МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

КАФЕДРА КОНСТРУКЦІЇ ЛІТАЛЬНИХ АПАРАТІВ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
д.т.н., професор.
___________ С.Р. Ігнатович
«___» __________ 2021 р.

ДИПЛОМНА РОБОТА

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ БАКАЛАВРА

ЗІ СПЕЦІАЛЬНОСТІ
«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Аванпроект дальньомагістрального пасажирського літака місткістю до 440 пасажирів»

Виконавець: ___________ **Л.О. Погнірибко**

Керівник: к.т.н., доцент ___________ **В.С. Краснопольський**

Нормоконтролер: к.т.н., доцент ___________ **С.В. Хижняк**

Київ 2021

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

DEPARTMENT OF AIRCRAFT DESIGN

APPROVED BY
Head of department
D.Sc., professor
__________ S.R. Ignatovich
«___» _________ 2021.

BACHELOR THESIS

ON SPECIALITY
"AVIATION AND SPACE ROCKET TECHNOLOGY"

Topic: «Preliminary design of the long-range passenger aircraft with 440 seats capacity»

Prepared by: __________ **L.O. Pohnirybko**

Supervisor: PhD, associate professor __________ **V.S. Krasnopolskii**

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

Kyiv 2021

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет ____аерокосмічний____

Кафедра конструкції літальних апаратів

Освітньо-кваліфікаційний ступінь __«Бакалавр»__

Спеціальність 134 «Авіаційна та ракетно-космічна техніка»

Освітня програма «Обладнання повітряних суден»

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
д.т.н., професор.
_______________ С.Р. Ігнатович
«___» __________ 2021 р.

ЗАВДАННЯ

на виконання дипломної роботи студента

Погнірибко Ліани Олегівни

1. Тема роботи: «Аванпроект дальньомагістрального пасажирського літака місткістю до 440 пасажирів», затверджена наказом ректора від 21 травня 2021 року №815/ст.

2. Термін виконання проекту: з 24 травня 2021 р. по 20 червня 2021 р.

3. Вихідні дані до проекту: крейсерська швидкість V_{cr} = 905 км/год, дальність польоту L = 9700 км, крейсерська висота польоту H_{op} = 13 km.

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

5. Перелік обов’язкового графічного матеріалу: загальний вигляд літака (А1×1), компонувальне креслення фюзеляжу (А1×1), проект пасажирського крісла (А1×1).

6. Календарний план-графік

№ пор.	Завдання	Термін виконання	Відмітка про виконання
1	Отримання завдання, обробка статистичних даних.	24.05.2021-30.05.2021	
2	Розрахунок мас літака та його основних льотно-технічних характеристик.	31.05.2021-02.06.2021	

3	Розрахунок центрування літака.	03.06.2021-04.06.2021	
4	Розробка креслень по основній частині.	05.06.2021-06.06.2021	
5	Проектування пасажирського крісла та розробка креслень по спеціальній частині.	07.06.2021-11.06.2021	
6	Оформлення пояснювальної записки.	12.06.2021-13.06.2021	
7	Захист дипломної роботи	14.06.2021-20.06.2021	

7. Дата видачі завдання: «24» травня 2021 року.

Керівник дипломної роботи ____________ В.С. Краснопольський

(підпис керівника) П.І.Б.

Завдання прийняв до виконання ____________ Л.О. Погнірибко

(підпис студента) П.І.Б.

NATIONAL AVIATION UNIVERSITY

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

APPROVED BY
Head of department
D.Sc., professor
__________ S.R. Ignatovich
«___» _________ 2021.

TASK
for the bachelor thesis
Pohnirybko Liana

1. Topic: «Preliminary design of the long-range passenger aircraft with 440 seats capacity» approved by the Rector's order №815/ст. «21» May 2021 year.
2. Thesis terms: since 24.05.2021 year till 20.06.2021 year.
3. Initial data: cruise speed V_{cr} = 905 km/h, flight range L = 9700 km, operating altitude H_{op} = 13 km.
4. Content: introduction; main part: analysis of prototypes and brief description of designing aircraft, selection of initial data, wing geometry calculation and aircraft layout, landing gear design, engine selection, center of gravity calculation, special part: introduction and calculation of the passenger seat.
5. Required material: general view of the airplane (A1×1), layout of the airplane (A1×1), passenger seat design (A1×1).
6. Thesis schedule

№	Task	Time limits	Done
1	Task receiving, processing of statistical data.	24.05.2021-30.05.2021	
2	Aircraft take-off mass determination and flight performances calculation.	31.05.2021-02.06.2021	
3	Aircraft centering determination.	03.06.2021-04.06.2021	
4	Graphical design of the aircraft and its layout.	05.06.2021-06.06.2021	
5	Design of passenger seat and calculations. Drawings of the special part.	07.06.2021-11.06.2021	
6	Completion of the explanation note.	12.06.2021-13.06.2021	

7	Preliminary examination and defense of the diploma work.	14.06.2021-20.06.2021	

7. Date: «24» May 2021 year.

Supervisor ______________ V.S. Krasnopolskii

Student ______________ L.O. Pohnirybko

РЕФЕРАТ

Дипломна робота «Аванпроект дальньомагістрального пасажирського літака місткістю до 440 пасажирів» містить:

69 сторінок, 21 рисунків, 8 таблиць, 10 літературних посилань

Об'єкт дослідження: процес проектування літака транспортної категорії.

Предмет дослідження: аванпроект дальньомагістрального пасажирського літака місткістю до 440 пасажирів.

Мета роботи: створити аванпроект дальньомагістрального пасажирського літака та визначити його основні льотно-технічні характеристики.

Методи дослідження: в роботі застосовано метод порівняльного аналізу літаків-прототипів для вибору найбільш обґрунтованих технічних рішень, а також методи інженерних розрахунків для отримання основних параметрів проектованого літака. В спеціальній частині застосовано аналіз напружено-деформованого стану для розрахунку на міцність елементів пасажирського крісла.

Наукова новизна результатів: в спеціальній частині обґрунтовано застосування нового пасажирського крісла, що підвищує комфорт.

Практична цінність роботи: результати роботи можуть бути використані в авіаційній галузі та в навчальному процесі авіаційних спеціальностей.

ПАСАЖИРСЬКИЙ ЛІТАК, АВАНПРОЕКТ ЛІТАКА, ЦЕНТРУВАННЯ ЛІТАКА, КОМПОНУВАННЯ ПАСАЖИРСЬКОЇ КАБІНИ, РОЗРАХУНОК НА МІЦНІСТЬ КРІСЛА

ABSTRACT

Bachelor thesis «Preliminary design of the long-range passenger aircraft with 440 seats capacity»

69 pages, 21 figures, 8 tables, 10 references

Object of study – design process of a civil airplane.

Subject of study – is preliminary design of the long-range passenger aircraft with 440 seats capacity.

Aim of bachelor thesis – is to create a preliminary design of an airplane and estimate its flight performances.

Research and development methods – the design methodology is based on prototype analysis to select the most advanced technical decisions and engineering calculations to get the technical data of designed aircraft. In special part the stress-strain analysis is used to estimate stress state of passenger seat.

Novelty of the results – is a new passenger seat that increases comfort.

Practical value – the results of the work can be used in the aviation industry and in the educational process of aviation specialties.

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

Format	№	Designation	Name	Quantity	Notes
			<u>General documents</u>		
A4	1	NAU 21 15P 00 00 00 17 TW	Task for work	1	
	2	NAU 21 15P 00 00 00 17	Long-range passenger aircraft	2	
A1		Sheet 1	General view		
A1		Sheet 2	Fuselage layout		
A4	3	NAU 21 15P 00 00 00 17 EN	Long-range passenger aircraft	69	
			Explanatory note		
			<u>Documentation for assembly units</u>		
A1	4	NAU 21 15P 00 00 00 17	Passenger seat design	1	

NAU 21.08W.00.00.00.28 EN

Done by	Pohnirybko L.O.	Preliminary design of long-range passenger aircraft with 440 seats capacity (List of diploma work)	list	sheet	sheets
Supervisor	Krasnopolskii V.S.			9	69
St.control.	Khyzhniak S.V.		ASF 402		
Head of dep.	Ignatovich S.R.				

CONTENT

INTRODUCTION

The indisputable fact that science is inexorably moving forward makes us think about improving and simplifying our lives. Flights by air despite the fact that it is the safest kind of transport still make passengers worry about problems during flight.

1. The main disadvantage is the high price of tickets, so many passengers prefer to use trains that cost several times less.

2. Another problem is the risk of an accident, which is rather high due to the fact that even an insignificant fail may cause a serious problem.

3. Although the seats are of a fairly high quality, it can be quite uncomfortable for people to be in the same position during several hours.

But we need to pay attention to the advantages of aircraft such as:

1. High speed. With limited time it is very convenient to use an airplane that can take you to the destination point for thousands of kilometers in a few hours.

2. High quality service. Drinks, food and entertainments (movies, magazines or press) help spend the time and feel the maximum comfort.

3. The view from the illuminator is really impressive, unimaginable landscapes or clouds unattainable on ground.

4. Plane provides much more choice of countries and places to visit than train or car.

Therefore, the goal of this diploma project is to create long-range aircraft with the greatest advantages and minimum disadvantages for 440 passengers.

1. PROJECT PART. PRELIMINARY DESIGN OF LONG-RANGE AIRCRAFT

1.1 Analysis of prototypes

1.1.1 Overview of general performances

To create an aircraft that meets safety requirements it is necessary to select the optimal design parameters such as: flight, technical, weight, geometric, aerodynamic and economic characteristics. In order to make the "General view of the plane" in the first stage are used statistic methods, approximate aerodynamic and statistical dependences. The second stage uses a full aerodynamic calculation, aircraft specified formulas of units weight calculations and experimental data.

For designed airplane were chosen the prototypes: McDonnell Douglas DC-10-10, Lockheed L-1011-1 TriStar, Boeing 767-100. Their statistic data are presented in table 1.1.

Table 1.1

Performances of prototypes

PARAMETER	AIRCRAFTS		
	DC-10-10	L-1011-1	Boeing 767-100
1	2	3	4
The purpose of airplane	Passenger	Passenger	Passenger
Crew/flight attend. persons	¾	¾	2/2
Maximum take-off weight, m_{tow}, kg	195 045 kg	200 000 kg	142 900 kg
Max pay-load, mk_{max}, kg	43 014 kg	41 370 kg	33 300 kg
Passengers	270	256	245
The flight altitude, $V_{w.ex}$, m	12 800 m	12 800 m	13 100 m
Flight range, $m_{k.max}$, km	6 500 km	4 963 km	7 200 km

Ending of the table 1.1

1	2	3	4
Take-off distance $L_{TO.d.}$, m	2 700 m	3 300	1 900 m
Number and type of engines	3× GE CF6-6D	3×R-RRB211-2B	2×JT9D / PW4000 / CF6
The shape of the fuselage cross-section	circular	circular	circular
Length of the fuselage	51.97 m	54.2 m	61.64 m
Length of the nose and rear part	15.59 m	16.26 m	18.49 m
Sweepback angle at 1/4 chord line, ^{0}	35	35	32

The scheme is determined by the relative position of the aircraft units, their number and shape. Aerodynamic and operational characteristics of the aircraft depend on the aircraft layout and aerodynamic scheme of the aircraft. Fortunately chosen scheme allows to increase safety, regularity of flights and economic efficiency of the aircraft.

1.1.2 Brief description of the main parts of the aircraft

The plane is a cantilever low-wing monoplane with bypass turbojet engines mounted in a wing and tricycle landing gear with a nose single-strut landing gear and two main gears.

A swept wing with a high aspect ratio is based on new supercritical airfoil. Fuselage has circular cross section. Empennage has a conventional configuration with adjustable vertical stabilizer mounted on the fin. Rudder and elevators are equipped with aerodynamic balance.

1.1.2.1 Fuselage

An important advantage comparatively to other modern airliners is the usage of a variety of lightweight but extremely strong alloys and composite materials in its design. Passenger cabin floor beams, aerodynamic fairings and other parts are made of composite materials. The total part of composite materials in design airplane is 9% of aircraft take-off weight. Thus, the weight of the aircraft and the cost of its production are significantly reduced [1].

The main part of the fuselage has a circular cross-section and at the rear goes into a blade-like tail cone in which the auxiliary power unit is located.

The cockpit of aircraft meets the highest requirements for comfort and functionality: excellent visibility, low noise level, excellent air conditioning, adjustable seat position. Basic information about flight, navigation and engine operation is displayed on six screens. Color displays provide easier understanding of incoming data about the general condition of the aircraft, the need for repair operations on it, the functioning of control and communication systems, and the operation of engines. The cockpit unified with the Boeing 747. It is equipped with LCD displays and Fly-By-Wire controls. The aircraft's fuel efficiency is 10% better than similar airplanes (A330 and MD-11).

Aircraft is equipped with a Fly-by-Wire control system. However, for the convenience of the pilots, it was decided to leave the usual control columns. Along with the traditional helm control system, the cockpit has a simplified layout that is similar to Boeing models. The wireless control system is also equipped with flight parameter protection, which ensures that pilots' movements of control sticks do not go beyond the flight limits. Also, the system prevents dangerous maneuvers. In case of emergency, the system can be turned off by the command of the pilot.

There are places for rest of the crew. They are located above the main cockpit and are equipped with ladders. The seating area consists of two chairs and two beds at the front of the fuselage as well as several seats at the rear of the fuselage. The aircraft is a long-haul liner able to perform non-stop commercial flights up to 18 hours in duration. However, the rules of various aviation regulators, professional and trade union organizations limit the hours of continuous work of the crew and flight attendants. For the rest of the pilots seats are usually reserved in business class or special containers are installed in the luggage compartment. They are equipped with berths and communication with the cockpit and the cabin of the aircraft. There is a resting compartment for the pilots in the front part of the aircraft above the passenger cabin. It includes two comfortable armchairs, 2 or 3 beds separated by partitions, a wardrobe, a TV set and a washbasin. The entrance to this compartment is via the stairs located at front left door. This solution allows to free up to 47 seats. The entrance to the flight attendant rest room is via a staircase in the central part of the aircraft. This compartment is designed for 6 or 7 flight attendants and equipped with berths, lighting and communication with the cabin.

The comfortable and cozy cabin of aircraft is equipped with comfortable recliners, a modern lighting system Sky Interior, power supplies for mobile devices, as well as widescreen monitors so passengers may enjoy the onboard entertainment system. Each passenger is provided with high-quality service and full hot meals.

Seats in economy class are placed according to the scheme 3 + 4 + 3.

There are no sockets for recharging, however, USB-ports located under the monitors in each seat will help passengers to charge mobile devices. A standard audio jack is mounted over the screens so passengers can use headphones without an adapter.

The free economy class service provides online check-in for a flight, a separate check-in desk at the airport, an increased baggage allowance and hand luggage[1].

1.1.2.2 Wing

Wing has a supercritical airfoil optimized for a cruise speed 0.85M. The wings are designed with increased thickness and a longer span than previous airliners, resulting in greater payload and range, improved take-off performance and a higher cruising altitude.

The structural scheme of the wing is torsion-box type and includes two spars and set of stringers covered by working skin. The wing also serves as fuel tank and is able to carry up to 47,890 US gallons (181,300 L) of fuel. This capacity allows the aircraft to operate ultra-long-distance, trans-polar routes such as Toronto - Hong Kong. Wing is made of composite materials with a wider span. Its design features are based on the 767's wings. Under the fuselage in the wing fairing is located an emergency aircraft turbine – a small propeller that extends in emergency situations to provide a minimum power supply.

Airplane has folding wingtips of 11 feet (3.35 m) in length that will allow aircraft to use the same airport gates and taxiways as earlier airplanes[2].

