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 середньомагістрального літака пасажиромісткостю 227 осіб»

Виконавець: ___________ **А.В. Борисова**

Керівник: к.т.н., доцент ___________ **Т.П. Маслак**

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. Ignatovych
«___» _________ 2021

BACHELOR THESIS

ON SPECIALITY
"AVIATION AND SPACE ROCKET TECHNOLOGY"

Topic: «Preliminary design of a mid-range aircraft with 227 passenger capacity»

Prepared by: __________ **A.V. Borysova**

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

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

Kyiv 2021

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аерокосмічний
Кафедра конструкції літальних апаратів
Освітній 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
БОРИСОВА АННА

1. Тема роботи: «Аванпроект середньомагістрального літака пасажиромісткостю 227 осіб», 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}=850 км/год, дальність польоту L =5000 км, крейсерська висота польоту H_{op}=10 км, 227 пасажирів.

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

5. Перелік обов’язкового графічного матеріалу: загальний вигляд літака (А1×1), компонувальне креслення фюзеляжу (А1×1), монтажне креслення пасажирських дверей (А3×1).

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 пасажирських дверей 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 ____________ Т.П. Маслак

Завдання прийняв до виконання ____________ А.В. Борисова

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. Ignatovych
«___» __________ 2021

TASK
for the bachelor thesis
BORYSOVA ANNA

1. Topic: **«Preliminary design of a mid-range aircraft with 227 passenger capacity»** confirmed by Rector's order № 815/ст from 21.05.21
2. Thesis term: from 24.05.2021 to 20.06.2021
3. Initial data: maximum passenger capacity 227 people; flight range with maximum payload 5000 km; cruise speed 850 km/h at operating altitude 10 km.
4. Content (list of topics to be developed): selection of design parameters; choice and substantiations of the airplane scheme; calculation of aircraft masses; determination of basic geometrical parameters; aircraft layout; center of gravity position calculation; determination of basic flight performance; description of the aircraft design; engine selection; conceptual design of the passenger door.
5. Required materials:
   – general view of the airplane (A1×1);
   – layout of the airplane (A1×1);
   – assembly drawing of the skycouch passenger's seats (A3×1).
   – Graphical materials are performed in AutoCad and Solidworks.

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 seats 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	

Date: 24 May 2021 year.

Supervisor ___________ T.P. Maslak

Student ___________ A.V. Borysova

РЕФЕРАТ

Дипломна робота **«Аванпроект дальньомагістрального літака пасажиромісткістю 158 осіб»** містить:

66 сторінок, 22 рисунків, 14 таблиць, 10 літературних посилань, 3 креслень

Об'єкт проектування: пасажирський літак середньої дальності для 227 пасажирів.

Предмет проектування: концепція пасажирських вхідних дверей з аналізом пружно-деформованого стану під дією надлишкового тиску.

Мета роботи: аванпроект пасажирського літака середньої дальності відповідно до прототипів, планування пасажирського салону та проектування пасажирських дверей.

Методи дослідження: аналіз прототипів і вибір найбільш досконалих технічних рішень, оцінка геометричних характеристик, розрахунок центру мас літака, аналіз пружньо-деформаваного стану пасажирських дверей під дією навантажень надлишкового тиску в гермокабіні, 3D-модель проектування пасажирських дверей.

Наукова новизна результатів полягає у визначенні пружно-деформованого стану конструкції дверей та аналізу зон в районі вирізів під двері для забезпечення їх міцності.

Практична цінність роботи: визначається розширенням лінійки середньомагістральних літаків підвищеної пасажиромісткості. Результати роботи можуть бути використані в авіаційній галузі та в навчальному процесі авіаційних спеціальностей.

ЛІТАК, АВАНПРОЕКТ ЛІТАКА, КОМПОНУВАННЯ ПАСАЖИРСЬКОЇ КАБІНИ, ЦЕНТРУВАННЯ ЛІТАКА, ПАСАЖИРСЬКІ ДВЕРІ, АНАЛІЗ ПРУЖНЬО ДЕФОРМОВАННОГО СТАНУ

ABSTRACT

Bachelor thesis «**Preliminary design of a long-rang aircraft with 158 passenger capacity**»

66 sheets, 22 figures, 10 tables, 10 references and 3 drawings

Object of study – design is a middle-range aircraft with 227 passenger capacity.

