}{0.0032} = 1.32 \text{ MPa};$$

Acrylonitrile Butadiene Styrene plastic (ABS) is selected as the material for massage head and shell, ABS is an impact-resistant engineering thermoplastic and amorphous polymer. ABS is made up of three monomers: acrylonitrile, butadiene and styrene [8] which has excellent mechanical properties and has good impact strength, it's suitable to be used here and it can fully undertake the expected normal stress acts on the massage device.

2.5.2 Strength calculation for main gear and secondary gear

The most stressed part of the massage device is the contact of gears, which are rotated. The initial data for the strength calculation of gears are: main gear and secondary gear have same module which equals 2 mm, and they have same pressure angle equal α=20 degrees, the width of them are 10 mm. The material of them are 45 steel which has good processing, small deformation and good fatigue performance. A pair of gear tooth in action generally subjected to cyclic stress failure includes contact corrosion and tooth bending fatigue and impact. [9]

One of the reason for the damages of gears in massage device can be the initiation of pitting corrosion. Pitting corrosion is the localized corrosion of a metal surface confined to a point or small area, that takes the form of cavities. [10] Too large contact stress can cause pitting corrosion (figure 2.11) on the surface of gear teeth during gear operation, long period over stress could cause gear fail, so it is necessary to check contact stress between gears.

Figure 2.11 - Pitting corrosion

Calculation of contact stress during gear engagement:

We use Hertz contact deformation theory to determine the contact stress between gear teeth. The schematic diagram of Hertz contact deformation of gear teeth is shown in Figure 2.12.

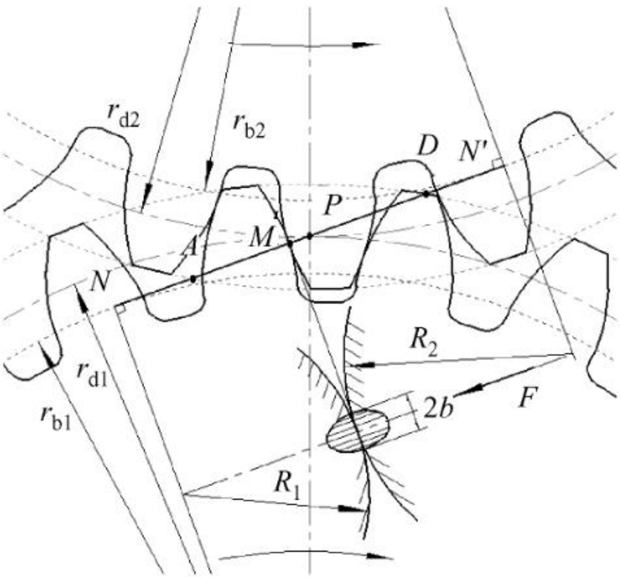


Figure 2.12 - Hertz contact deformation of gear teeth.

Normal force at the contact point:

$$F_n = \frac{2 * T_m}{d_m * \cos\alpha} = \frac{2 * 23.8}{0.072 * \cos 20°} = 703.5 \text{ N};$$

Liner velocity at the contact point:

$$V_{main} = n * \pi * d = 0.1 * 3.14 * 72 = 22.4 \text{ mm/s};$$

Stress at gear contact point:

$$\sigma_H = Z_H * Z_E * Z_{\varepsilon\beta} * \sqrt{\frac{F_t}{b*d} * \frac{u+1}{u} * K_A * K_V * K_{H\beta} * K_{H\alpha}};\ [11]$$

Where Z_H - coefficient of contact area; Z_E - material elasticity coefficient; $Z_{\varepsilon\beta}$ - coefficient of coincidence; u - gear ratio; F_t - Transmitted tangential load; K_A - application factor; K_V - gear dynamic factor; $K_{H\beta}$- load distribution factor; $K_{H\alpha}$- load distribution coefficient between gears.

Coefficient of contact area:

$$Z_{Hm} = Z_{Hs} = \sqrt{\frac{2 * \cos\beta_B}{(\cos\alpha)^2 * \tan\alpha}} = 2.2;$$

Material elasticity coefficient:

$$Z_E = \sqrt{\frac{1}{\left(\frac{1-\mu_1^2}{E_1} + \frac{1-\mu_2^2}{E_2}\right) * \pi}};$$

For 45 steel, $Z_{Em} = Z_{Es} = 189.8$.

Coefficient of coincidence:

$$Z_{\varepsilon\beta} = \sqrt{\frac{4-\varepsilon_a}{3} * (1-\varepsilon_\beta) + \frac{\varepsilon_\beta}{\varepsilon_a}},$$

$$Z_{\varepsilon\beta m} = Z_{\varepsilon\beta s} = 0.905;$$

Application factor: According to the required characteristic of gear during work, we choose the factor: K_A =1.

Gear dynamic factor:

$$K_V = 1 + [\frac{K_1}{K_A * \frac{F_t}{b}} + K_2] * \frac{Z * V}{100} * \sqrt{\frac{u^2}{1+u^2}};$$

For seven-level precision spur gear: K_1=26.8, K_2=0.0193. So we can get the results $K_{Vm} = 1; K_{Vs} = 1.032$.

Load distribution factor in normal direction: Select the parameters with reference to the design instructions $K_{H\beta} = 1$.