1.1.2.3 Tail unit

The empennage consists of the horizontal and vertical stabilizers, elevators, and rudder. Each stabilizer is configured as a two-cell box, consisting of a main structural box and an auxiliary or forward torsion box, leading edges, tip, and fixed trailing edges. The main torsion boxes are made from CFRP composite material: solid-laminate front and rear spars, honeycomb sandwich ribs and integrally stiffened laminate skin panels.

The main box panels and spars feature a toughened-matrix It provides improved resistance to impact damage over previous brittle materials. The auxiliary torsion box and fixed trailing edges are glass or glass/CFRP sandwich panels with aluminum ribs. The leading edge, tip, and auxiliary spar are made of aluminum alloy.

The elevator and rudder are also constructed from CFRP sandwich panels, ribs, and spars and are hinged from the stabilizer or fin fixed trailing edge. The rudder incorporates a lower tab of CFRP sandwich construction.

The sweep of the vertical and horizontal tail unit is greater than the sweep of the wing so that the aerodynamic characteristics of the tail unit with an increase in the Mach number do not deteriorate faster than the characteristics of the wing. The grater sweep of the fin is also suitable because at the same time the horizontal stabilizer efficiency is increased due to the increase of its moment arm[3].

1.1.2.4 Landing gear

The aircraft has the largest landing gear and the biggest tires ever used in a commercial jetliner. The six-wheel bogies are designed to spread the load of the aircraft over a wide area without requiring an additional centerline gear. This helps reduce weight and simplifies the aircraft's braking and hydraulic systems. Each tire of six-wheel main landing gear can carry load of 76,000 lb (34,430 kg), which is heavier than other wide-bodies such as the 747-400[4].

1.1.2.5 Choice and description of power plant

During the aerodynamic calculation performed according program developed at department of aircraft design the maximum required take-off thrust was obtained. It is 381.6 kN. With respect to this value for designed aircraft was chosen the engine Rolls-Royce Trent 800.

It is an axial flow, high bypass turbofan with three coaxial shafts. The fan is driven by a 5-stage axial LP turbine (3300 rpm), the 8-stage IP compressor (7000 rpm) and the 6-stage HP compressor (10611 rpm) are each powered by a single stage turbine. It has an annular combustor with 24 fuel nozzles and is controlled by an EEC. The engine has a 6.4:1 bypass ratio in cruise and an overall pressure ratio of 33.9 to 40.7:1 at sea level, for a 340.6-413.4 kN (76,580-92,940 lbf) take-off thrust. The 280 cm (110 in) fan has 26 diffusion bonded, wide chord titanium fan blades [6]. Characteristics of this engine and its competitors are represented in table 1.2.

Table 1.2

Characteristics of engines

Name	PW 4000	Trent 800	GE 90
Type	Two spool high bypass ratio Turbofan	Three-shaft high bypass turbofan engine	Dual rotor, axial flow, high bypass turbofan
Compressor	1 fan, 7 LP, 11 HP	Eight-stage IP axial compressor, six-stage HP axial compressor	1 fan, 3-stage LP, 10-stage HP
Weight	16,260 lb 7,375 kg	13,400 lb 6,078 kg	17,400 lb 7,893 kg
Thrust	91,790-99,040 lbf 408-441 kN	76,580-92,940 lbf 340.6-413.4 kN	81,070-97,300 lbf 360.6-432.8 kN
Length	190.4 in (484 cm)	179.8 in (456.8 cm)	286.9 in (729 cm)
Bypass ratio	6.4:1	6.4:1	9:1
Diameter	112 in (284 cm)	280 cm (110 in)	123 in (310 cm)
Overall pressure ratio	42.8:1	40.7:1	40:1

1.2 Geometry calculations for the main parts of the aircraft

Aircraft layout calculation is based on the selection of the designed aircraft purpose, its main dimensions and operational requirements.

Layout consists of geometry calculation of principle structural units as wing, fuselage, tail unit and landing gear. Besides all above mentioned this analytical part includes choice of interior scheme. Its estimation includes dimensional calculation based on aircraft capacity requirements. This layout was implemented in line with both modern standards and well-established calculation methods.

1.2.1 Wing geometry calculation

Geometrical characteristics of the wing are determined from the take-off weight m_0 and specific wing load P_0.

Full wing area with extensions is:

$$S_w = \frac{m_0 \cdot g}{P_0} = \frac{289310 \cdot 9.8}{4977} = 569.668\, m^2 ,$$

where S_w – wing area, m^2; g – acceleration due to gravity m/s^2.

Relative wing extensions area is 0.1

Wing area is:

$$S_w = 569.668 \cdot 0.8 = 455.73\, m^2.$$

Wing span is:

$$l = \sqrt{S_w \cdot \lambda_w} = \sqrt{455.73 \cdot 8.7} = 62.97\, m ,$$

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

Root chord is:

$$b_0 = \frac{2\, S_w \cdot \eta_w}{(1 + \eta_w) \cdot l_w} = \frac{2 \cdot 455.73 \cdot 3}{(1+3) \cdot 62.97} = 10.86 \text{ m} ,$$

where b_0 – root chord, m; η_w – wing taper ratio.

Tip chord is:

$$b_t = \frac{b_0}{\eta_w} = \frac{10.86}{3} = 3.62\ m\ ,$$

where b_t – tip chord, m.

Maximum wing thickness is determined in the forehead i-section and is equal to:

$$c_i = c_w \cdot\ b_t = 0.11\ \cdot 3.62 = 0.3982\ m\ ,$$

where c_i – wing thickness in i-section, m; c_w – related wing thickness.

On board chord for trapezoidal shaped wing is:

$$b_{ob} = b_0\ \cdot \left(1 - \frac{(\eta_w - 1) \cdot D_f}{\eta_w \cdot l_w}\right) = 10.86\ \cdot \left(1 - \frac{(3-1) \cdot 6.2}{3 \cdot 62.97}\right) = 10.15\ m\ ,$$

where b_b – wing board chord, m; D_f – fuselage diameter, m.

Type of structural scheme of the wing determines quantity of spars and its position as well as places of wing joints. The designed aircraft has two spars.

For mean aerodynamic chord length calculation was used geometrical method (fig. 1.1).

Mean aerodynamic chord is equal to:

$$b_{MAC} = 7.84\ m\ .$$

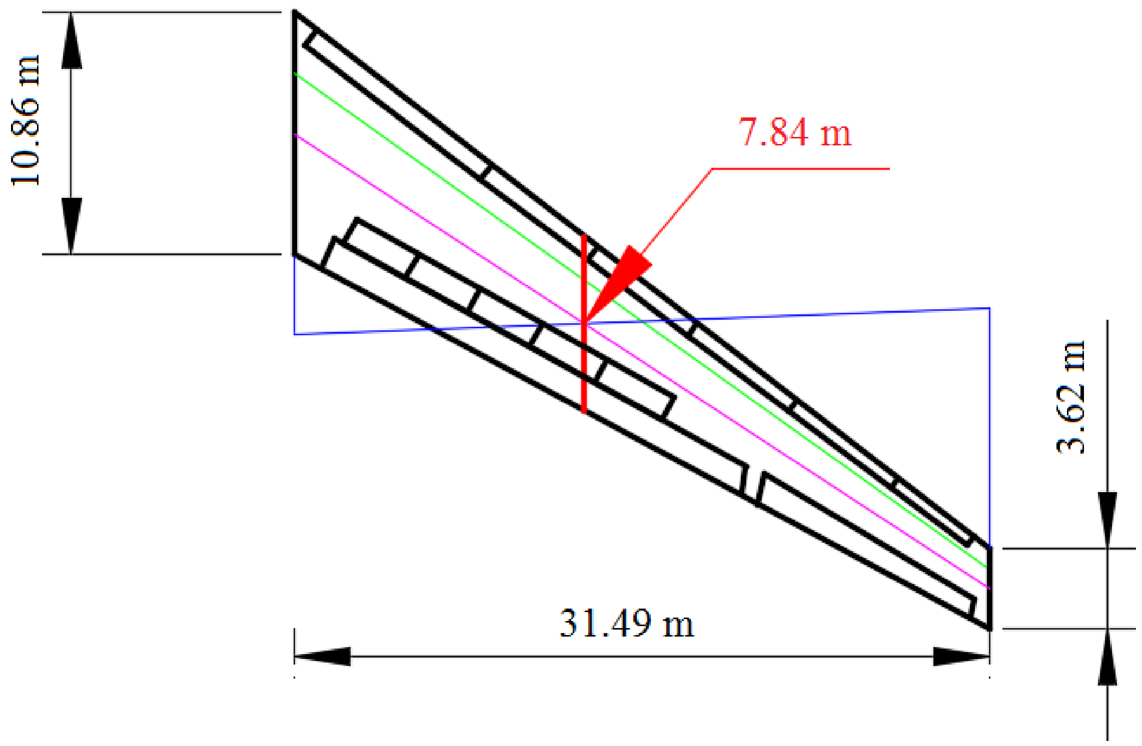

Fig. 1.1. Determination of mean aerodynamic chord.

After the determination of the geometrical characteristics of the wing it is possible to estimate ailerons and high-lift devices geometry.

Ailerons geometrical parameters are determined in next consequence:

Ailerons span is:

$$l_{ai} = 0.375 \cdot \frac{l_w}{2} = 0.375 \cdot \frac{62.97}{2} = 11.807\, m\,,$$

where l_{ail} – ailerons span, m.

Aileron area is:

$$S_{ai} = 0.065 \cdot \frac{S_w}{2} = 0.065 \cdot \frac{455.73}{2} = 14.81\, m^2\,,$$

where S_{ail} – ailerons area, m.

Increasing of l_{ail} and b_{ail} more than recommended values is not necessary and convenient. With the increase of l_{ail} more than given value the increase of the ailerons coefficient falls, and the high-lift devices span decreases. With b_{ail} increase, the width of the wing chord decreases.

In the airplanes of the third generation there is a tendency to decrease relative wing span and ailerons area. In this case for the transversal control of the airplane we use spoilers together with the ailerons. Due to this the span and the area of high-lift devices may be increased that improves take-off and landing characteristics of the aircraft.

The aim of determination of wing high-lift devices geometrical parameters is the providing take-off and landing coefficients of wing lift force, assumed in the previous calculations with the chosen rate of high-lift devices and the type of the airfoil.

Effectiveness of high-lift devices rises proportionally to the wing span increase, serviced by high-lift devices, so we need to obtain the biggest span of high lift devices due to use of flight spoiler and minimize the area of engine and landing gear nacelles.

To choose the structural scheme, hinge-fitting scheme and kinematics of the high-lift devices it is needed to take into account the statistics and experience of native and foreign aircraft designs. Have to be mentioned that in the majority of existing designs of high-lift devices they are made by spar structural scheme.

1.2.2 Fuselage layout

To choose the shape and the size of fuselage cross section it is needed to take into account aerodynamic demands. The shape of the fuselage influences on value of aerodynamic drag. Application of circular shape of fuselage nose part significantly minimize its drag. For transonic airplanes fuselage nose part has to be:

$$l_{nfp} = 2.1 \cdot D_f = 2.1 \cdot 6.2 = 13.02\, m,$$

where D_f – fuselage diameter, m; l_{fnp} – length of fuselage nose part.

Except aerodynamic requirements it is necessary to consider cross section shape, strength and layout requirements. To improve weight, strength and aerodynamic parameters circular cross section is usually chosen. In this case the fuselage has minimal skin area. As the partial case it may be used the combination of two or more vertical or horizontal series of circles.

The geometrical parameters are: fuselage diameter D_f; fuselage length l_f; fineness ratio λ_f; nose part fineness ratio λ_{np}. Fuselage length is determined considering the aircraft scheme, layout and airplane center-of-gravity position peculiarities and the landing angle of attack α_{land}.

Fuselage length is equal to:

$$l_f = \lambda_f \cdot D_f = 11.9 \cdot 6.2 = 69.44\, m\,.$$

Fuselage nose part fineness ratio is equal to:

$$\lambda_{fnp} = \frac{l_{fnp}}{D_f} = \frac{7.6}{6.2} = 1.23\,.$$

Length of the fuselage rear part is equal to:

$$l_{frp} = \lambda_{frp} \cdot D_f = 2.3 \cdot 6.2 = 14.26\, m\,.$$

During the determination of fuselage length it is needed to get minimum mid-section S_{ms} on the one hand and meet layout demands on the other hand.

For passenger and cargo airplanes fuselage mid-section first of all depends on the size of passenger or cargo cabin. One of the main parameter that determines the mid-section of passenger airplane is the height of the passenger cabin.

For long range airplanes the height is h_1 = 1.9 m; passage width b_p = 0.6 m; the distance from the window to the flour h_2 = 1 m; luggage space h_3 = 0.9...1.3 m.

Cabin height is equal to:

$$H_{cab} = 0.296 + 0.383 B_{cabin} = 0.296 + 0.383 \cdot 5.720 = 2.487\, m\,,$$

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

From the design point of view it is convenient to have round cross section, because in this case it'll be the strongest and the lightest. But for passenger and cargo placing this shape is not always the most convenient one. In the most cases one of the most suitable ways is to use the combination of two circles intersection or oval shape of the fuselage. The oval shape is not suitable in the production because the upper and lower panels will bend due to extra pressure and will demand extra bilge beams and other structural features.

The windows are placed in one row. The shape of the window is rectangular with the rounded corners. The window step corresponds to bulkhead step and amount 500...510 mm.

In economic class with the scheme of seats location in one row (3 + 4 + 3) the appropriate width of the cabin is determined.

$$B_{cab} = 2 \cdot (n_{3block} \cdot b_{3block}) + n_{4block} \cdot b_{4block} + 2 \cdot b_{aisle} + 2\delta ,$$

where n_{3block} – number of three-seat blocks; b_{3block} – width of three-seat blocks, m; n_{4block} – number of four-seat blocks; b_{4block} – width of four-seat blocks, m; b_{aisle} – width of aisle, m; δ – distance between external armrests to the decorative panels, m.

$$B_{cab} = 2 \cdot 1430 + 1 \cdot 1940 + 2 \cdot 410 + 2 \cdot 50 = 5.720\, m .$$

The length of passenger cabin is equal to:

$$L_{cab} = L_1 + (n_{rows} - 1) \cdot L_{seatpitc\ h} + L_2 ,$$

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

$$L_{cab} = 1200 + (44 - 1) \cdot 810 + 300 = 36.330\, m .$$

1.2.3 Luggage compartment

Given the fact that the unit of load on floor K = 400… 600 kg/m^2

The area of cargo compartment is defined:

$$S_{cargo} = \frac{M_{bag}}{0.4K} + \frac{M_{cargo\ \&mail}}{0.6K} = \frac{20 \cdot 440}{0.4 \cdot 600} + \frac{15 \cdot 440}{0.6 \cdot 600} = 55\, m^2 ,$$

where S_{cargo} – cargo compartment volume, m^3; M_{bag} – mass of the baggage, kg; $M_{cargo\&mail}$ – mass of the cargo and mail, kg.

Cargo compartment volume is equal to:

$$V_{cargo} = \nu_c \cdot n_{pass} = 0.2 \cdot 440 = 88\ m^3$$

where V_{cargo} – cargo compartment volume, m^3; ν_c – cargo volume coefficient, m^3; n_{pass} – number of passengers. Luggage compartment design is similar to the prototype.

Luggage compartment design is similar to the prototype.

1.2.4 Galleys and buffets

Kitchen cupboards must be placed at the door, preferably between the cockpit and passenger cabin and have separate doors. Refreshment and food can not be placed near the toilet facilities or connect with wardrobe.

Volume of buffets (galleys) is equal to:

$$V_{galley} = \nu_g \cdot n_{pass} = 0.1 \cdot 440 = 44\ m^3,$$

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

Area of buffets(galleys) is equal to:

$$S_{galley} = \frac{V_{galley}}{H_{cab}} = \frac{44}{2.487} = 17.69\ m^2,$$

where S_{galley} – galley area, m^2.