Subject of study – the conceptual design of the passenger entry door with stress-strain analysis of the passenger entry door.

Aim of bachelor thesis – preliminary design of a middle-range passenger aircraft, according to the prototypes, the layout of the passenger compartment, and the conceptual design of the passenger door.

Research and development methods – the design method is the analysis of prototypes and selection of the most advanced technical solutions, evaluation of geometric characteristics, the calculation of the center of gravity of the aircraft, analysis of the elastic-deformed state of the passenger door under the overpressure loads in the pressurized cabin, 3D model of passenger door design.

Novelty of the results – practical implementation is determined by the expansion of the line of medium-range aircraft with increased passenger capacity, recommendations for strengthening individual zones near the cutout for the door.

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

AIRCRAFT, PRELIMINARY DESIGN, PASSENGER CABIN LAYOUT, CENTER OF GRAVITY POSITION, PASSENGER DOOR, STRESS-STRAIN ANALYSIS

Format	№	Designation	Name	Quantity	Notes
			<u>General documents</u>		
A4	1	NAU 21 03 B 00 00 00 15 TW	Task for work	1	
	2	NAU 21 03 B 00 00 00 15	Mid-range passenger aircraft	2	
A1		Sheet 1	General view		
A1		Sheet 2	Fuselage layout		
A4	3	NAU 21 03 B 00 00 00 15 EN	Mid-range passenger aircraft	66	
			Explanatory note		
			<u>Documentation for assembly units</u>		
A3	4	NAU 21 03 B 00 00 00 15	Passenger door assembly drawing	1	

		NAU 21.03B.00.00.00.15 EN		
Done by	Borysova A.V.	Preliminary design of a mid-range aircraft with 227 passenger capacity (List of diploma work)	list	sheet	sheets
Checked by	Maslak T.P				
			402 AF 134		
St.control.	Khyzhniak S.V.				
Head of dep.	Ignatovich S.R.				

INTRODUCTION

Aviation is a very important component for the development of a global business, providing the only high-speed transport network around the world. It promotes economic growth, creates jobs and generates international trade and tourism. I'm tempted to quote the words of the great novelist Arthur Hailey from the novel “Airport”: “Aviation was the only truly successful international undertaking. It transcended ideological boundaries as well as the merely geographic. Because it was a means of intermingling diverse populations at ever-diminishing cost, it offered the most practical means to world understanding yet devised by man.”

In this regard, the need arose for aircraft for short-distance transportation, which, with a low load, allows avoiding financial losses, which in the future may increase the demand for the development of aviation trade (air transportation). To ensure the economical operation of aviation equipment with high reliability and regularity of flights in a highly competitive world market, new civil aviation aircraft are needed that meet the requirements of the international air transport organization, namely: flight safety during flight; increased passenger comfort.

The projected aircraft must also meet the following requirements:

- Comfortable salon that meets the highest requirements;
- Perform takeoff and landing on unequipped unpaved runways;
- Work in a high-temperature range;

The aim of the diploma work is to create an aircraft designed to carry 227 passengers and luggage on middle-distance routes. Also, in a special part, to make investigation of the design of the main passenger door to ensure the safety of passengers during the flight from depressurization of the cabin.

CONTENT

1. PRELIMINARY DESIGN OF MID-RANGE AIRCRAFT

1.1 Analysis of prototypes and short description of designing aircraft

The choice of the optimal design parameters of the aircraft is a multidimensional optimization problem aimed at shaping the "look" of a promising aircraft. Its layout means the whole range of flight, technical, weight, geometric, aerodynamic and economic characteristics. When informing “Airplane appearance” at the first stage, statistical methods of transfers, approximate aerodynamic and statistical dependencies are widely used. In the second stage, a complete aerodynamic calculation is used; the formulas for calculating the mass of aggregates, experimental data are refined.