Load distribution coefficient between gears: for seven-level precision spur gear, $K_{Ha} = 1.1$.

$$\sigma_H = Z_H * Z_E * Z_{\varepsilon\beta} * \sqrt{\frac{F_t}{b * d} * \frac{u+1}{u}} * K_A * K_V * K_{H\beta} * K_{Ha},$$

$$\sigma_{Hm} = 437 \text{ MPa};$$

$$\sigma_{Hs} = 638 \text{ MPa};$$

Allowable stress:

$$\sigma_{HP} = \frac{\sigma_{Hlim} * Z_{NT} * Z_{LVR} * Z_W * Z_X}{S_{Hmin}};$$

Where σ_{Hlim} - gear fatigue limit obtained in the test; Z_{NT} - life factor; Z_{LVR} - oil film influence coefficient; Z_W - hardening factor; Z_X - size factor; S_{Hmin} - minimum safety factor.

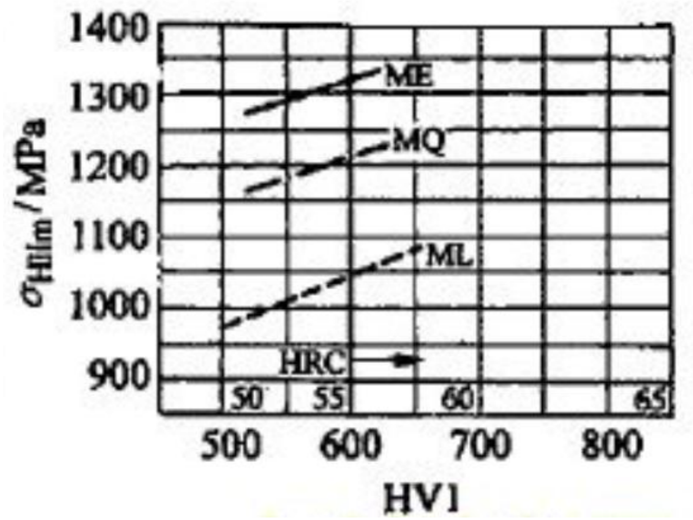


Figure 2.13 - The tooth contact fatigue limit when the failure probability is 1%. [12]

The tooth contact fatigue limit can be taken from figure 2.13 where shows the tooth contact fatigue limit when the failure probability is 1%, for Steel 45 of HRC=52, t σ_{Hlim}=1180 MPa [13].

Number of cycles (we assume that aircraft will flight 10000 times, and massage device will be used one hour each flight), the relation between life factor and cycles is shown in figure 2.13:

$$N_L = 60 * n * k * h = 60 * 6 * 1 * 10000 = 3.6 * 10^6 \text{ cycles;}$$

Where n - rotation speed (rpm), k - number of load application by 1 turn of gear, h - Estimated working hours.

We can find the life factor in above figure or by following formula:

$$Z_{NT} = (\frac{2 * 10^6}{N_L})^{0.0191} = 0.99;$$

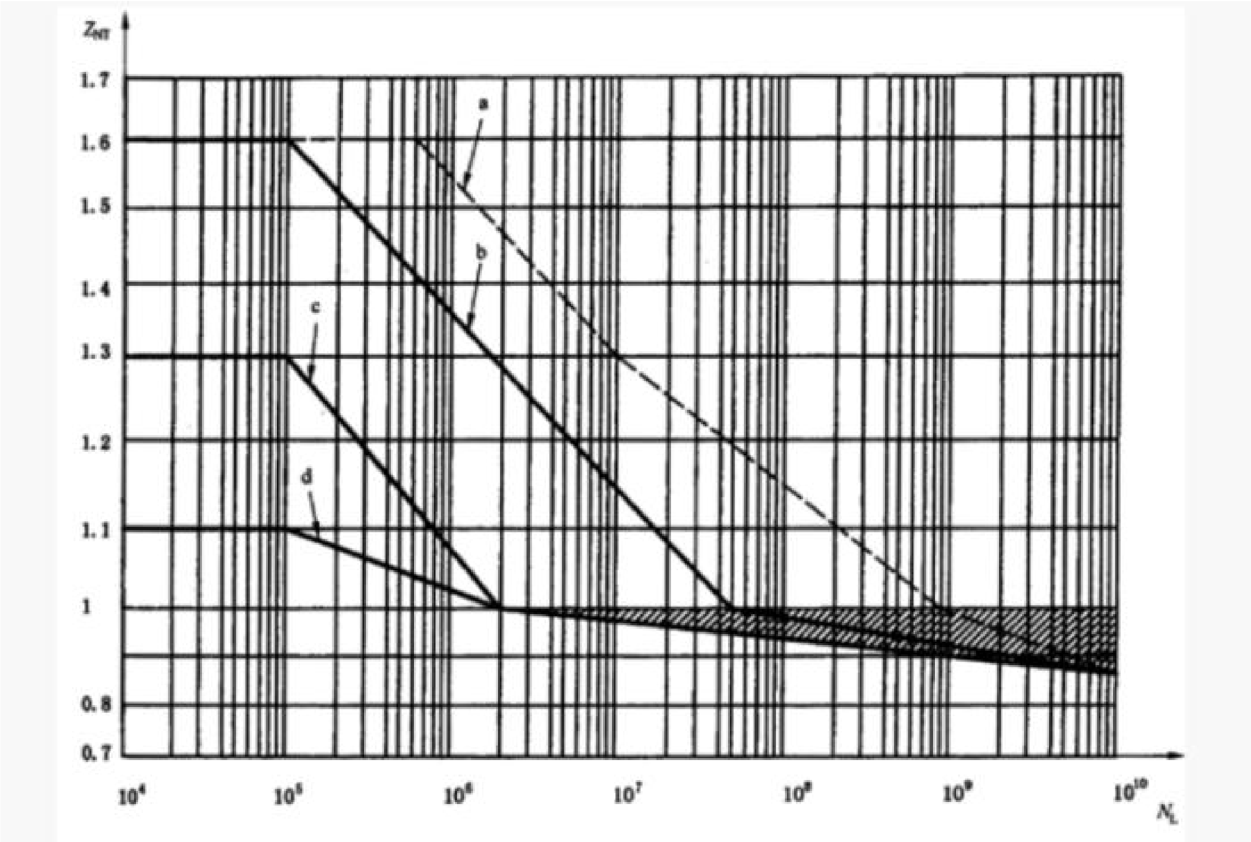


Figure 2.13 - Pitting resistance stress cycles factor [13]: a - for St, V, GGG (perl, bai), GTS , Eh, IF that allows for finite spot erosion; b - St, V, GGG (perl, bai), GTS (perl), Eh, IF; c - for GG , NT (nitr.), GGG (ferr.), NV (nitr.); d - for NV (nitr.)

Oil film influence coefficient: $Z_{LVR} = 1$.

Hardening factor: for HBW>470, $Z_W = 1$.

Size factor: $Z_X = 1$

Minimum safety factor: for gears in massage device, we hope they can work for a long period without failure, but we also hope can reduce manufacturing costs, so we choose $S_{Hmin} = 1.25$.

So the allowable stress:

$$\sigma_{HP} = \frac{\sigma_{Hlim} * Z_{NT} * Z_{LVR} * Z_W * Z_X}{S_{Hmin}} = \frac{1180 * 0.99 * 1 * 1 * 1}{1.25} = 934.6 \text{ MPa};$$

$$\sigma_{Hm} = 437 \text{ MPa} < \sigma_{HP}$$

$$\sigma_{Hs} = 638 \text{ MPa} < \sigma_{HP}$$

Strength coefficient:

$$\eta_{Hm} = \frac{\sigma_{HP}}{\sigma_{Hm}} = \frac{934.6}{437} = 2.14;$$

$$\eta_{Hs} = \frac{\sigma_{HP}}{\sigma_{Hs}} = \frac{934.6}{638} = 1.46;$$

After the calculation, we can know the strength coefficient of main gear and secondary gear are more than 1, so both main gear and secondary gear meet the requirements of the contact strength. The next step is checking the bending stress of gear teeth.

Calculation of endurance bending strength:

When the tooth is loaded, the bending moment at the tooth root is the largest, so the bending fatigue strength at the tooth root is the weakest [8]. The stress at the gear root are shown is figure 2.14. So in the calculation of endurance bending strength we will calculate the strength at the root of tooth.

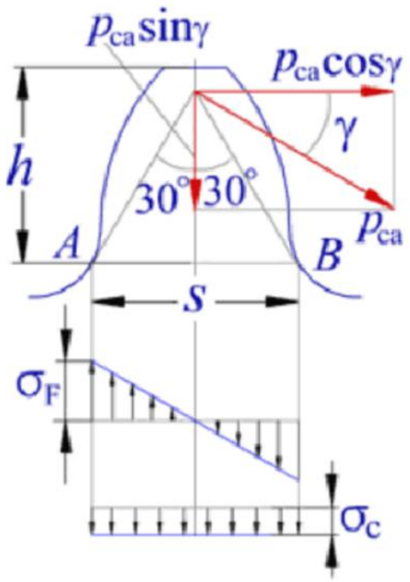


Figure 2.13 - Stress at the gear root. [14]

Bending stress at the teeth root:

$$\sigma_F = \frac{F_t}{b * m_n} * K_A * K_V * K_{F\beta} * K_{Fa} * Y_{Fs} * Y_{\varepsilon\beta};$$

Where Y_{Fs} - compound tooth profile coefficient; $Y_{\varepsilon\beta}$ - coefficient of bending resistance;

Compound tooth profile coefficient (obtained from the following figure 2.14): $Y_{Fsm} = 2.65$; $Y_{Fss} = 2.25$.

Coefficient of bending resistance: $\varepsilon_\beta = 1.6 > 1$, so that $Y_\beta = 1$.

$$Y_{\varepsilon\beta} = Y_\varepsilon * Y_\beta = 0.25 + \frac{0.75}{\varepsilon_a} = 0.719;$$