Number of meals per passenger breakfast, lunch and dinner – 0,8 kg; tea and water – 0,4 kg. One meal is 0,62 kg and passengers are fed every 3.5…4 hour of flight. Buffet design is similar to prototype.

1.2.5 Lavatories

Number of toilet facilities is determined by the number of passengers and flight duration: with t > 4 hours one toilet for 40 passengers.

$$n_{lav} = 11$$

Area of lavatory is:

$$S_{lav} = 1.5 m^2$$

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

1.2.6 Layout and calculation of tail unit basic parameters

One of the most important tasks of the aerodynamic layout is the choice of tail unit location. To provide longitudinal stability during overload its center of gravity should be placed in front of the aircraft focus and the distance between these points, related to the mean value of wing aerodynamic chord, determines the rate of longitudinal stability.

Determination of the tail unit geometrical parameters.

Area of vertical tail unit is equal to:

$$S_{VTU} = (0.12 \dots 0.2) S_w = 0.12 \cdot 455.73 = 54.69 \, m^2,$$

where S_{VTU} – area of vertical tail unit, m^2.

Area of horizontal tail unit is equal to:

$$S_{HTU} = (0.18 \dots 0.25) \, Sw = 0.2 \cdot 455.73 = 91.15 \text{ m}^2,$$

where S_{HTU} – area of horizontal tail unit, m^2.

Determination of the control surfaces area.

Elevator area is:

$$S_{el} = 0.3 \cdot 54.69 = 16.41 \text{ m}^2,$$

where S_{el} – elevator area, m^2; k_{el} – relative elevator area coefficient.

Rudder area is:

$$S_{rud} = 0.2 \cdot 91.15 = 18.23 \text{ m}^2,$$

where S_{rud} – rudder area, m^2; k_r – relative rudder area coefficient.

Area of aerodynamic balance is $M \geq 0.75$, $S_{abea} \approx S_{abed} = (0.18 \dots 0.2) \, S_e$.

Elevator balance area is equal to:

$$S_{eb} = 0.2765 \cdot S_{HTU} = 0.2765 \cdot 91.15 = 25.2 \text{ m}^2 ,$$

where S_{eb} – area of elevator aerodynamic balance, m^2.

Rudder balance area is equal to:

$$S_{rb} = 0.2337 \cdot S_{VTU} = 12.78 \text{ m}^2 ,$$

where S_{rb} – area of rudder aerodynamic balance, m^2.

The area of elevator trim tab is:

$$S_{te} = 0.08 \cdot S_{el} = 0.08 \cdot 16.41 = 1.31 \text{ m}^2 ,$$

where S_{te} –elevator trim tab area, m^2.

Area of rudder trim tab is equal to:

$$S_{tr} = 0.06 \cdot S_{rud} = 0.06 \cdot 18.23 = 1.09 \text{ m}^2 ,$$

where S_{tr} –rudder trim tab area, m^2.

Root chord of horizontal stabilizer is:

$$b_{0HTU} = \frac{2S_{HTU} \cdot \eta_{HTU}}{(1+\eta_{HTU}) \cdot l_{HTU}} = \frac{2 \cdot 91.15 \cdot 2.5}{(1+2.5) \cdot 27.39} = 4.75\ m ,$$

where η_{HTU} – horizontal tail unit taper ratio; b_{0HTU} – root chord of horizontal stabilizer, m.

Tip chord of horizontal stabilizer is:

$$b_{tHTU} = \frac{b_{0HTU}}{\eta_{HTU}} = \frac{4.75}{2.5} = 1.9\ m ,$$

where b_{tHTU} – tip chord of horizontal stabilizer, m.

Root chord of vertical stabilizer is:

$$b_{0VTU} = \frac{2S_{VTU} \cdot \eta_{VTU}}{(1+\eta_{VTU}) \cdot l_{VTU}} = \frac{2 \cdot 54.69 \cdot 1.33}{(1+1.33) \cdot 27.39} = 2.28\ m\ ,$$

where b_{0VTU} – root chord of vertical stabilizer, m; η_{VTU} – vertical tail unit taper ratio; L_{VTU} – vertical tail unit span.

Tip chord of vertical stabilizer is:

$$b_{tVTU} = \frac{b_{0VTU}}{\eta_{VTU}} = \frac{2.28}{1.33} = 1.71\ m\ ,$$

where b_{tVTU} – tip chord of vertical stabilizer, m.

1.2.7 Landing gear design

In the primary stage of design when the airplane center-of-gravity position is defined and there is no drawing of airplane general view only the part of landing gear parameters may be determined.

Main wheel axis offset is:

$$e = 0.18 \cdot b_{MAC} = 0.18 \cdot 7.84 = 1.41\ \text{m}\ ,$$

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

With the big wheel axial offset the lift-off of the front gear during take-off is complicated and with small, the ground strike of the airplane is possible when the loading of back of the aircraft comes first. Landing gear wheel base may be obtained from the expression:

$$B = k_b \cdot L_f = 0.4 \cdot 69.44 = 27.77\ \text{m}\ ,$$

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

Front wheel axial offset will be equal to:

$$d_{ng} = B - e = 27.77 - 1.41 = 26.36\ \text{m}$$

where d_{ng} – nose wheel axes offset, m.

Wheel track is:

$$T = K \cdot B = 0.396 \cdot 27.77 = 11 \text{ m},$$

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

To prevent nose-over the value K should be > 2H, where H – is the distance from runway to the center of gravity.

Type of the pneumatics (balloon, half balloon, arched) and the pressure in it is determined by the runway surface. Breaks are installed on the main wheels.

Nose wheel load is equal to:

$$F_n = \frac{g \cdot e \cdot k_d \cdot m_0}{B \cdot z} = \frac{9.81 \cdot 1.41 \cdot 1.5 \cdot 289\,310}{27.77 \cdot 2} = 108\,077.913\ N,$$

where F_n – nose wheel load, N; k_d – dynamics coefficient; z – number of wheels.

Main wheel load is equal to:

$$F_m = \frac{g \cdot (B - e) \cdot k_g \cdot m_0}{B \cdot z \cdot n}$$

where F_m – main wheel load, N; n – number of main landing gear struts.

$$F_m = \frac{9.81 \cdot (27.77 - 1.41) \cdot 1.5 \cdot 289\,310}{27.77 \cdot 2 \cdot 6} = 336\,753.403\ N.$$

According the calculated values of wheel loading and take-off speed it is possible choose the tires for landing gear from the catalog (table 1.3):

Table 1.3

Aviation tires for designing aircraft

Nose gear				Main gear			
Tire size	Ply Rating	Rated Speed (mph)	Rated load (Lbs)	Tire size	Ply Rating	Rated Speed (mph)	Rated load (Lbs)
38×12	20	210	25275	56×16	38	217	76000

1.3 Center of gravity calculation

1.3.1 Trim-sheet of the equipped wing

Mass of the equipped wing contains the mass of its structure, mass of the equipment placed in the wing and mass of the fuel. Regardless of the place of mounting (to the wing or to the fuselage) the main landing gear and the front gear are included in the mass register of the equipped wing. The mass register includes names of the objects, their masses and center of gravity coordinates. The origin of given coordinates of the mass centers is chosen by the projection of the leading edge of the mean aerodynamic chord (MAC) for the surface XOY. The positive values of the coordinates of the mass centers are accepted for the end part of the aircraft.

The list of the mass objects for the aircraft where the engines are located under the wing are given in the table 1.4. Coordinate of the center of mass for the equipped wing is defined by the formula (1.1).

$$X_w^{/} = \frac{\Sigma m_i^{/} x_i^{/}}{\Sigma m_i^{/}} \qquad (1.1)$$

where $X_w^{'}$ – center of mass for equipped wing, m; $m_i^{'}$ – mass of a unit, kg; x_i – center of mass of the unit, m.

Table 1.4

Trim sheet of equipped wing

N	Name	Mass		CG coordinates x_i (m)	Moment $m_i x_i$ (kgm)
		Units	total mass m_i (kg)		
1	2	3	4	5	6
1	Wing (structure)	0.12764	36927.5284	3.528	130280.3202
2	Fuel system, 40%	0.0116	3355.996	3.528	11839.95389
3	Control system, 30%	0.0012	347.172	4.704	1633.097088
4	Electrical equip. 10%	0.00225	650.9475	0.784	510.34284
5	Anti-icing system 70%	0.00975	2820.7725	0.784	2211.48564

Ending of the table 1.4

1	2	3	4	5	6
6	Hydraulic system, 70%	0.00889	2571.9659	2.166	5570.878139
7	Power units	0.07032	20344.2792	-5.44	34585.27464
8	Equipped wing without fuel and LG	0.23165	67018.6615	0.617338485	41373.19894
9	Nose landing gear	0.003589	1038.33359	-23.066	23950.20259
10	Main landing gear	0.032301	9345.00231	4.704	43958.89087
11	Fuel	0.35246	101970.2026	3.528	359750.8748
	Equipped wing	0.62	179372.2	2.614859868	469033.1672

1.3.2 Trim-sheet of the equipped fuselage

Origin of the coordinates is chosen in the projection of the nose of the fuselage on the horizontal axis. The list of the mass objects for the equipped fuselage with engines mounted under the wing is given in table 1.5.

The CG coordinates of the equipped fuselage is determined by formula (1.2).

$$X_f = \frac{\Sigma m_i^{/} X_i^{/}}{\Sigma m_i^{/}}; \qquad (1.2)$$

where $X^{'}_{f}$ – center of mass for equipped fuselage, m; $m_i^{'}$ – mass of a unit, kg; x_i – center of mass of the unit, m.

After the determination of the CG of equipped wing and fuselage, the moment equilibrium equation is made relatively to the fuselage nose (1.3).

$$m_f x_f + m_w (x_{MAC} + x_w^{/}) = m_0 (x_{MAC} + C) \qquad (1.3)$$

where m_0 – aircraft take-off mass, kg; m_f – mass of fully equipped fuselage, kg; m_w – mass of fully equipped wing, kg; $\boldsymbol{C}$ – distance from MAC leading edge to the CG point determined by the designer.

The position of MAC leading edge relative to fuselage nose may be calculated by formula (1.4).

$$X_{MAC} = \frac{m_f x_f + m_w \cdot x_w^{/} - m_0 C}{m_0 - m_w} \quad (1.4)$$

where m_0 – aircraft take-off mass, kg; m_f – mass of equipped fuselage, kg; m_w – mass of equipped wing, kg; C – distance from MAC leading edge to the CG point, determined by the designer.

$$X_{MAC} = \frac{109937.8 \cdot 32.097 + 179372.2 \cdot 2.615 - 289310 \cdot 2.51}{289310 - 179372.2} = 29.758\, m$$

C = (0,22...0,25) B_{MAC} –low wing ;

For swept wings at X = 30°...40° C = (0,28...0,32) B_{MAC}

at X= 45° C = (0,32...0,36) B_{MAC}

Table 1.5

Trim sheet of equipped fuselage

№	Objects	Mass		Coordinates of CG	Moment (kgm)
		Units	Total (kg)		
1	2	3	4	5	6
1	Fuselage	0.0875	25314.625	34.72	878923.78
2	Horizontal tail unit	0.01152	3332.8512	60.29	200937.5988
3	Vertical tail unit	0.00877	2537.2487	60.29	152970.7241
4	Anti-icing system and air-conditioning	0.00975	2820.7725	34.72	97937.2212
5	Heat and sound isolation	0.0064	1851.584	34.72	64286.99648
6	Control sys 70%	0.0028	810.068	34.72	28125.56096
7	Hydraulic sys 30%	0.00381	1102.2711	48.608	53579.19363
8	Electrical eq, 90%	0.01575	4556.6325	34.72	158206.2804
9	Radar	0.0019	549.689	0.5	274.8445
10	Air-navig. system	0.0029	838.999	2	1677.998
11	Radio equipment	0.0015	433.965	1	433.965
12	Instrument panel	0.0034	983.654	2.5	2459.135
Passenger aircraft					
Passenger eq + Non typical eq + Additional equipment + Service equipment					
13	Onboard meal	0.0014189	410.501959	25	10262.54898

Ending of the table 1.5

1	2	3	4	5	6
14	Seats of pass.	0.0122	3529.582	34	120005.788
15	Seats of crew	0.00047	135.9757	3.3	448.71981
16	Seats of flight attendance	0.00037	107.0447	22	2354.9834
Furnishing (Lavatory, Galley/buffet)					
17	lavatory 1, galley 1, lavatory 2, galley 2 20%	0.00486	1406.0466	5.014	7049.917652
18	lavatory 3, galley 3, lavatory 4, galley 4, lavatory 5, galley 5 30%	0.00324	937.3644	20.42	19140.98105
19	lavatory 6, lavatory 7, lavatory 8, lavatory 9 20%	0.00324	937.3644	25.786	24170.87842
20	lavatory 10, galley 6, lavatory 11, galley 7, galley 8, galley 9 30%	0.00486	1406.0466	54.728	76950.11832
21	Non typical eq.	0.002	578.62	20	11572.4
22	Additional eq.	0.00805	2328.9455	18	41921.019
	Equipped fuselage without payload	0.19719	57049.3499	34.05927989	1943059.776
Payload					
23	Mail/Cargo	0.0518	14986.258	25	374656.45
24	Crew/attendant	0.00285507	826	20	226392.3078
25	Baggage	0.031301	9055.69231	25	16520
26	Passengers	0.09886	28160	34	957440
	Total	0.38152497	109937.802	32.09723444	3528699.411

1.3.3 Calculation of center of gravity positioning variants

The list of mass objects for centre of gravity variant calculation given in table 1.6 and center of gravity calculation options given in table 1.7, completes on the base of both previous tables.

Table 1.6

Calculation of CG positioning variants

№	Name / Object	Mass, kg m_i	Coordinates CG M	Moment kgm
1	2	3	4	5
1	Equipped wing without fuel and LG	67018.6615	29.75334419	1994029.303
2	Nose landing gear (retracted)	1038.33359	7.82546683	8125.445067
3	Main landing gear (retracted)	9345.00231	34	317730.0785
4	Fuel	101970.203	32.6640057	3330755.293
5	Equipped fuselage	56499.3499	34.00545	1921285.818
6	Passengers	28160	34	957440
7	Baggage	10918.5594	25	272963.985
8	Cargo	16403.877	25	410096.925
9	Crew/attendant	826	20	16520
10	Nose landing gear (extended)	1038.33359	8.57076	8899.308
11	Main landing gear (extended)	9345.00231	36.34076	339604.4861

Table 1.7

Airplane's CG position variants

№	Variants of the loading	Mass, kg	Moment of the mass, kgm	Center of the mass, m	Centering
1	Take-off mass (LG extended)	289310	9321319.205	32.21913935	0.31388
2	Take-off mass (LG retracted)	289310	9298670.935	32.1408556	0.30389
3	Landing variant (LG extended)	200488.968	6316449.734	31.50522344	0.22282
4	Transportation variant (without payload)	236697.55	7693610.5	32.5039718	0.3492
5	Parking variant (without fuel and payload)	133901.347	4305525.736	32.15446164	0.30563

Conclusion to project part

Designed aircraft satisfies the planned aim of usage, its geometrical characteristics will provide the necessary aerodynamic performance, which will lead to efficient usage.

During the calculation the main geometrical parameters caused by operational purpose, planned quantities of passengers and cargo, speed and altitude of flight, conditions of landing and take-off, were considered. All obtained values meet requirements for the long-range passenger aircrafts.

The centering of the designed aircraft was performed. The most forward center of gravity position of equipped aircraft is 22.28% from the leading edge of main aerodynamic chord. The most aft center of gravity position of equipped aircraft is 34.92% from the leading edge of main aerodynamic chord. Between these values centering of the aircraft should be performed.

Geometrical parameters almost match with chosen prototypes. That fact allows to make a conclusion that designed aircraft will successfully compete with another models on the chosen market segment.