The prototypes of the aircraft, accepted for design, were in the class of 204-256 passengers. Aircraft such as B737 and Lockheed L-1011 Tristar, Tu-204 will compete with the projected aircraft in this market segment. The statistics of prototypes are presented in table 1.1.

Table 1.1 - Operational-technical data of prototypes

Name and dimensions	L-1011	Tu-204	B737
Passenger's seat	256	210	204
Crew/flight attend, persons	3/4	3/4	2/4
Range of flight with $m_{k\ max}$, km	5760	2700	7130
Cruising speed, Vkm/h	890	850	938
Wing span, m	47	42	35.8
Number and type of engines	Rolls-Royce RB211-22	Rolls-Royce RB211-535E4B	CFM LEAP-1B
Maximum flight altitude, km	12.5	12.1	12.5
Cruising thrust, kN	222	192	214
Maximum take off weight, kg	211374	110750	88300

The scheme is determined by the relative position of the aircraft units, their number and shape. The aerodynamic and operational characteristics of an airplane depend on the layout of the airplane and its aerodynamic structure. Correctly selected scheme increases the safety and regularity of flights, as well as the economy of the aircraft.

1.2 Brief description of the general parts of the aircraft

The aircraft is a twin-engine, narrow-body, medium-range passenger aircraft that is 80 percent more fuel efficient than the older B727s.

The aircraft is a cantilever monoplane with a low wing and a conventional tail unit with one tail and rudder. The aircraft has good technical advances in propulsion, aerodynamics, avionics and materials.

The aircraft has some new features including a redesigned wing, under-wing engines and lighter materials, as well as a fuselage nose, cockpit layout and T-tail configuration. The aircraft can deliver the lowest fuel consumption per passenger-kilometer of any narrow-body airliner.

It has the ability to fly both transcontinental and transatlantic flights, with a published range of up to 5,000 km. The twin-engine configuration was chosen for better fuel economy. The aircraft is powered by a Rolls-Royce RB211 engine. The aircraft has a supercritical wing to reduce aerodynamic drag and a conventional tail unit with a two-seater glass cockpit.

The fuselage has an all-metal beam-stringer structure (like a semi-monocoque). This type of construction is supported by stringers and frames and is characterized by relatively thick skin. The cross-section of the fuselage has an upper protrusion. This was mainly to reduce drag. The main structural elements of the fuselage are frames, stringers, stiffeners, spars and skin.

The cockpit has space for the first and second pilots. The pilots are located in the cockpit. In flight, the first pilot is on the left, the second pilot is on the right. The following rooms and compartments are located under the sealed part of the fuselage floor: front landing gear (non-sealed), front cargo compartment, rear cargo compartment, technical compartment. The front and rear cargo compartments are sealed, each has a hatch on the right side and is equipped with a container locking system.

The aircraft is a cantilever low-wing aircraft. Each wing has a supercritical cross-section and is equipped with five-panel leading edge slats, one- and two-slotted flaps, an outboard aileron and six spoilers. The wing sweep is 25 degrees and is optimized for a Mach 0.8 cruise speed. The reduced wing sweep eliminates the need for airborne ailerons, but at the same time reduces drag on short and medium routes, during which most of the flight is spent on climb or descent.

The shape, loaded aft, provided lift over most of the upper wing surface. The more efficient wings had less drag and more fuel. The wider wingspan provided less lift resistance, while the larger wing roots increased the storage space for the landing gear and provided room for future extended versions of the aircraft.

To distribute the weight of the aircraft on the ground, the aircraft has a retractable tricycle landing gear with four wheels on each main landing gear and two wheels on the front landing gear.

The landing gear is robustly constructed of aluminum and magnesium to withstand landing forces when fully loaded. The landing gear has been specially designed to be taller than previous narrow-body aircraft in order to ensure ground clearance for stretched models. This aircraft is a subsonic airliner with durable carbon fiber brakes. The stretched aircraft has retractable support on the tail section of the fuselage to avoid damage if the tail section touches the surface of the runway during takeoff.

This tail is designed to prevent the risk of a deep stall and allow more passengers to be carried in the less tapered aft fuselage. The tail section consists of fixed surfaces (horizontal stabilizer and vertical stabilizer), which help stabilize the aircraft, and movable surfaces (rudder and elevator), which help control the aircraft during flight.