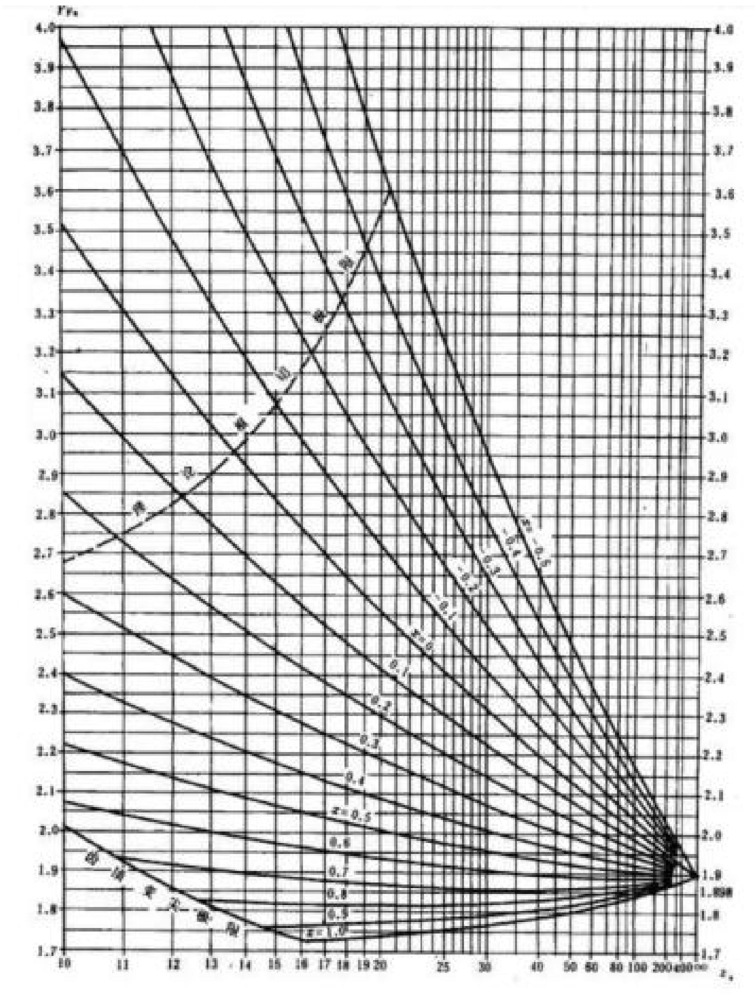


Figure 2.14 - Gear compound profile coefficient. [15]

Bending stress at the teeth root:

$$\sigma_{Fm} = \frac{F_t}{b*m_n} * K_A * K_{Vm} * K_{F\beta} * K_{Fa} * Y_{Fsm} * Y_{\varepsilon\beta},$$

$$\sigma_{Fm} = \frac{622}{10*2} * 1 * 1 * 1 * 1.1 * 2.65 * 0.719 = 65.2 \text{ MPa};$$

$$\sigma_{Fs} = \frac{F_t}{b*m_n} * K_A * K_{Vs} * K_{F\beta} * K_{Fa} * Y_{Fss} * Y_{\varepsilon\beta},$$

$$= \frac{622}{10*2} * 1 * 1.032 * 1 * 1.1 * 2.25 * 0.719 = 57.1 \text{ MPa};$$

Allowable bending stress at the teeth root:

$$\sigma_{FP} = \frac{\sigma_{FE} * Y_{NT} * Y_{\delta relt} * Y_{Rrelt} * Y_x}{S_{Fmin}};$$

Where σ_{FE} - flexural strength of Steel 45 is 400 MPa; Y_{NT} - life factor; $Y_{\delta relt}$ - root fillet sensitivity coefficient; Y_{Rrelt} - tooth root surface condition coefficient; Y_x - coefficient of bending resistance; S_{Fmin} - minimum safety factor.

As for life factor, bending strength stress cycles factor is shown in figure 2.15:

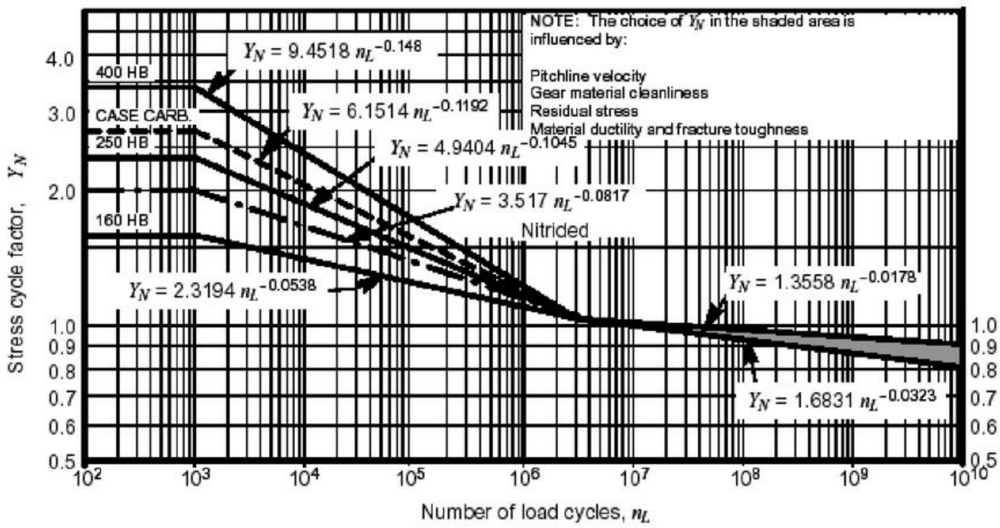


Figure 2.15 - Bending strength stress cycles factor. [13]

$$Y_{NT} = (\frac{2*10^6}{N_L})^{0.115} = (\frac{2*10^6}{3.6*10^6})^{0.115} = 0.935;$$

For the round corner qs>1.5, root fillet sensitivity coefficient $Y_{\delta relt} = 1$.

Surface roughness of the tooth root $R_a \le 2.6\mu m$, $Y_{Rrelt} = 1$.

For gears with normal modulus less than 5, Y_x=1.

Minimum safety factor $S_{Fmin} = 1.4$.

Allowable bending stress at the teeth root:

$$\sigma_{FP} = \frac{\sigma_{FE} * Y_{NT} * Y_{\delta relt} * Y_{Rrelt} * Y_x}{S_{Fmin}} = \frac{400*0.935*1*1*1}{1.4} = 267.1 \text{ MPa};$$

$$\sigma_{Fm} = 65.2 \text{ MPa} < \sigma_{FP};$$

$$\sigma_{Fs} = 57.1 \text{ MPa} < \sigma_{FP};$$

Strength coefficient:

$$\eta_{Fm} = \frac{\sigma_{FP}}{\sigma_{Fm}} = \frac{267.1}{65.2} = 4.10;$$

$$\eta_{Fs} = \frac{\sigma_{FP}}{\sigma_{Fs}} = \frac{267.1}{57.1} = 4.68;$$

Model simulation:

After the calculation, I use ANSYS to simulate the working situation of the model, and then I can get the solutions of deformation and equivalent stress of gears. The deformation solution is shown in figure 2.16, and equivalent stress shown in figure 2.17.