Furthermore, the engine Trent 800 that meets the requirements considering efficiency for designed aircraft was approximated. Main peculiarities of basic section of an aircraft and their influence on outline creation were figured out.

2. SPECIAL PART. PASSENGER SEAT DESIGN

2.1 Technical and ergonomic characteristics of passenger seats

The seat must provide the maximum comfort for passengers during flight. Therefore, the process of creating and producing of seats is very important[5].

To meet the standards of the aerospace industry the design of seat is constantly evolving. The seat isn't nearly as complex as an airplane but passengers quickly identify the seat with a specific manufacturer, meaning that seat manufacturers have competition in comfort and aesthetics. Meanwhile, operators are also pushing them to reduce weight and monitor their maintenance needs. Usual seat contain several necessary elements (fig.2.1).

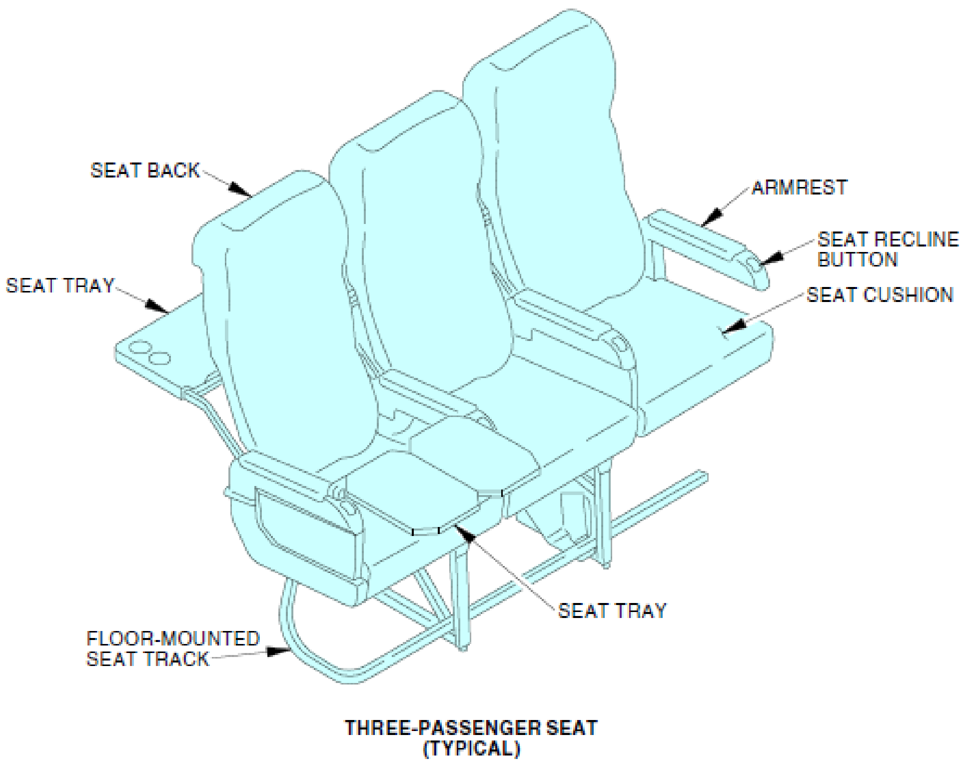

Fig. 2.1. Passenger seat assembly.

Passenger's seats features:

Electronics: seats may be equipped with power ports (either EmPower, AC, DC, or USB power-only sockets) for small electrical appliances and ports for headphones for the audio entertainment. There also can be TV-screens in the back of each seat as part of the In-flight Entertainment system on long-range aircraft.

Adjustable headrest: most long-range aircraft (and short-range on some airlines) has headrests in all classes, allowing the passenger to change the position of the headrest for comfort.

Adjustable lumbar support: electrically adjustable lumber support can be found on many long-range first class and business class seats. Economy class may also include a mechanically adjustable lumbar support on some long-range aircraft. But this happens very rare.

"Slimline" economy seating. Airlines are introducing new "slimline" seats in economy class. While "slimline" is not a defined term, slimline seats have less padding in the back. Seat pitch and width in economy class have also been decreasing. In 1985 none of the main four US carriers offered a seat less than 19 inches wide. Since the beginning of the 21st Century average seat width decreased from 18.5 to 17 inches, and sometimes lower than 16.1 inches.

Slimline seats weigh less than full-size seats and are demand to allow airlines increase capacity without significantly affecting on passenger comfort. Despite this many passengers have expressed discontent with new seats. These seats may or may not feature moveable headrests, and generally do not feature adjustable lumbar support. Furthermore, the safety issues associated with increased aircraft capacity and reduced seat pitch require more investigations.

A newer innovation by Zodiac Seats U.S. is an articulating seat bottom where the seat bottom moves forward in addition to the seat back tilting backwards. Such seats have been installed in some aircrafts of different airlines[6].

Seats type

1. Traditional economy (fig. 2.2)

• Same old;

• May have on-demand IFE, AC power & USB;

• Newer versions come with tablet ledges, phone slots [7].

Fig. 2.2. Traditional economy seat.

2. Barebones Slimline economy (fig. 2.3)

• More knee-room at the same pitch allows 30 pitch to feel like 31;

• Fewer seat monuments to poke into passengers; can feel wider;

• Frequent lack of padding, short seat pans, less back support;

• Instead of measuring traditional seat pitch, was considered new "butt-to-knee" and "eyeball to seat-back" measurements.

3. Full featured slimline economy (fig. 2.4)

• Similar underpinnings to barebones version, but with more padding, usually at 31-32 pitch;

• Often come with bells and whistles of newer traditional economy;

• Cleverly constructed models don't make passengers think slimline;

• Updates like winged headrests give a premium look and feel.

Fig. 2.3. Barebones Slimline economy seat.

Fig. 2.4. Full featured slimline economy seat.

4. Economy plus (extra legroom economy seats) (fig. 2.5)

• Same economy seats as the rest of the plane but with more legroom and sometimes more recline;

• Usually pitched at 34-38, generally 3-5 inches more than economy;

• Sometimes alcohol, meals, full range of AVOD programs are included.

Fig. 2.5. Economy plus seat.

Basic amenities

1. Life Vest Stowage Pocket

A life vest stowage pocket is provided under each passenger position. The passenger can easily remove the life vest by pulling the life vest pull strap that sticks out from the pocket.

2. Baggage Bar (Restraint Tube)

The baggage bar (restraint tube) assembly is a tubular structure attached to the aisle/outboard spreaders and legs with brackets and screws.

3. Leg Assembly

Each seat assembly has two leg assemblies. Each leg assembly is a machined aluminum leg structure attached to the main frame beams by screws. The leg assembly also contains a pivoted rear foot assembly, which contains stud fasteners with a spring-loaded shear plunger.

Tighten or loosen the clamp screw on top of the block to adjust the stud fasteners in the seat track. The front of the leg assembly contains a stud fastener and anti-rattle nut, which helps eliminate seat rattle. Outboard leg assemblies have the SEB housing (when present) attached to the inboard side.

4. Armrest Assembly

Armrests are aluminum box structures. Except for seats with in-arm tables, aisle armrests can turn upright. To do so, it is necessary to push the release latch installed below and to the rear of the armrest in front of the armrest pivot and lift the armrest. Each passenger position has a recline control button.

5. IAT Module Assembly

IAT (In-Arm Table) module assemblies are used as an alternative to armrests on front row seats or when a standard back-mounted food tray table assembly can not be used. The IAT module has a recline control button and contains a fold-out food tray table assembly.

6. Backrest Assembly

The passenger can adjust the recline of the backrest assembly. Contoured foam cushions cover the aluminum backrest assemblies. They are installed on hook and loop straps attached to the backrest frame. The backrest cover is attached with hook and loop tape. A fabric pocket for literature is attached to the back panel. A rotating latch, attached to the back of the backrest, holds the back-mounted food tray table against the backrest assembly.

7. Seat Recline

The passenger cam control the recline of the backrest assembly with a recline unit connected to the recline arm of the backrest. The units are tamper-proof and pre-set to the correct recline dimensions. In accordance with aviation regulations, some seat that are located in certain positions on the aircraft have limited recline or no recline.

8. Back-Mounted Food tray Table Assembly

The food tray table assembly is a vacuum-formed ABS plastic table with aluminum slide rods. The tables are located on the rear of the backrest assembly. The position of the table can not be changed by the recline of the backrest assembly, when the table is in use. When the table is in use, it can slide to a maximum of 3.0" as necessary for the passenger. Each table is supported by two machined aluminum leg assemblies. When the table is lowered from the seat back, the lower part of the leg assembly stops on the tray leg stop. To remove the food tray table assembly, break the backrest assembly forward and pull the food tray table legs away from the pivot pins.

9. Seat Cushion

Backrest seat cushions are made of fire retardant foam. Bottom seat cushions are made of fabricated polyurethane foam with fire block covers. The bottom cushions attach to the fabric diaphragms with hook and loop tape [8].

Materials

Costlier leather seats are usually used. Two main reasons for using leather seats are that the material is easy to clean and that it prevents soaking of spilt liquid into padding, also this material adds luxury to the passenger seat.

Airline seats are designed to be lightweight, but at the same time strong and fire resistant, while also taking into account passenger comfort. A typical design is an aluminum frame with blocks of polyurethane foam attached to it. In some cases a layer of fire-resistant fabric, for instance Kevlar or Nomex goes over this and at the top is a layer of cloth or leather. Leather seats are more costly than traditional cloth seats.

2.2 Design of a seat «Morph»

Despite the variety of seats and comfort devices, passengers are often unhappy after flying in economy class. What do people imagine when they hear about flying in economy class? Hard seats, uncomfortable armrests and narrow aisles. Every day passengers complain about small airline seats. Incredibly, when asked why airlines decided to shrink the amount of space between seats, they say passengers asked for it by always choosing the least expensive seat. In this diploma work will be presented seat that will fix limitations and help to change the opinion of passengers[9].

A new seat developed by Lloyd Weaver and Burk Daggett of the Bend, Ore., design firm SE Aeronautics promises to end the nightmare of millions of airline passengers by offering extra legroom, almost enough recline for sleep, and business-class level comfort.

The airline’s new "morphing" seat is a universally adjustable long-range, comfortable seat. The pan seat tips forward up to 15 degrees and the sliding seat back tips about the same amount, effectively doubling the angle to 30 degrees. This allows passengers to stretch and the recline doesn’t affect the rear or front passenger, according to the designers (fig. 2.6).

Fig 2.6. Morph concept

Instead of three separate seats, each made up of several pieces of fabric and foam, Morph is better described as a bench. One piece of fabric is stretched across to form the seats and another forms the back of the chair. The individual seats are appointed using armrests and dividers to clamp the fabric in place.

Rather than moving the entire backrest to adjust the pitch of the chair, mechanized seat formers are positioned under the fabric, allowing passengers to select the recline and support that suits them best.

Since the backrest is fixed in place, the seat in front will never recline. "The semantics of the architecture and visual cues indicate that the seatback belongs to the passenger in front of it" the company explains. There are also folding sections that increase the width of armrests, which according to Seymourpowell, increases a passenger's sense of independence and control over their own space. Where Morph comes into its own is in the design flexibility (fig. 2.7).

Fig 2.7. Morph side view.

By moving the dividers that define each seat, airline employees can effectively adapt each bench for its passengers. All three seats take up 54 inches of width – a fairly standard economy bench size (fig. 2.8). When shared between a trio of passengers, they each have 18 inches. However, there are times when three equal places are not required.

Seymourpowell offers up a traveling couple with a child as an example. The father, presumably larger than the rest of the family, can take 20 inches, the mother keeps the standard 18 inches, and the child takes 16 inches. This simple adjustment gives the father more lateral space than almost any major airline can offer in economy, at no additional cost to the family (fig. 2.9).

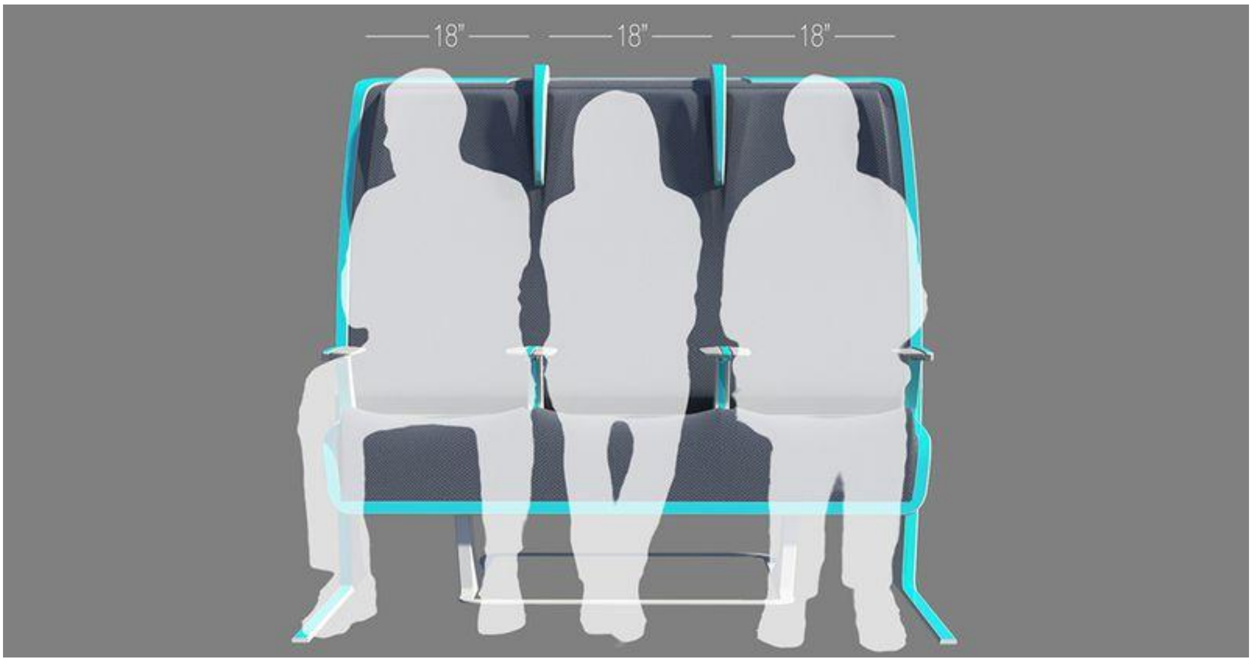

Fig. 2.8. Morph with 3 equal seats.