The cockpit uses six Rockwell Collins CRT screens to display on-board equipment, as well as an Electronic Flight Instrument System (EFIS) and an Engine Status Indication and Crew Alert System (EICAS). These systems enable pilots to perform monitoring tasks. An advanced flight control system automates navigation and other functions.

The cockpit has flight instruments on the dashboard and controls that allow the pilot to fly the aircraft. Electronic flight instruments consist of multi-function display, primary flight display, engine indicating and crew alerting system, flight management system and redundant instruments.

The multifunction display, usually a long narrow panel centered in front of the pilot, can be used to control course, speed, altitude, vertical speed, vertical navigation, and lateral navigation. It can also be used to turn autopilot and autothrottle on or off.

The navigation display, which may be next to the primary flight display, shows route and information about the next waypoint, wind speed and direction.

The engine status indication and the crew warning system will allow the pilot to monitor the following information: values of fuel temperature, fuel consumption, electrical system, temperature and pressure in the cockpit, control surfaces.

The passenger compartment comprises three classes. The first class includes 5 rows with a two-by-two seat configuration with sofa seats. The business class includes 5 rows with a three-by-three seat configuration with seats offset fully flat. And the economy class includes 30 rows with a three-by-three seat configuration with seats of the full-featured slimline economy. The airplane has 5 comfortable lavatories and 5 galleys with a varied delicious menu.

Each seat consists of an aviation-grade aluminum mainframe consisting of high-strength front and rear beams, machined struts with support legs, individually adjustable reclining backrests, armrests, full-width food tray table assemblies and literature pockets.

1.3 Aircraft geometry calculations and fuselage layout

The layout of the aircraft consists of drawing up the relative position of its parts and structures, as well as all types of cargo (passengers, baggage, cargo, fuel, etc.).

The choice of the configuration of the composition and parameters of the aircraft is aimed at maximum compliance with operational requirements.

1.3.1 Wing geometry calculation

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

Full wing area with extensions is:

$$S_{wfull} = \frac{m_0 * g}{P_0} = \frac{104398 * 9.8}{5984} = 170.973\ [m^2] \quad (1.1)$$

Wing span: $l_w = \sqrt{S_w * \lambda_w} = \sqrt{162.42 * 8.30} = 36.72\ [m]$ (1.2)

Relative wing extensions area is 0.050

Wing area is: $S_w = 170.973 * 0.95 = 162.42\ [m^2]$ (1.3)

Root chord is:

$$b_0 = \frac{2S_w * \eta_w}{(1+\eta_w) * l_w} = \frac{2 * 162.42 * 4.74}{(1+4.74) * 36.72} = \frac{1539.7416}{210.7728} = 7.305\ [m] \quad (1.4)$$

Tip chord is: $b_t = \frac{b_0}{\eta_w} = \frac{7.305}{4.74} = 1.541\ [m]$ (1.5)

Maximum wing width is determined in the forehead i-section and by its span it is equal:

$c_i = c_w * b_t = 0.112 * 1.541 = 0.173\ [m]$ (1.6)

On board chord for trapezoidal shaped wing is:

$$b_{ob} = b_0 * \left(1 - \frac{(\eta_w - 1) * D_f}{\eta_w * l_w}\right) = 7.305 * \left(1 - \frac{(4.74-1)*4.54}{4.74*36.72}\right) = 6.59 \text{ [m]} \qquad (1.7)$$

When choosing a wing power scheme, we determine the number of longerons and their position and the places of wing portioning.

On an airplane, longerons prevent tension and compression from bending in the fuselage. Our plane has three spars.

I used the geometrical method of mean aerodynamic chord determination (figure 1.1). Mean aerodynamic chord is equal: $b_{MAC} = 5.049\ [m]$.