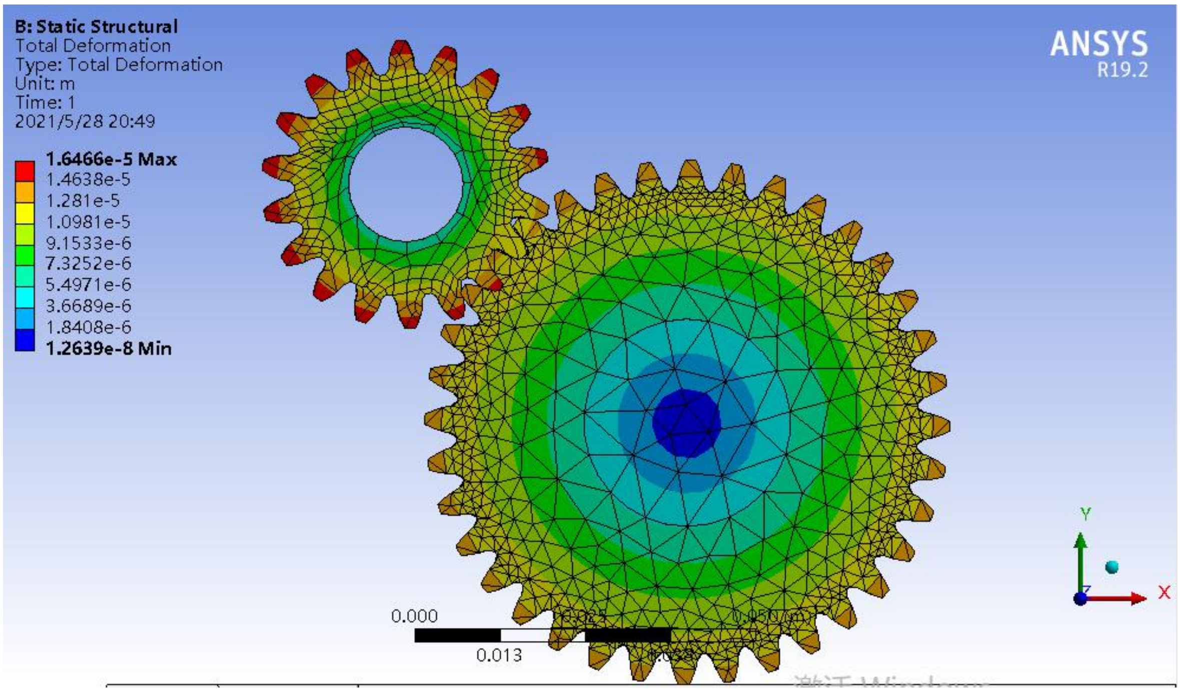


Figure 2.16 - Deformation solution

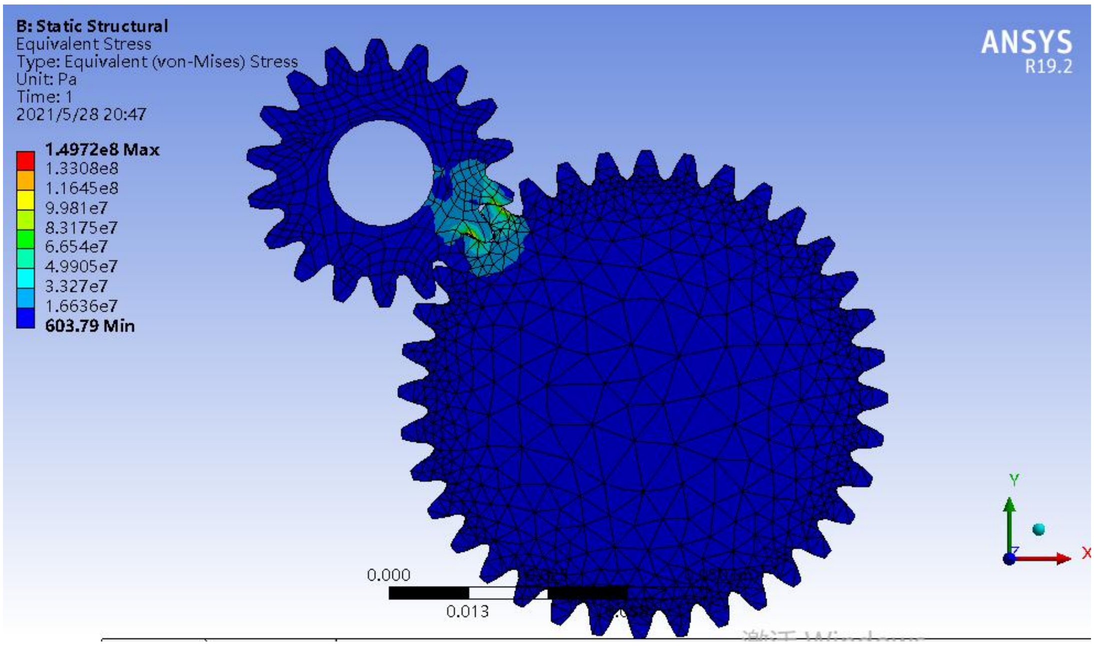


Figure 2.17 - Equivalent stress solution

Comparison with selected material (Steel 45) performance parameters, both the contact and bending strength of the main and secondary gears are meet the strength requirement according to selected safety factors, so the gears will not format pitting corrosion or teeth root crack in their designed life.