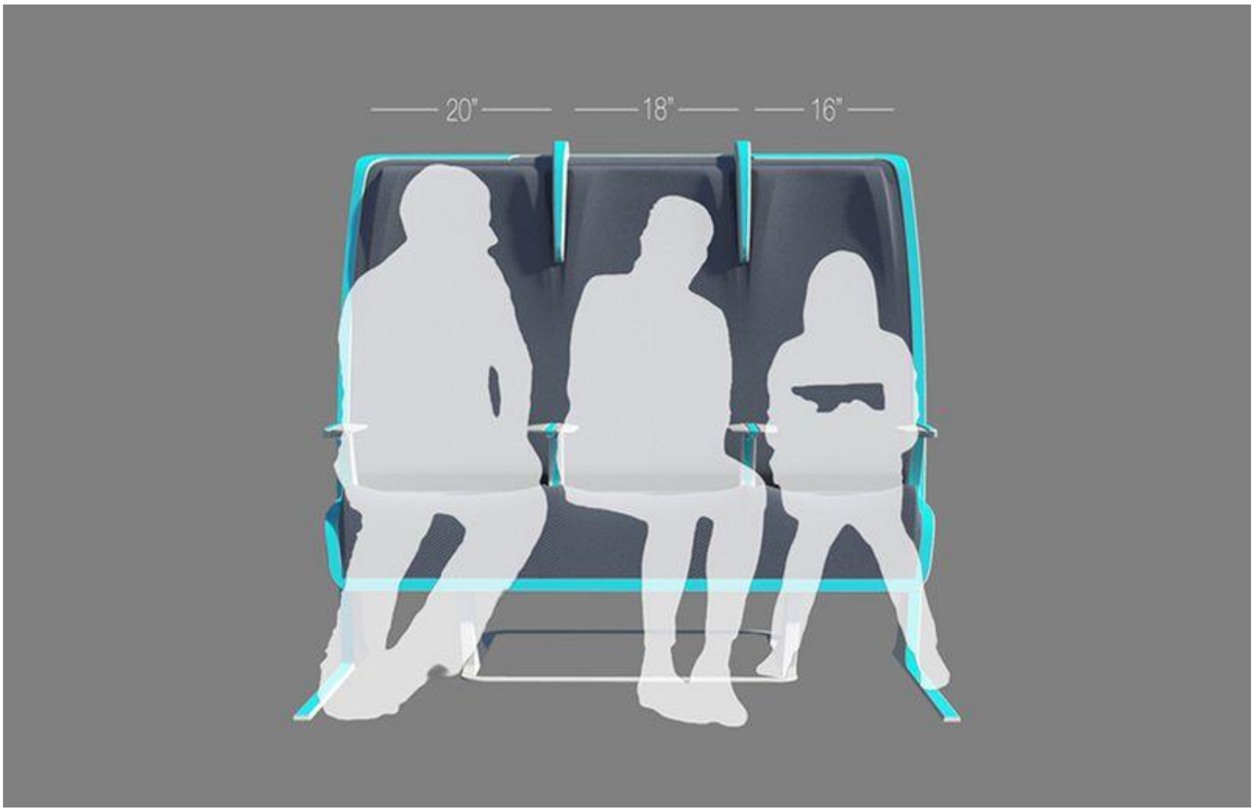

Fig 2.9. Morph for family.

Since some economy airlines charge significantly more for sitting in an exit row or closer to the front of the plane, it's easy to imagine the second scenario Seymourpowell suggests would become a reality. Morph's design allows the center seat to be made just 10 inches wide. This creates two 22-inch seats, offering airlines and passengers a "premium" row for those would like to pay more for the space (fig. 2.10). This configuration can also potentially save money for overweight people, some of whom buy two adjacent seats when traveling.

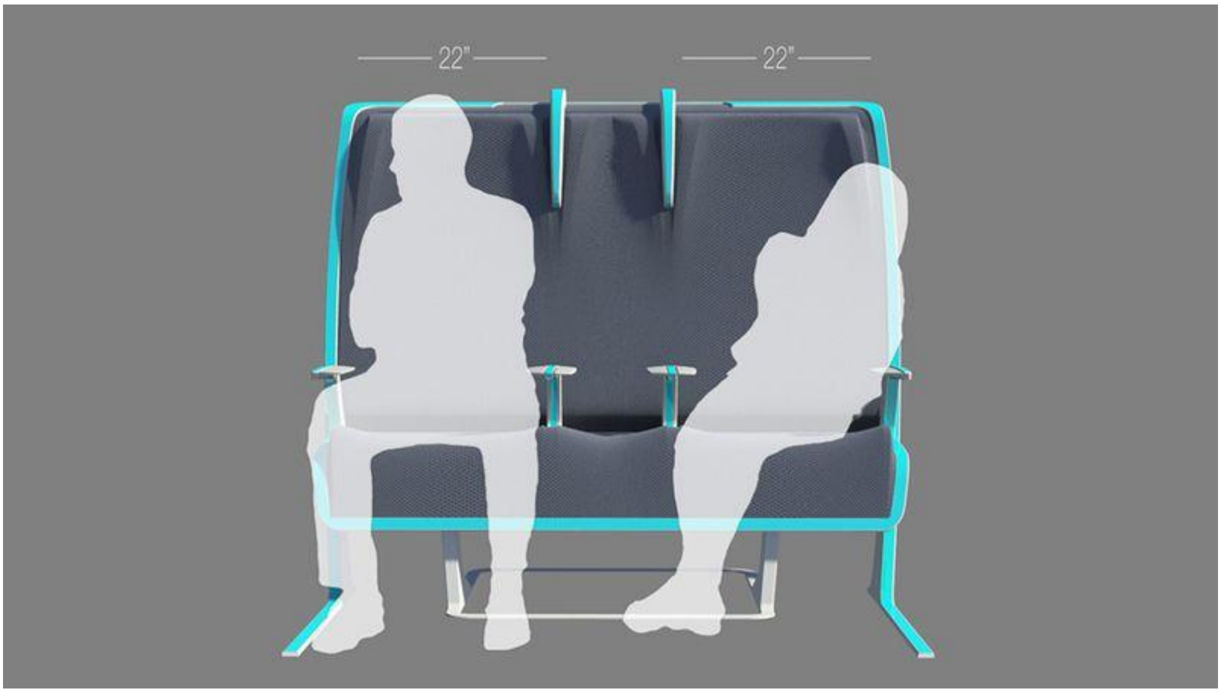

Fig. 2.10. Morph for 2 passengers.

In all of the configurations, the seat formers and adjusting mechanisms move with the dividers (they're also on rails) to form a new seat [10].

Comparison with other passenger seats Morph show a number of advantages. The list of the geometrical parameters of the passenger seats is given in table 2.1.

Table 2.1

The main geometrical parameters of the passenger seats in economy class

№	NAME, SIZE	Minimal size	Average size	Maximum size	Morph size
1	2	3	4	5	6
1	Distance between the armrests, mm	405	440	470	254/559

Ending of the table 2.1

1	2	3	4	5	6
2	Arm-rest width, mm	40	45	50	81
3	Height of armrest above floor, mm	585	607	630	670
4	Height of the seat cushion above the flour, mm	425	441	457	450
5	Height of the seat, mm	1120	1145	1170	1250
6	Seat pitch, mm	750	810	870	895
7	Angle of seat back deflection, mm	25	25	25	30
8	Width of the block from three seats, mm	1430	1480	1530	1500
9	Mass of one seat, kg	6	7	8	6
10	Mass of the block from three seats, kg	18	19	20	18

During the flying, all needs are different. Some may not mind taking a small seat to save money, while others may want a larger seat to work on a long flight. Airlines are currently can't offer such flexibility to their passengers. Morph could provide operators with the ability to maximize their profits and more importantly give passengers more control over their journey (fig. 2.11).

Figure 2.11. Morph design.

2.3. Strength analysis

The main element of the loaded structure is a curved beam (fig. 2.12). Considered curved beam has next features:

- cross-section has an axis of symmetry;
- geometric axis is a flat curve lying in the plane of symmetry;
- the acting forces lie in the same plane;
- stiffness is sufficient to apply the principle of independence of the action of forces.

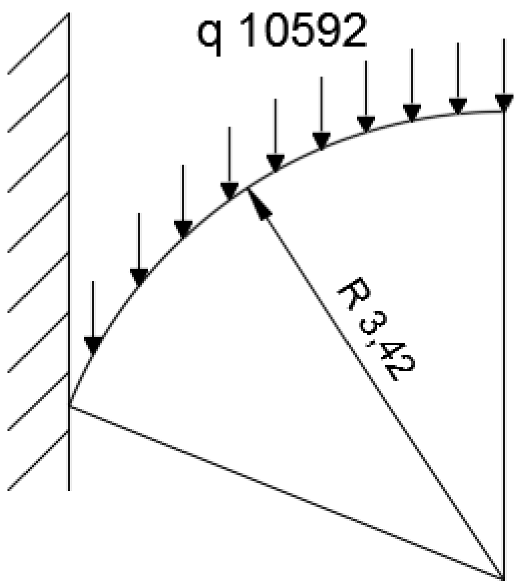

Fig. 2.12. Task scheme.

Internal forces in the cross-section of a curved beam are determined in the same way as in beams and frames by the method of sections. In this case, they are reduced to three force factors – bending moment *M*, longitudinal force *N* and shear force *Q*.

Displacement (linear and angular) in plane curved beams of small curvature in the general case (taking into account the bending moment M, the longitudinal force N and shear force Q) can be determined using the Mohr integral (2.1).

$$\delta_{iP} = \sum \int_s \frac{MM_i ds}{EJ} + \sum \int_s \frac{NN_i ds}{EF} + \sum \int_s \frac{kQQ_i ds}{GF}, \qquad (2.1)$$

where M, N, Q – force factors from a given load in an arbitrary section of the curved bar; M_i, N_i, Q_i – similar force factors in the same section from a unit force (moment) applied in the direction of the unknown displacement; k – cross-sectional factor; ds – arc element; s – arc length.

Since the influence of the N and Q on the magnitude of the displacement is usually insignificant in comparison with the influence of M, then practically the last two terms of the Mohr integral can be neglected.

Let's consider the curved axis of the beam and select in it an elementary part of length ds. On this part acts an elementary force which can be represented as $dP = qds = qRd\alpha$. The direction of this force is not on the axes so it is needed to decompose its vector into components and fix its position by angle α (figure 2.13). Because the angle alpha is small, sinus of this angle can be represented as the angle.

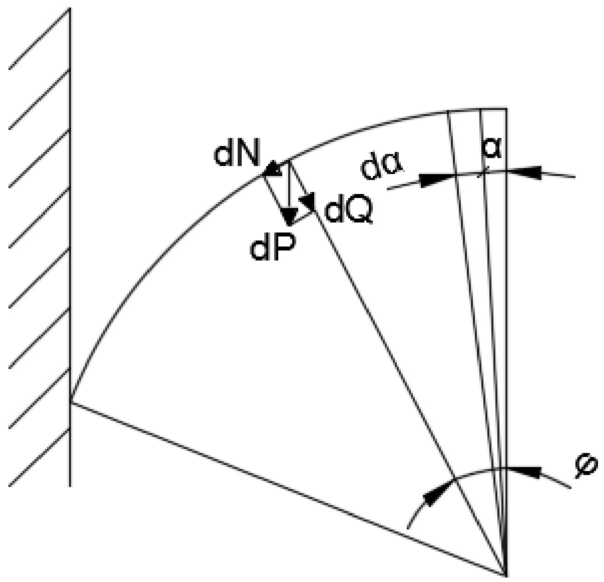

Fig. 2.13. Vector diagram.

Let's consider what force factors acts in the cross-sections of the curved section of the beam from the distributed load with the intensity q. In an arbitrary cross section, the position of which is fixed by the angle φ measured from the vertical, from the elementary concentrated force, appear:

$$dM(q) = dPR(\sin\varphi - \sin\alpha) = qR^2(\sin\varphi - \sin\alpha)d\alpha$$

$$dN = -dP\sin\varphi = -qR\sin\varphi\, d\alpha$$

$$dQ = dP\cos\varphi = qR\cos\varphi d\alpha$$

Total strength factors are:

$$M(q) = qR^2\int_0^\varphi (\sin\varphi - \sin\alpha)\, d\alpha = qR^2\left(\int_0^\varphi \sin\varphi d\alpha - \int_0^\varphi \sin\alpha d\alpha\right) =$$

$$= qR^2\left(d\alpha\Big|_0^\varphi \sin\varphi + \cos\alpha\Big|_0^\varphi\right) = qR^2[\sin\varphi(\varphi - 0) + \cos\varphi - \cos 0] =$$

$$= qR^2(\varphi\sin\varphi + \cos\varphi - 1)$$

$$N(q) = -qR\int_0^\varphi \sin\varphi d\alpha = -qR\sin\varphi\int_0^\varphi d\alpha = -qR\sin\varphi\,\alpha\Big|_0^\varphi =$$

$$= -qR\sin\varphi(\varphi - 0) = -qR\varphi\sin\varphi$$

$$Q = qR\int_0^\varphi \cos\varphi d\alpha = qR\cos\varphi\int_0^\varphi d\alpha = qR\cos\varphi\alpha\Big|_0^\varphi = qR\cos\varphi(\varphi - 0) =$$

$$= qR\varphi\cos\varphi$$

Substitute different angles:

$\varphi = 0$ $\quad M(q) = qR^2(0\sin 0 + \cos 0 - 1) = 0$

$$N(q) = -qR0\sin 0 = 0$$

$$Q(q) = qR0\cos 0 = 0$$

$\varphi = 15^o = \frac{\pi}{12}$ $\quad M(q) = qR^2\left(\frac{\pi}{12}\sin\frac{\pi}{12} + \cos\frac{\pi}{12} - 1\right) \approx 0.0337qR^2$

$$M(q) = 0.0337 \cdot 10592 \cdot 3.42^2 = 4175.035\, N\cdot m$$

$$N(q) = -qR\frac{\pi}{12}\sin\frac{\pi}{12} \approx -0.0677qR$$

$$N(q) = -0.0677 \cdot 10592 \cdot 3.42 = -2452.408\ N$$

$$Q(q) = qR\frac{\pi}{12}\cos\frac{\pi}{12} \approx 0.2529qR$$

$$Q(q) = 0.2529 \cdot 10592 \cdot 3.42 = 9161.211\ N$$

$$\varphi = 30^o = \frac{\pi}{6} \quad M(q) = qR^2\left(\frac{\pi}{6}\sin\frac{\pi}{6} + \cos\frac{\pi}{6} - 1\right) \approx 0.1278qR^2$$

$$M(q) = 0.1278 \cdot 10592 \cdot 3.42^2 = 15832.921\ N \cdot m$$

$$N(q) = -qR\frac{\pi}{6}\sin\frac{\pi}{6} \approx -0.2618qR$$

$$N(q) = -0.2618 \cdot 10592 \cdot 3.42 = -9483.611\ N$$

$$Q(q) = qR\frac{\pi}{6}\cos\frac{\pi}{6} \approx 0.4534qR$$

$$Q(q) = 0.4534 \cdot 10592 \cdot 3.42 = 16424.252\ N$$

$$\varphi = 45^o = \frac{\pi}{4} \quad M(q) = qR^2\left(\frac{\pi}{4}\sin\frac{\pi}{4} + \cos\frac{\pi}{4} - 1\right) \approx 0.2625qR^2$$

$$M(q) = 0.2625 \cdot 10592 \cdot 3.42^2 = 32520.671\ N \cdot m$$

$$N(q) = -qR\frac{\pi}{4}\sin\frac{\pi}{4} \approx -0.5554qR$$

$$N(q) = -0.5554 \cdot 10592 \cdot 3.42 = -20119.165\ N$$

$$Q(q) = qR\frac{\pi}{4}\cos\frac{\pi}{4} \approx 0.5554qR$$

$$Q(q) = 0.5554 \cdot 10592 \cdot 3.42 = 20119.032\ N$$

$$\varphi = 60^o = \frac{\pi}{3} \quad M(q) = qR^2\left(\frac{\pi}{3}\sin\frac{\pi}{3} + \cos\frac{\pi}{3} - 1\right) \approx 0.4069\ qR^2$$

$$M(q) = 0.4069 \cdot 10592 \cdot 3.42^2 = 50410.137\ N \cdot m$$

$$N(q) = -qR\frac{\pi}{3}\sin\frac{\pi}{3} \approx -0.9069qR$$

$$N(q) = -0.9069 \cdot 10592 \cdot 3.42 = -32852.126\ N$$

$$Q(q) = qR\frac{\pi}{3}\cos\frac{\pi}{3} \approx 0.5236qR$$

$$Q(q) = 0.5236 \cdot 10592 \cdot 3.42 = 18967.222\ N$$

Results of all performed calculations can be represented as graphs of strength factors (fig. 2.14-2.16).