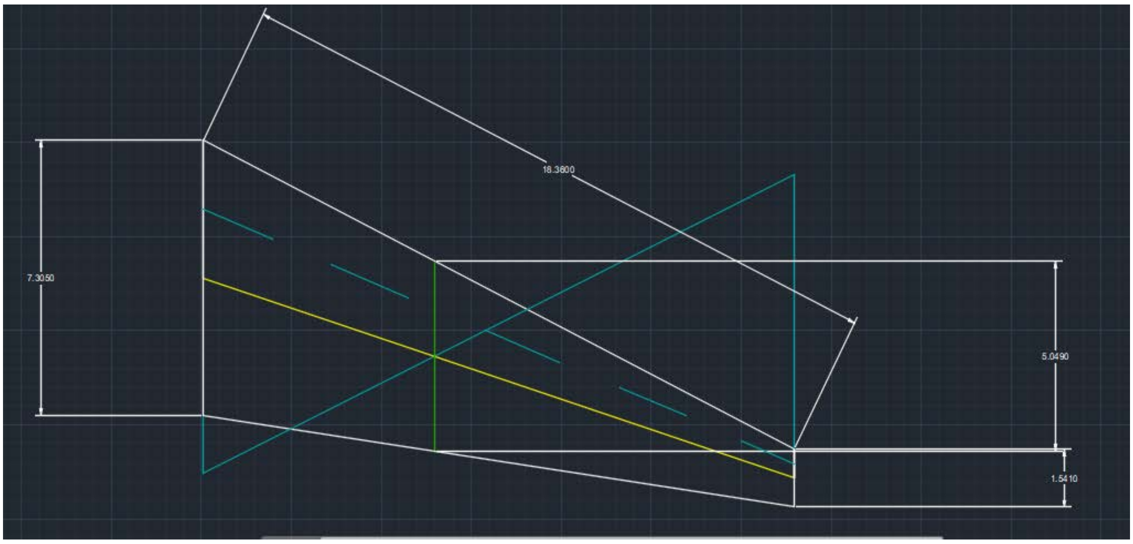


Figure 1.1 – Determination of mean aerodynamic chord

After determining the geometric characteristics of the wing, it can proceed to assess the geometry of the ailerons and high-lift devices.

Ailerons geometrical parameters are determined in next consequence:

Ailerons span: $l_{ail} = 0.38 * \frac{l_w}{2} = 0.38 * \frac{36.72}{2} = 6.977 \text{ [m]}$ (1.8)

Aileron area: $S_{ail} = 0.07 * \frac{S_w}{2} = 0.07 * \frac{162.42}{2} = 5.685\ [m]$ (1.9)

It is not necessary and convenient to raise l_{ail} and b_{ail} more than the recommended values. 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 xenon width decreases.

In aircraft of the third generation, there is a tendency towards a decrease in the relative wing span and aileron area. So l_{ail} = 0.122. In this case, we use spoilers together with ailerons for lateral control of the aircraft. Due to this, the span and area of high-lift devices can be increased, which improves the takeoff and landing characteristics of the aircraft.

Aerodynamic indemnification of the aileron.

$$S_{axinail} \le (0.25 \dots 0.28)S_{ail} = 0.26 * S_{ail} = 0.26 * 5.685 = 1.478\ [m] \tag{1.10}$$

$$S_{inaxinail} = (0.3 \dots 0.31)S_{ail} = 0.3 * S_{ail} = 0.3 * 5.685 = 1.706\ [m] \tag{1.11}$$

For two engine airplane the area of trim tab:

$$S_{tt} = (0.04..0.06)S_{ail} = 0.05 * 5.685 = 0.284\ [\mathrm{m}] \tag{1.12}$$

Range of aileron deflection are upward $\delta'_{ail} \ge 25^\circ$ and downward $\delta''_{ail} \ge 15^\circ$.

The preliminary drawing of the wing structure is represented in fig. 1.2.