Conclusion for massage device design

In this part of my diploma work, I introduced the conceptual design of massage device for the passenger. The specific structure of the massage device and how it works were described above.

The strength calculation of the massage device was performed taking into account the safety factor. The Acrylonitrile Butadiene Styrene plastic (ABS) was chosen for the massage head and shell of the massage device to provide necessary strength to protect the inner structure. The gears and worm are made of steel 45 which provide enough contacting and bending strength for gear teeth during work. And about the motor, 20W 115V AC motor is selected for the massage device which provides enough torque moment for this device. For the designed aircraft, about the seats I will refer to the current well-designed passenger seats on the market, as they have been tested to fully meet the safety standards and add my designed massage device on it.

GENERAL CONCLUSIONS

The presented bachelor diploma work is performed according to the tasks with the direction of my speciality: 134 "Aviation and Space Rocket Technology". The goals have been achieved in time.

The task of the diploma work is to preliminary design of a mid-range aircraft with 162 passenger capacity. It is based on prototypes: Boeing 737-800, COMAC C919 and Airbus A320. The parameters from prototypes, the general aviation statistics and the initial data from the first iteration through computer programs, all of these are helpful to perform this task. At the main part of my diploma, I have completed the preliminary design of the aircraft, the design of general view and fuselage layout, which are shown in the drawings. The preliminary calculations of main parts of aircraft such as fuselage, tail unit, wing, landing gear are performed. Two CFM56-7B engines from CFM international are selected for designed aircraft.

In addition to the design of the aircraft structure and geometrical dimensions, the calculation of the aircraft's center of gravity is also important for the safe operation of the aircraft. The aircraft’s center of gravity in different situations are calculated, we need to make sure that the center of gravity is always in correct range because the position of the aircraft's center of gravity directly affects the stability and control of the flight and the stability of ground taxing.

As for the special part, I focus on the design of the massage device for passenger. The assembly of massage device is shown in the drawing, the detail descriptions of its structure and how it works are introduced in the notes. I also created a 3D-model of it by SOLIDWORKS. The strength calculation and stress analysis are performed in the notes too, I used ANSYS to assist in the stress check, both of the results show that the selected material could withstand the applied loads.

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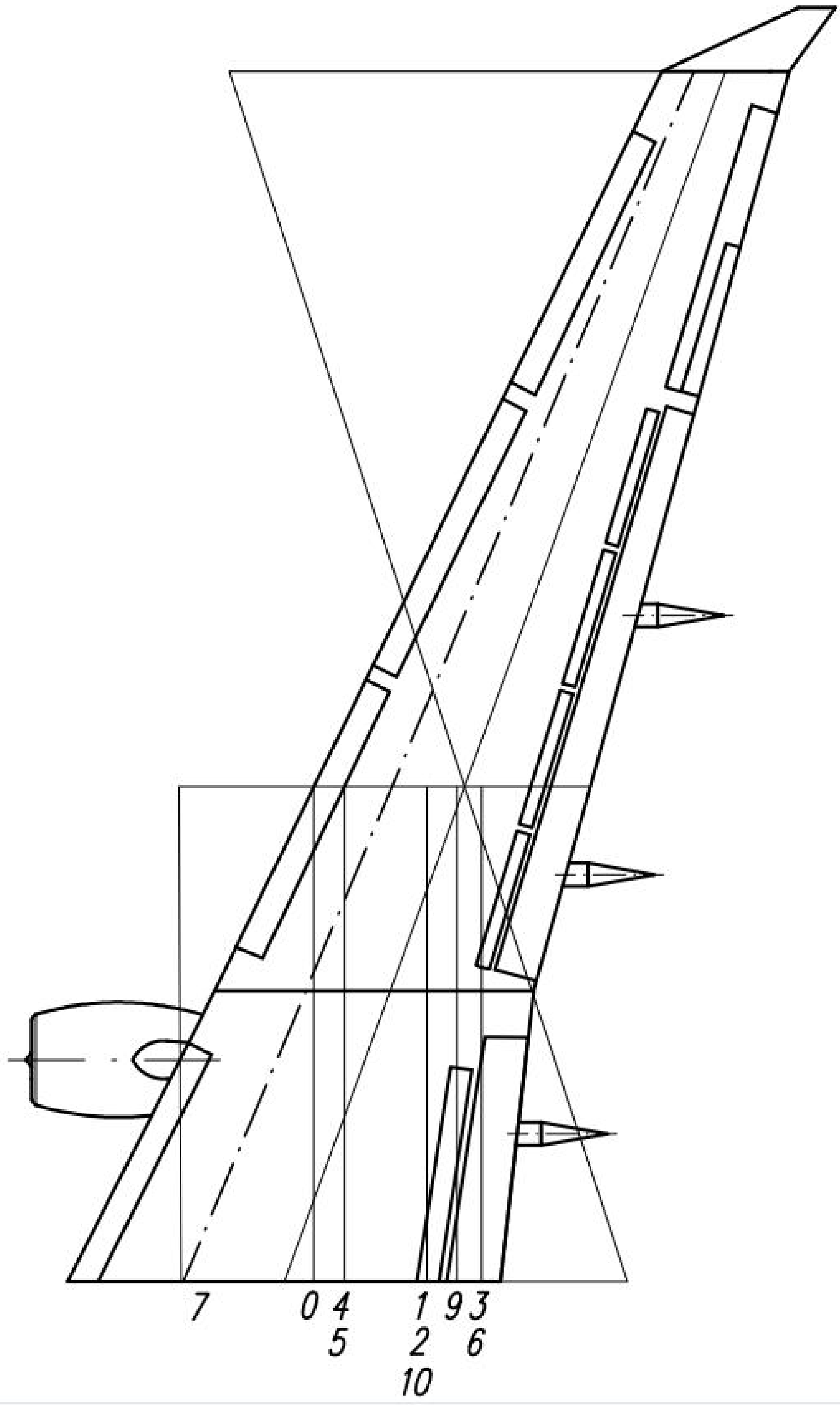
List of diploma work