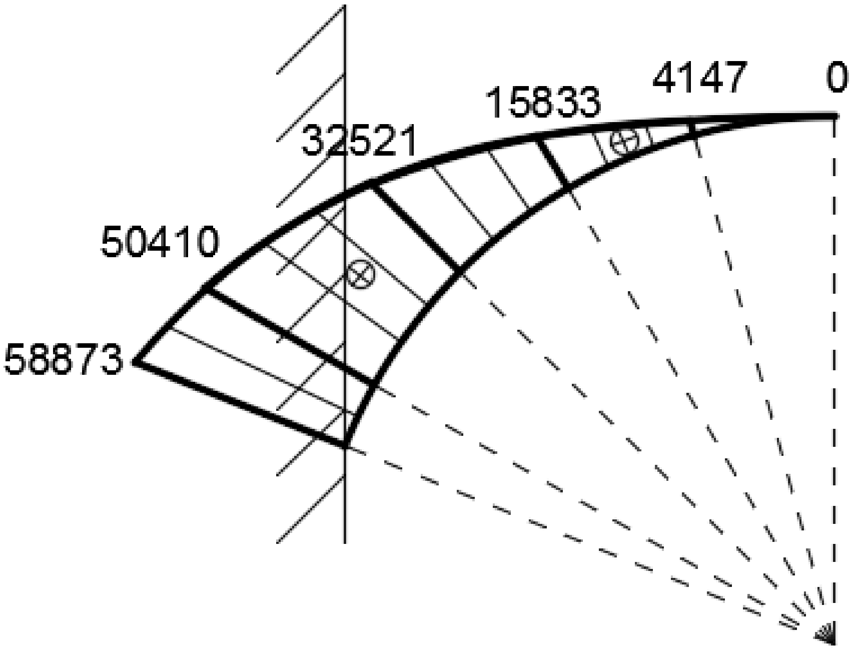

Figure 2.14. Bending moment M graph

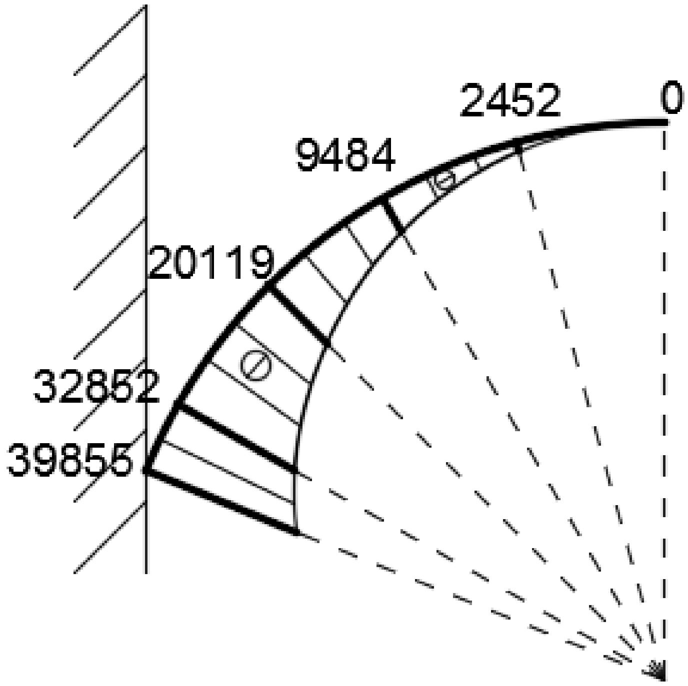

Figure 2.15. Longitudinal force N graph

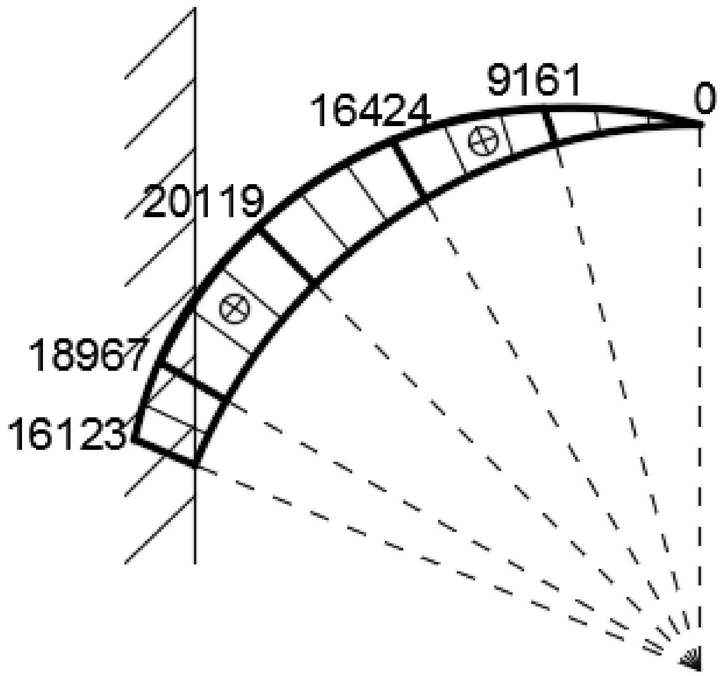

Figure 2.16. Shear force Q.graph

For the better understanding of a seat elements operation under design and operational loads solid modeling of the seat frame was carried out by software SolidWorks 2020 with subsequent strength analysis. For the analysis were taken average passenger weight about 80 kg, vertical operational load factor 2.5 with respect to safety coefficient 1.5. Results of the analysis are shown in the following figures (fig. 2.17-2.20). Similar modeling was performed for operational load factors in case of emergency landing. Results of that strength analysis are represented in the Appendix D.

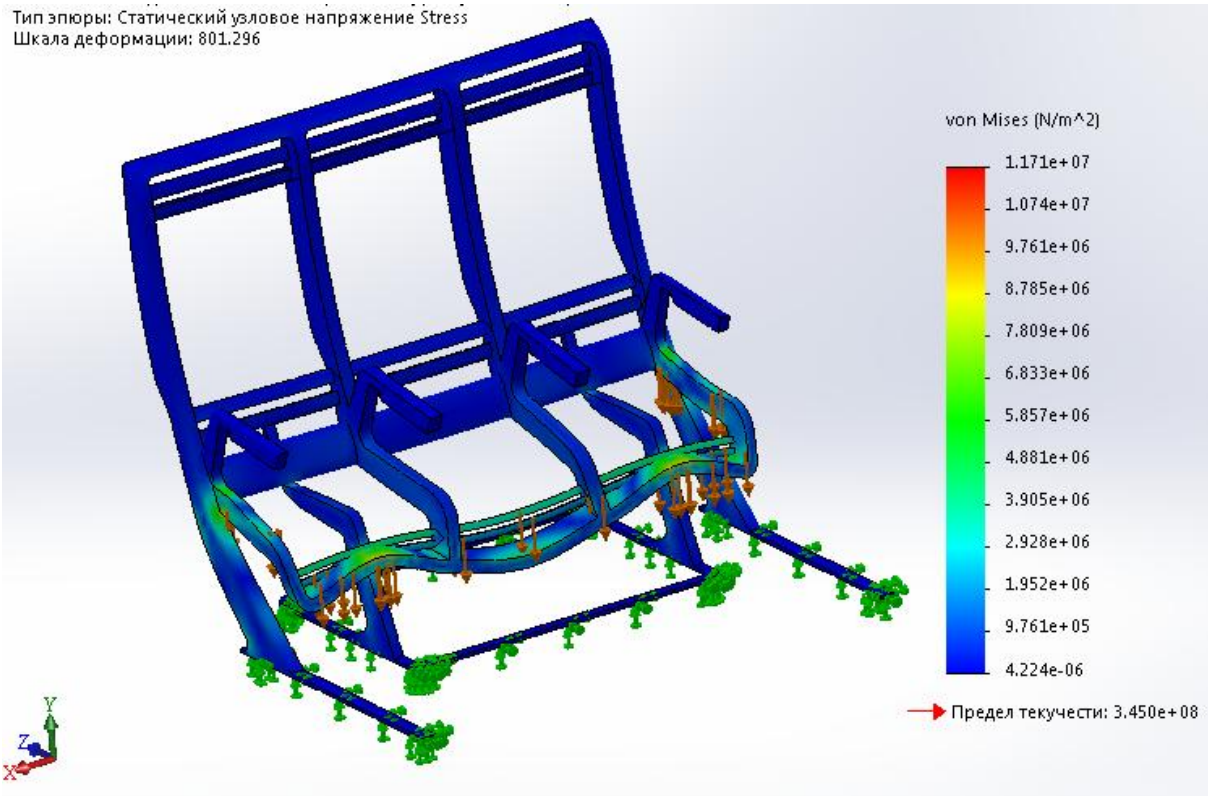

Figure 2.17. Diagram of the stress distribution.

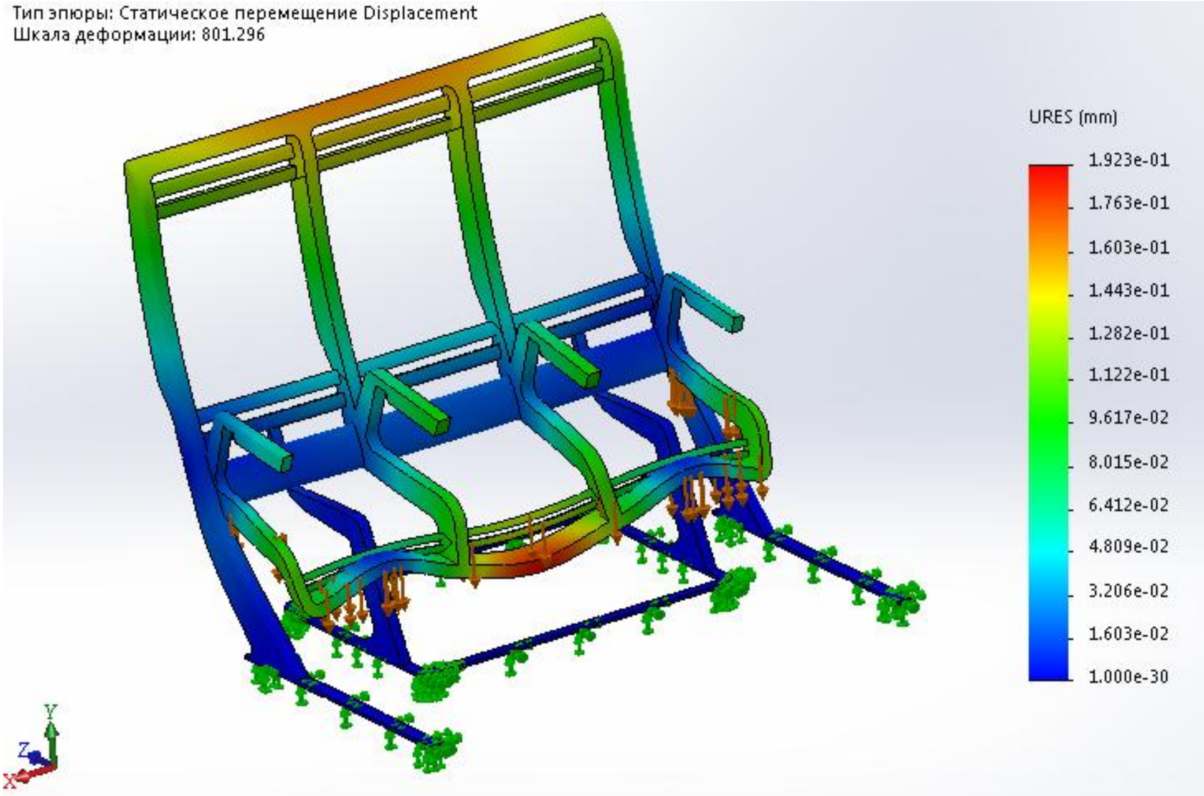

Fig. 2.18. Displacement diagram.

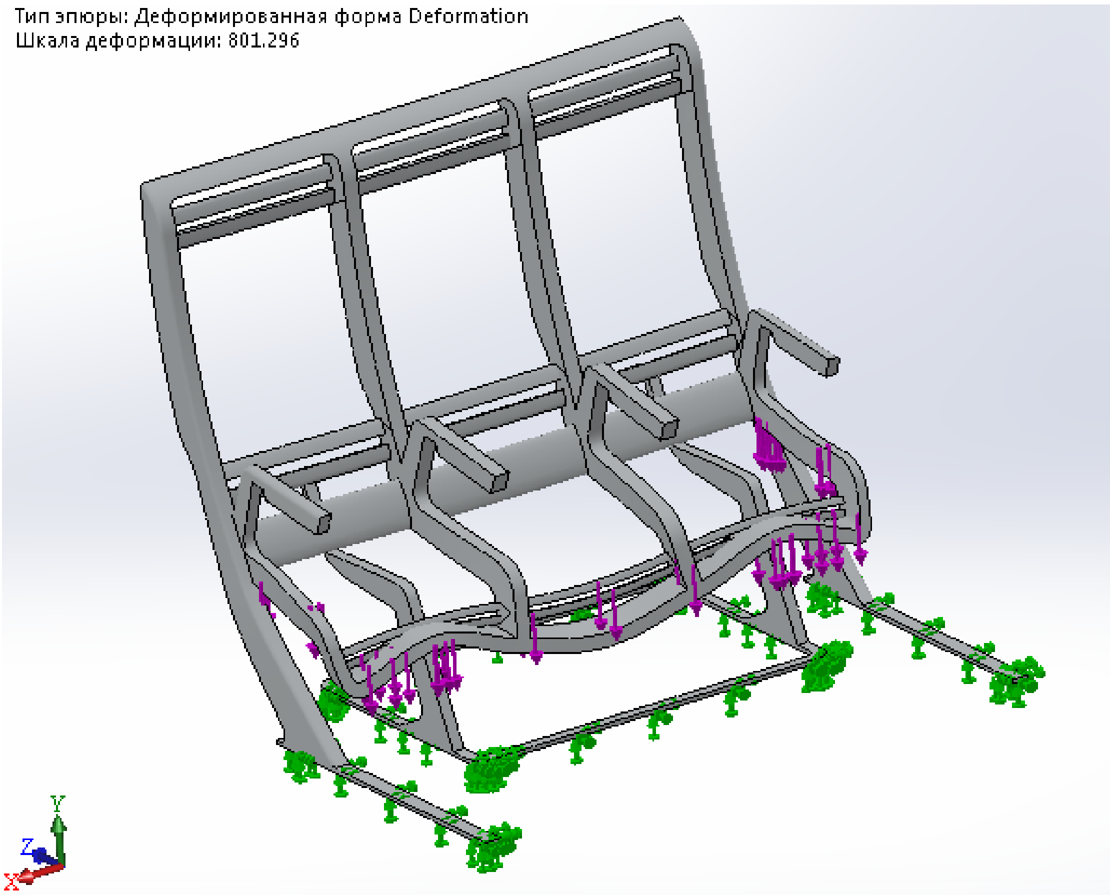

Fig. 2.19. Deformation diagram.

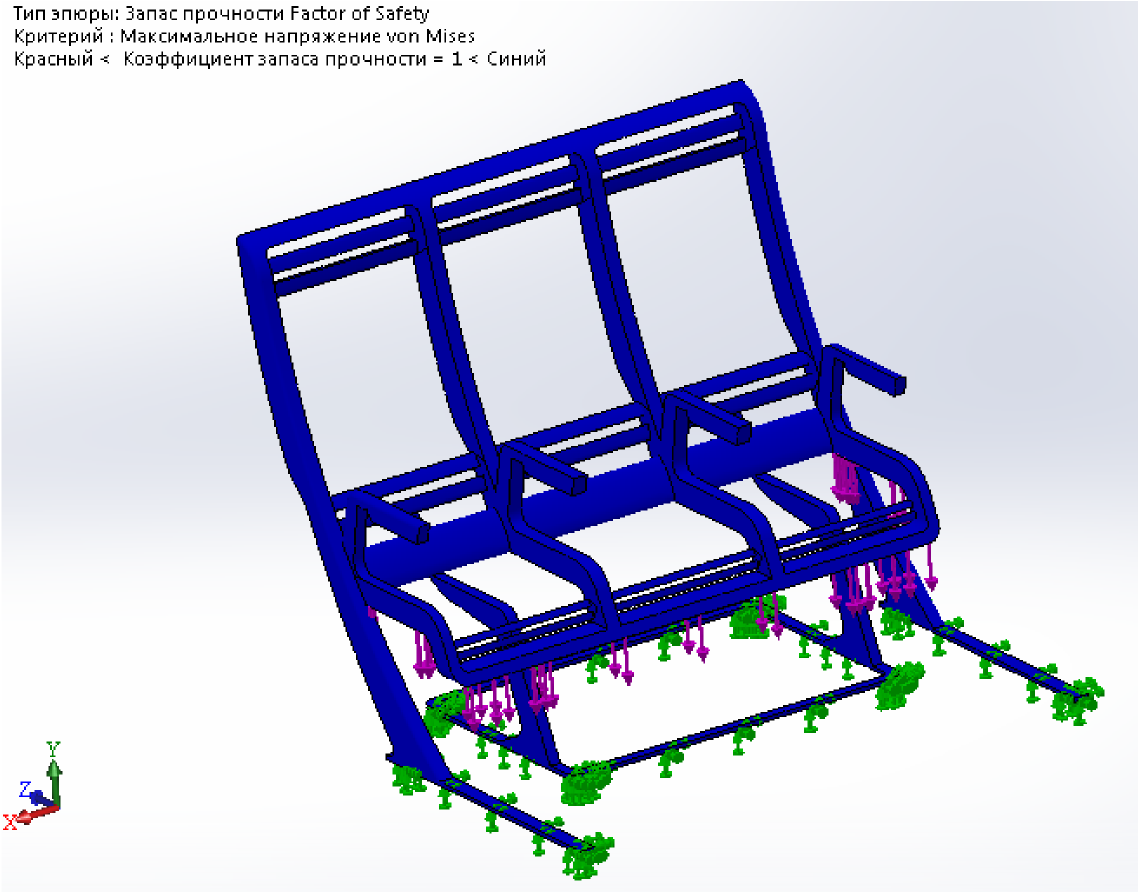

Fig. 2.20. Diagram of the safety factor.

According the performed strength analysis of seat frame the maximum stress that acts in it during flight and emergency landing is equal to 11.7 MPa and 175 MPa respectively, which is less than critical stresses for aluminum alloys. So it may be concluded that it is strong enough and can carry all operational load even in case of emergency landing.

Conclusion to special part

In this part:

1. Was developed a new design of passenger seat with improved comfort characteristics that provide better condition for passengers during long-term flight

2. Comparison of the designed seat with other seats show great benefits about the comfort of passengers and possible values for leg space and so on. It means that the passenger seat will successfully compete with other models in the selected market segment.

3. Performed strength calculations and strength strain analysis of the develop seat design that prove reliability and strength of the structure under the action of operation load and emergency landing case.

GENERAL CONCLUSIONS

In this diploma work were created:

- preliminary design of the long-range passenger aircraft with 440 seats capacity;
- the schematic design of the layout of the long-range aircraft with 440 passengers;
- the center of gravity of the airplane calculations;
- the calculation of the main geometrical parameters of the passenger equipment element;
- the design of passenger seat.

The created aircraft meets the intended purpose of use, its geometric characteristics will provide the necessary aerodynamic characteristics, which will lead to efficient use.

A new passenger seat is proposed. It has better characteristics and will be more comfortable for passengers.

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Appendix

Appendix A

INITIAL DATA AND SELECTED PARAMETERS

Passenger Number Flight	440
Crew Number	2
Flight Attendant or Load Master Number	11
Mass of Operational Items	5633.42 kg
Payload Mass	
Cruising Speed	905 km/h
Cruising Mach Number	0.8499
Design Altitude	13 km
Flight Range with Maximum Payload	9700 km
Runway Length for the Base Aerodrome	3.3 km
Engine Number	2
Thrust-to-weight Ratio in N/kg	2.8
Pressure Ratio	35
Assumed Bypass Ratio	5
Optimal Bypass Ratio	3.5
Fuel-to-weight Ratio	0.38
Aspect Ratio	8.7
Taper Ratio	3
Mean Thickness Ratio	0.11
Wing Sweepback at Quarter Chord	35 degree
High-lift Device Coefficient	1.1
Relative Area of Wing Extensions	0

Wing Airfoil Type - supercritical
Winglets - yes
Spoilers - yes

Fuselage Diameter	6.2 m
Finesse Ratio	11.9
Horizontal Tail Sweep Angle	40 degree
Vertical Tail Sweep Angle	46 degree

CALCULATION RESULTS

Optimal Lift Coefficient in the Design Cruising Flight Point	0.48068
Induce Drag Coefficient	0.00886

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

Cruising Mach Number	0.84988
Wave Drag Mach Number	0.85729
Calculated Parameter D_m	0.00742

Wing Loading in kPa (for Gross Wing Area):

At Takeoff	4.977
At Middle of Cruising Flight	4.035
At the Beginning of Cruising Flight	4.772

Drag Coefficient of the Fuselage and Nacelles	0.00659
Drag Coefficient of the Wing and Tail Unit	0.00888
Drag Coefficient of the Airplane:	
At the Beginning of Cruising Flight	0.02652

At Middle of Cruising Flight	0.02490
Mean Lift Coefficient for the Ceiling Flight	0.48068
Mean Lift-to-drag Ratio	19.30092
Landing Lift Coefficient	1.469
Landing Lift Coefficient (at Stall Speed)	2.203
Takeoff Lift Coefficient (at Stall Speed)	1.807
Lift-off Lift Coefficient	1.319
Thrust-to-weight Ratio at the Beginning of Cruising Flight	0.467
Start Thrust-to-weight Ratio for Cruising Flight	2.510
Start Thrust-to-weight Ratio for Safe Takeoff	2.537
Design Thrust-to-weight Ratio	2.638
Ratio $D_r = R_{cruise} / R_{takeoff}$	0.989

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

Takeoff	35.8856
Cruising Flight	58.6593
Mean cruising for Given Range	61.3972

FUEL WEIGHT FRACTIONS:

Fuel Reserve	0.02863
Block Fuel	0.32383

WEIGHT FRACTIONS FOR PRINCIPAL ITEMS:

Wing	0.12764
Horizontal Tail	0.01152
Vertical Tail	0.01198
Landing Gear	0.03589
Power Plant	0.08192
Fuselage	0.08750
Equipment and Flight Control	0.10468
Additional Equipment	0.00805
Operational Items	0.01947
Fuel	0.35246
Payload	0.15893

Airplane Takeoff Weight	289310 kg
Takeoff Thrust Required of the Engine	381.61 kN

Air Conditioning and Anti-icing Equipment Weight Fraction	0.0195
Passenger Equipment Weight Fraction (or Cargo Cabin Equipment)	0.0122
Interior Panels and Thermal/Acoustic Blanketing Weight Fraction	0.0064
Furnishing Equipment Weight Fraction	0.0162
Flight Control Weight Fraction	0.0040
Hydraulic System Weight Fraction	0.0127
Electrical Equipment Weight Fraction	0.0225
Radar Weight Fraction	0.0019

Navigation Equipment Weight Fraction	0.0029
Radio Communication Equipment Weight Fraction	0.0015
Instrument Equipment Weight Fraction	0.0034
Fuel System Weight Fraction	0.0116

Additional Equipment:

Equipment for Container Loading	0.0061
No typical Equipment Weight Fraction (Build-in Test Equipment for Fault Diagnosis, Additional Equipment of Passenger Cabin)	0.0020

TAKEOFF DISTANCE PARAMETERS

Airplane Lift-off Speed	279.58 km/h
Acceleration during Takeoff Run	1.89 m/s^2
Airplane Takeoff Run Distance	1588 m
Airborne Takeoff Distance	578 m
Takeoff Distance	2166 m

CONTINUED TAKEOFF DISTANCE PARAMETERS

Decision Speed	256.6 km/h
Mean Acceleration for Continued Takeoff on Wet Runway	0.07 m/s^2
Takeoff Run Distance for Continued Takeoff on Wet Runway	5611 m
Continued Takeoff Distance	6189.38 m
Runway Length Required for Rejected Takeoff	6418.44 m

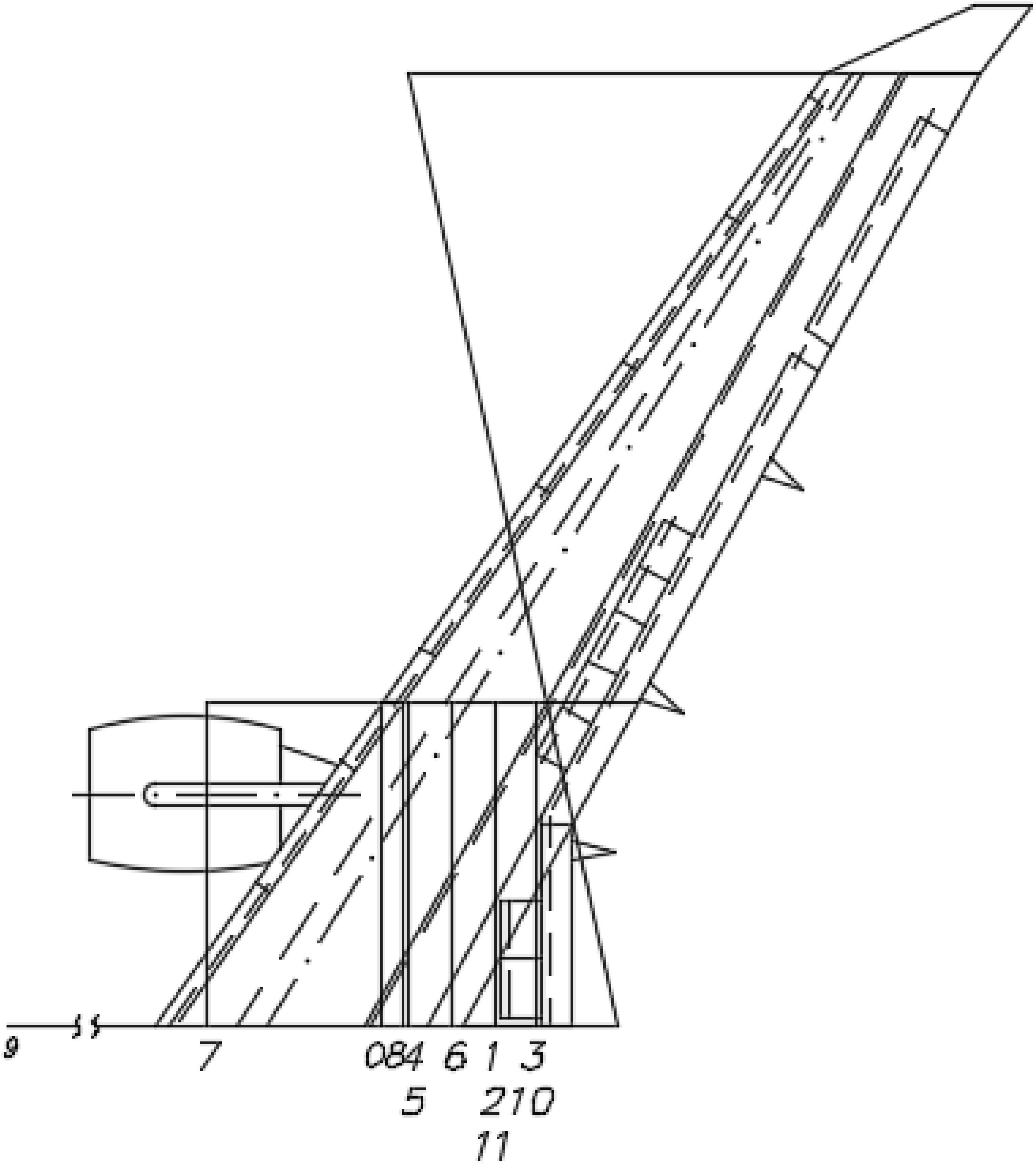
LANDING DISTANCE PARAMETERS

Airplane Maximum Landing Weight	210219 kg
Time for Descent from Flight Level till Aerodrome Traffic Circuit Flight	24.1 min.
Descent Distance	60.52 km
Approach Speed	242.86 km/h
Mean Vertical Speed	1.97 m/s
Airborne Landing Distance	514 m
Landing Speed	227.86 km/h
Landing run distance	713 m
Landing Distance	1227 m
Runway Length Required for Regular Aerodrome	2049 m
Runway Length Required for Alternate Aerodrome	1742 m

Appendix B

N	Object name	C.G coordinates Xi, м
1	Wing (structure)	3,528
2	Fuel system	3,528
3	Airplane control, 30%	4,704
4	Electrical equipment, 30%	0,784
5	Anti-ice system , 50%	0,784
6	Hydraulic systems , 70%	2,166
7	Power plant	-5,44
8	Equipped wing without landing gear and fuel	0,617
9	Nose landing gear	-23,066
10	Main landing gear	4,704
11	Fuel	3,528