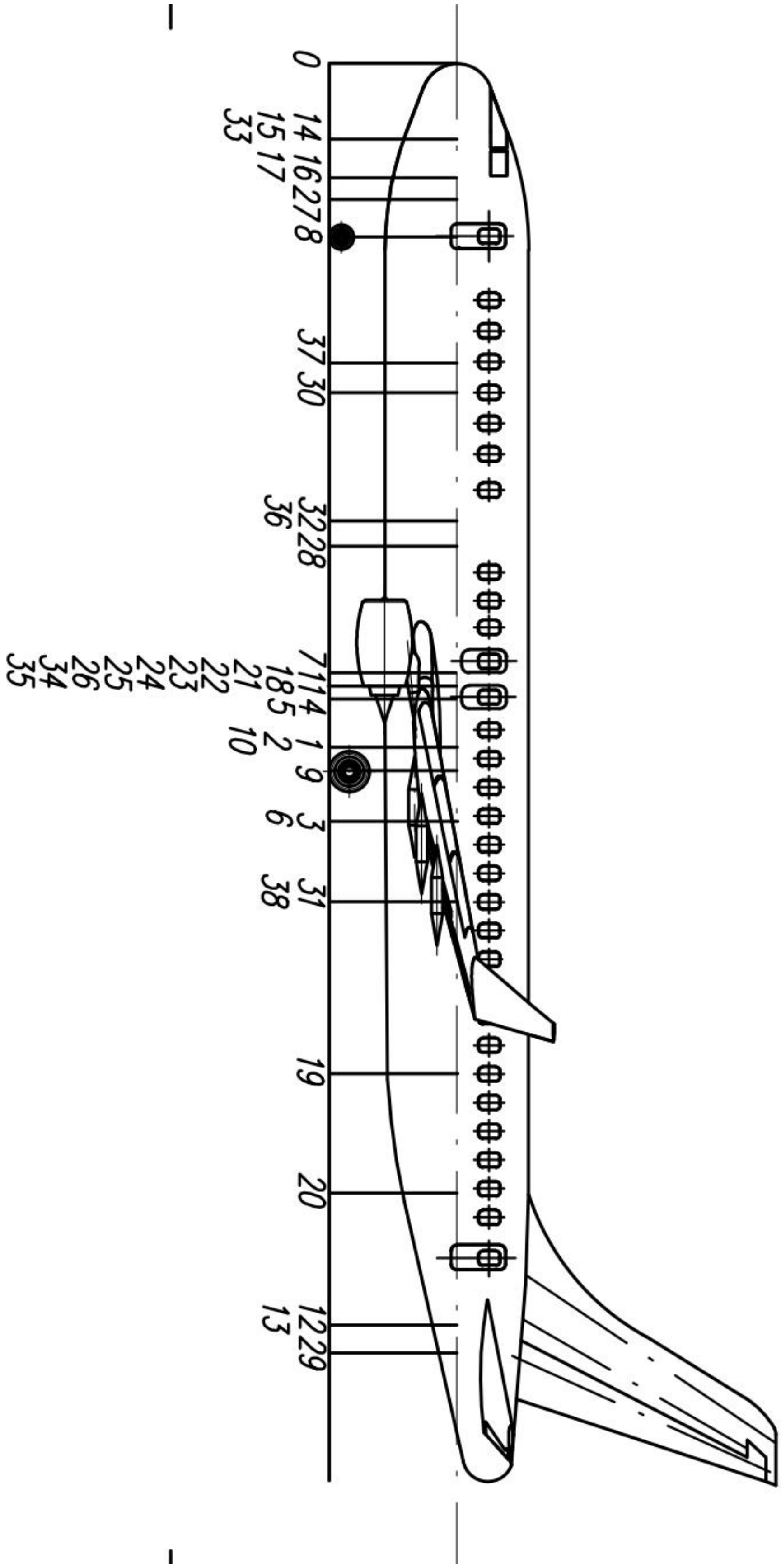
Format	№	Designation	Name	Quantity	Notes
			<u>General documentation</u>		
A4	1	NAU 21 17H 00 00 00 58 TW	Task of diploma work	1	
			<u>Graphic documentation</u>		
			Mid range passenger aircraft		
A1	2	NAU 21 17H 00 00 00 58 GV	General view	1	
A1	3	NAU 21 17H 00 00 00 58 FL	Fuselage layout	1	
A4	4	NAU 21 17H 00 00 00 58 EN	Explanatory note		
			<u>Documentation for assembly units</u>		
A1, A2	5	NAU 21 17H 00 00 00 58 AD	Massage device assembly drawing	1	

Department of aircraft design	NAU 21 17H 00 00 00 58 EN		
Done by	Han Wei	List of diploma work	list / sheet / sheets
Supervisor	Maslak T.P.		
			402 AF 134
N. contr.	Khizhnyak S.V.		
Head. of d.	Ignatovich S.R.		