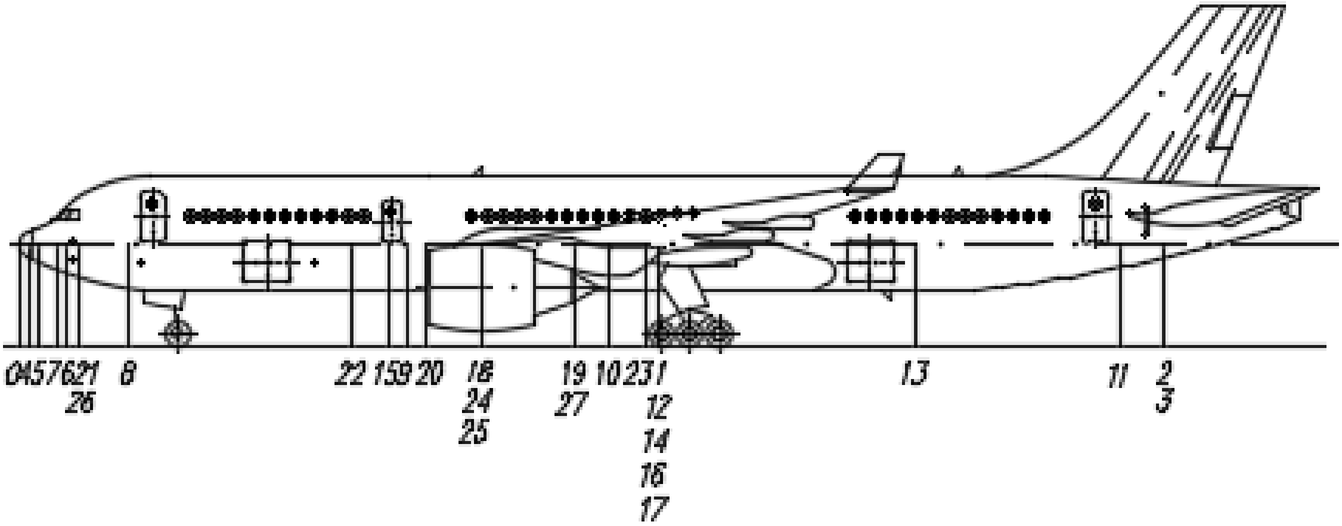
Appendix B



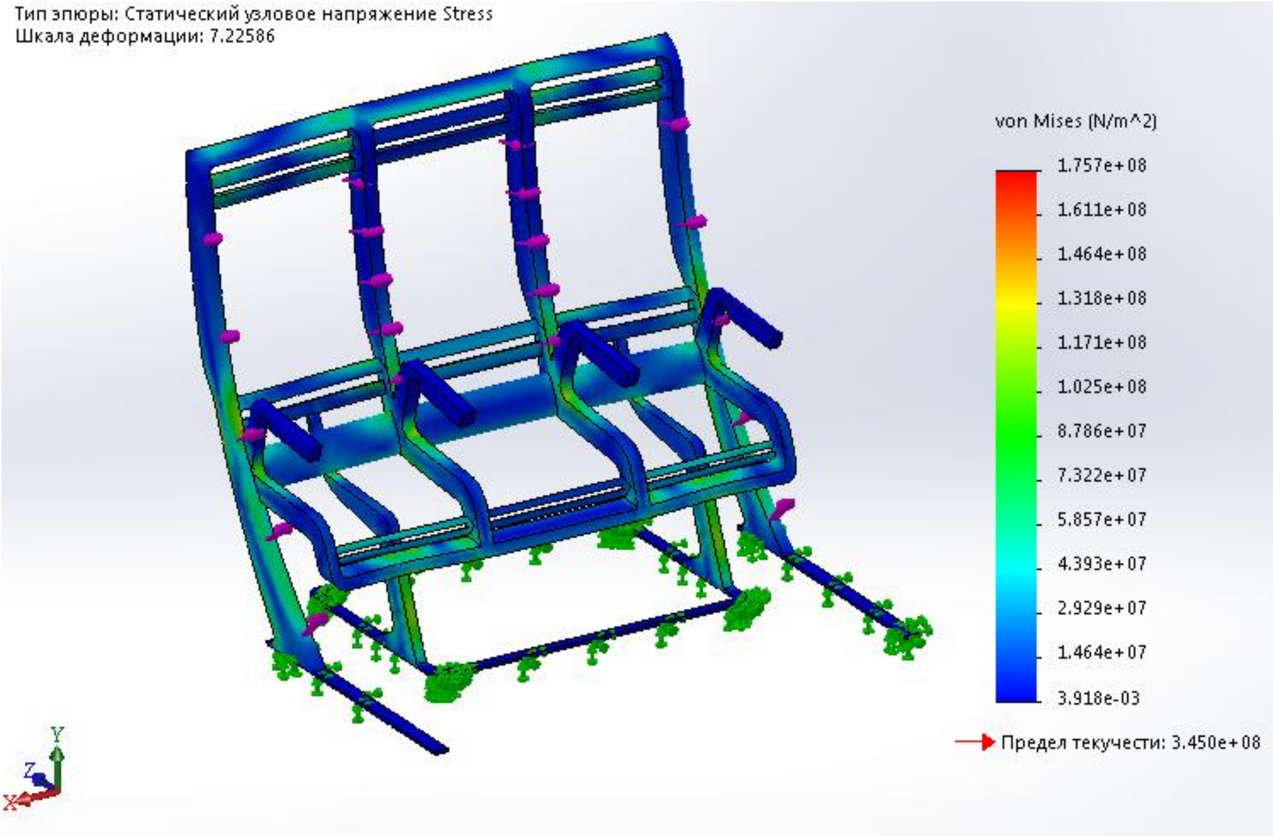
Appendix C

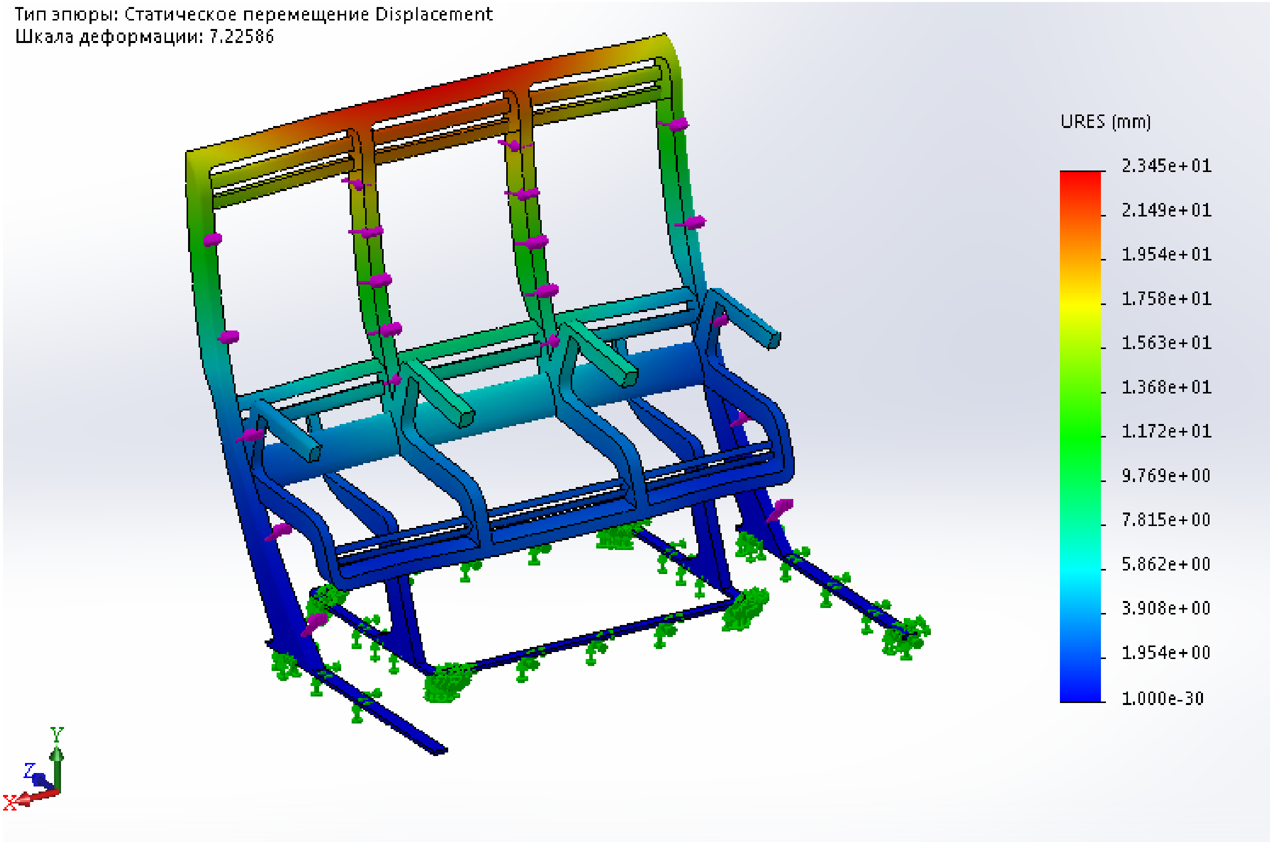
N	Object name	C.G coordinates Xi, м
1	Fuselage	34,72
2	Horizontal tail	60,29
3	Vertical tail	60,29
4	Radar	0,5
5	Radio equipment	1
6	Instrument panel	2,5
7	Aero navigation equipment	2
8	Lavatory 1, galley 1, lavatory 2, galley 2 20%	5,014
9	Lavatory 3, galley 3, lavatory 4, galley 4, lavatory 5, galley 5 30%	20,42
10	Lavatory 6, lavatory 7, lavatory 8, lavatory 9 20%	25,786
11	Lavatory 10, galley 6, lavatory 11, galley 7, galley 8, galley 9 30%	54,728
12	Aircraft control system 70%	34,72
13	Hydro-pneumatic sys 30%	48,608
14	Electrical equipment 70%	34,72
15	Not typical equipment	20
16	Furnishing and thermal equipment	34,72
17	Anti ice and air-conditioning system	34,72
18	On board meal	25
19	Passenger seats (economic class)	34
20	Seats of flight attendance	22
21	Seats of pilot	3,3
22	Additional equipment	18
23	Equipped fuselage without payload	34,325
24	Baggage	25
25	Cargo, mail	25
26	Crew/attendant	20
27	Passengers(economy)	34

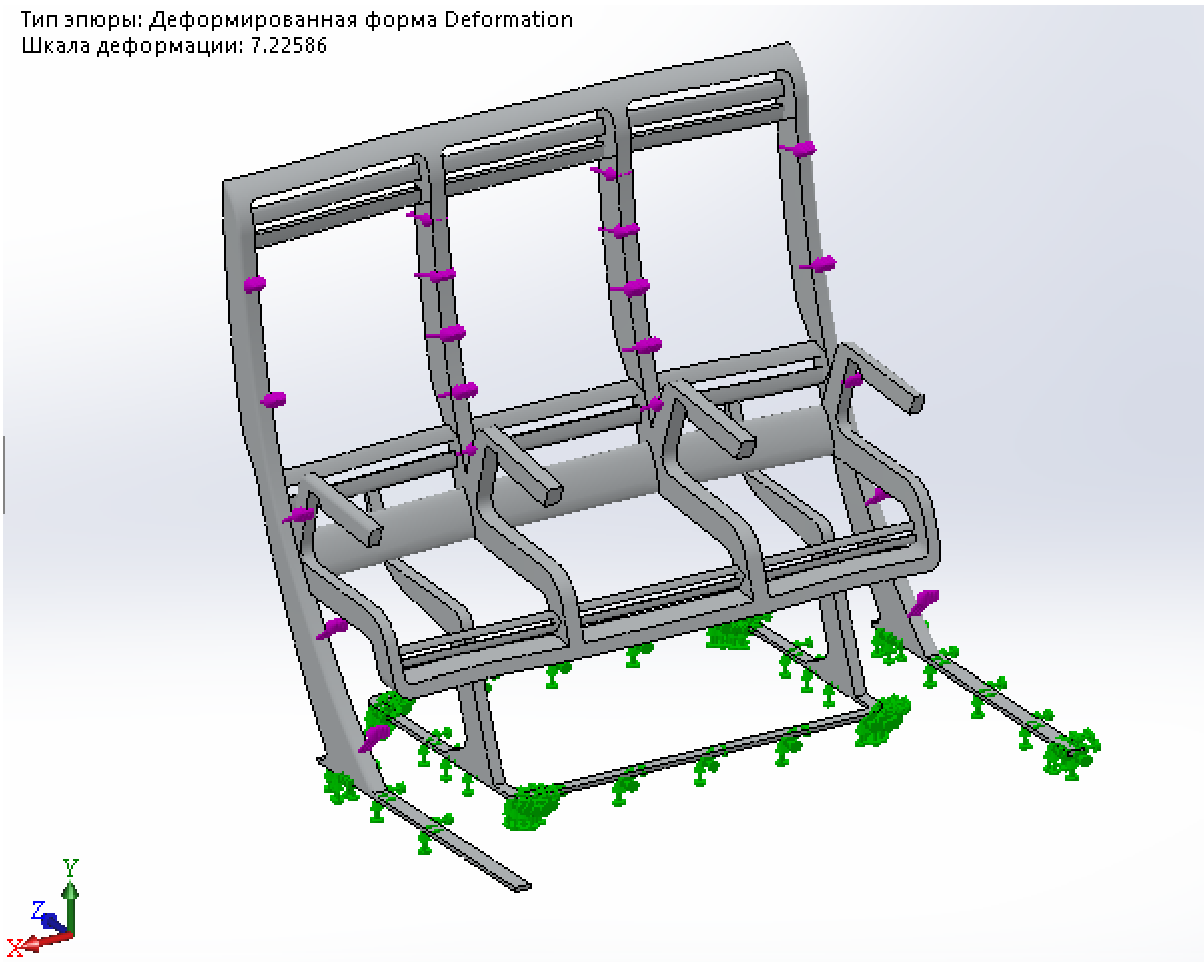
Appendix C

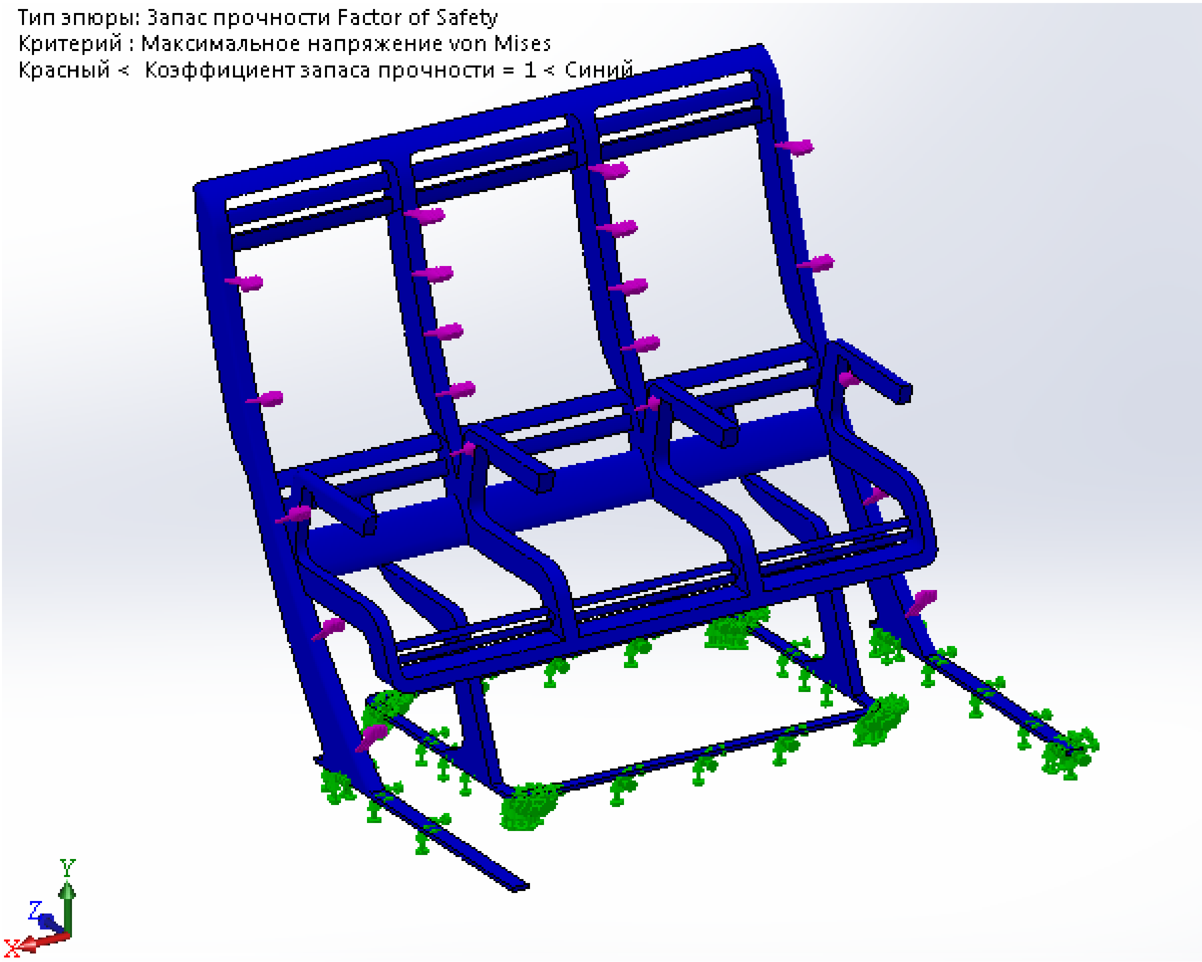


Appendix D


Тип эпюры: Статический узловое напряжение Stress
Шкала деформации: 7.22586
von Mises (N/m^2)
1.757e+08
1.611e+08
1.464e+08
1.318e+08
1.171e+08
1.025e+08
8.786e+07
7.322e+07
5.857e+07
4.393e+07
2.929e+07
1.464e+07
3.918e-03
Предел текучести: 3.450e+08
Y
Z
X


Тип эпюры: Статическое перемещение Displacement
Шкала деформации: 7.22586
URES (mm)
2.345e+01
2.149e+01
1.954e+01
1.758e+01
1.563e+01
1.368e+01
1.172e+01
9.769e+00
7.815e+00
5.862e+00
3.908e+00
1.954e+00
1.000e-30
Y
Z
X


Тип эпюры: Деформированная форма Deformation
Шкала деформации: 7.22586
Y
Z
X


Тип эпюры: Запас прочности Factor of Safety
Критерий : Максимальное напряжение von Mises
Красный < Коэффициент запаса прочности = 1 < Синий
Y
Z
X