Appendix B



Appendix C



Appendix A

INITIAL DATA AND SELECTED PARAMETERS

Passenger Number 162
Flight Crew Number 2
Flight Attendant or Load Master Number 6
Mass of Operational Items 1723.57kg
Payload Mass 16511 kg

Cruising Speed 828 km/h;
Cruising Mach Number 0.7891
Design Altitude 11km
Flight Range with Maximum Payload 5460km
Runway Length for the Base Aerodrome 2.55km

Engine Number 2
Thrust-to-weight Ratio in N/kg 3.04
Pressure Ratio 32.8
Assumed Bypass Ratio 5.5
Optimal Bypass Ratio 5.5
Fuel-to-weight Ratio 0.2630

Aspect Ratio 9.45
Taper Ratio 3.50
Mean Thickness Ratio 0.110
Wing Sweepback at Quarter Chord 27°
High-lift Device Coefficient 1.1
Relative Area of Wing Extensions 0.02
Wing Airfoil Type
Winglets used
Spoilers used

Fuselage Diameter 3.76m
Finess Ratio 10.5
Horizontal Tail Sweep Angle 30°
Vertical Tail Sweep Angle 35°

CALCULATION RESULTS

Optimal Lift Coefficient in the Design Cruising Flight Point Cy=0.45761

Induce Drag Coefficient Cx=0.00910

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

Cruising Mach Number 0.78910
Wave Drag Mach Number 0.79951

Calculated Parameter D_m 0.01040

Wing Loading in kPa (for Gross Wing Area):

At Takeoff 5.334

At Middle of Cruising Flight 4.541

At the Beginning of Cruising Flight 5.137

Drag Coefficient of the Fuselage and Nacelles 0.00900

Drag Coefficient of the Wing and Tail Unit 0.00911

Drag Coefficient of the Airplane:

At the Beginning of Cruising Flight 0.02936

At Middle of Cruising Flight 0.02817

Mean Lift Coefficient for the Ceiling Flight 0.45761

Mean Lift-to-drag Ratio 16.24755

Landing Lift Coefficient 1.62

Landing Lift Coefficient (at Stall Speed) 2.430

Takeoff Lift Coefficient (at Stall Speed) 1.993

Lift-off Lift Coefficient 1.455

Thrust-to-weight Ratio at the Beginning of Cruising Flight 0.567

Start Thrust-to-weight Ratio for Cruising Flight 2.387

Start Thrust-to-weight Ratio for Safe Takeoff 3.017

Design Thrust-to-weight Ratio 3.138

Ratio $D_r = R_{cruise} / R_{takeoff}$ 0.791

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

Takeoff 35.2687

Cruising Flight 57.5437

Mean cruising for Given Range 61.7084

FUEL WEIGHT FRACTIONS:

Fuel Reserve 0.03418

Block Fuel 0.24933

WEIGHT FRACTIONS FOR PRINCIPAL ITEMS:

Wing 0.11771

Horizontal Tail 0.01040

Vertical Tail 0.01026

Landing Gear 0.03898

Power Plant 0.09513

Fuselage 0.09448

Equipment and Flight Control 0.12808

Additional Equipment 0.00326
Operational Items 0.02063
Fuel 0.28351
Payload 0.19762

Airplane Takeoff Weight 83551 kg
Takeoff Thrust Required of the Engine 131.07

Air Conditioning and Anti-icing Equipment Weight Fraction 0.0219
Passenger Equipment Weight Fraction
(or Cargo Cabin Equipment) 0.0153
Interior Panels and Thermal/Acoustic Blanketing Weight Fraction 0.0071
Furnishing Equipment Weight Fraction 0.0115
Flight Control Weight Fraction 0.0060
Hydraulic System Weight Fraction 0.0165
Electrical Equipment Weight Fraction 0.0322
Radar Weight Fraction 0.0031
Navigation Equipment Weight Fraction0.0047
Radio Communication Equipment Weight Fraction 0.0023
Instrument Equipment Weight Fraction 0.0054
Fuel System Weight Fraction 0.0083

Additional Equipment:
Equipment for Container Loading 0
No typical Equipment Weight Fraction 0.0033
(Build-in Test Equipment for Fault Diagnosis,
Additional Equipment of Passenger Cabin)

TAKEOFF DISTANCE PARAMETERS

Airplane Lift-off Speed 275.61km/h
Acceleration during Takeoff Run 2.41 m/s^2
Airplane Takeoff Run Distance 1214m
Airborne Takeoff Distance 578m
Takeoff Distance 1793m

CONTINUED TAKEOFF DISTANCE PARAMETERS

Decision Speed 261.83km/h
Mean Acceleration for Continued Takeoff on Wet Runway 0.26m/s^2
Takeoff Run Distance for Continued Takeoff on Wet Runway 2162.76m
Continued Takeoff Distance 2741.14m
Runway Length Required for Rejected Takeoff 2838.90m

LANDING DISTANCE PARAMETERS

Airplane Maximum Landing Weight 66530kg
Time for Descent from Flight Level till Aerodrome Traffic Circuit Flight21.8h
Descent Distance 50.89km
Approach Speed 250.63 km/h
Mean Vertical Speed 2.02m/s

Airborne Landing Distance 517m

Landing Speed 235.63km/h

Landing run distance 743m

Landing Distance 1261m

Runway Length Required for Regular Aerodrome 2105m

Runway Length Required for Alternate Aerodrome 1790m

ECONOMICAL EFFICIENCY

THESE PARAMETERS ARE NOT USED IN THE PROJECT