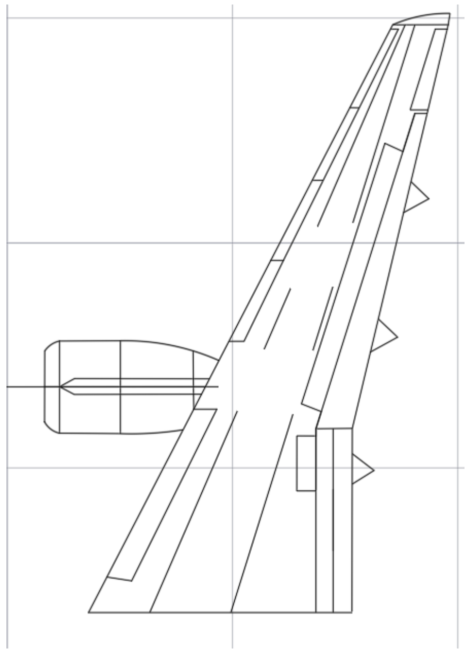


Figure 1.2 - wing structure drawing

1.3.2 Fuselage layout

During the choice of the shape and the size of fuselage cross section we need to come from the aerodynamic demands (streamlining and cross section).

Applicable to the subsonic passenger and cargo aircrafts (V < 800 km/h) wave resistance doesn’t affect it. So we need to choose from the conditions of the list values friction resistance C_{xf} and profile resistance C_{xp}.

During the transonic and subsonic flights, shape of fuselage nose part affects the value of wave resistance C_{xw}. Application of circular shape of fuselage nose part significantly diminishing its wave resistance.

For transonic airplanes fuselage nose part has to be:

$$l_{nfp} = (2..3)D_f = 2 * D_f = 2 * 4.54 = 9.08\ [m] \tag{1.13}$$

Except aerodynamic requirements consideration during the choice of cross section shape, we need to consider the strength and layout requirements.

For ensuring of the minimal weight, the most convenient fuselage cross section shape is circular cross section. In this case we have the minimal fuselage skin width. As the partial case we may use the combination of two or more vertical or horizontal series of circles.

To geometrical parameters we concern: fuselage diameter D_f; fuselage length l_f ; fuselage aspect ratio λ_f ; fuselage nose part aspect ratio λ_{np} ; tail unit aspect ratio λ_{TU} . Fuselage length is determined considering the aircraft scheme, layout and airplane center-of-gravity position peculiarities, and the conditions of landing angle of attack α_{land} ensuring.

Fuselage nose part aspect ratio is equal:

$$\lambda_{fnp} = \frac{l_{fnp}}{D_f} = \frac{9.08}{4.54} = 2 \tag{1.14}$$

Length of the fuselage rear part is equal:

$$l_{frp} = \lambda_{fnp} * D_f = 2 * 4.54 = 9.08\ [m] \tag{1.15}$$

If the tail is too short, it will add extra drag. A longer tail has low drag, but such a long tail will increase the operating mass of the empty vehicle and thus increase drag.

When determining the length of the fuselage, we strive to approach the minimum Sms amidships on the one hand and the layout requirements on the other.

For passenger and cargo aircraft, the middle part of the fuselage is determined primarily by the dimensions of the passenger compartment or cargo compartment. One of the main parameters that determine the middle section of a passenger aircraft is the height of the passenger compartment.

For mid-range airplanes we may take the height as h_1=1.8 m; passage width b_p=0.5…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:

$$H_{cab} = 1.48 + 0.17 * B_{cab} = 1.48 + 0.17 * 4.54 = 2.25\ [m] \qquad (1.16)$$

In terms of design, it is convenient to have a circular cross-section, because in this case, it will be the most durable and lightest. But for accommodating passengers and cargo, this form is not always comfortable. In most cases, one of the most suitable methods is to use a combination of the intersection of two circles or an oval fuselage shape.

The windows are arranged in one light row. The shape of the window is round, with a diameter of 300 ... 400 mm, or rectangular with rounded corners. The step of the window corresponds to the step of the partition and is 500 ... 510 mm.

For an economy cabin with a single row (3 + 3) seating arrangement, determine the appropriate cabin width.

$$B_{cabin} = 2a + n_{block} * b_{aisle} + n_{aisle} * b_{aisles} \qquad (1.17)$$

$$B_{cabin(economy\ class)=} 2 * 250 + 2 * 1430 + 500 * 2 = 4360\ [mm] \qquad (1.18)$$

$$B_{cabin(business)} = 2 * 250 + 2 * 1520 + 500 * 2 = 4540\ [\text{mm}] \qquad (1.19)$$

$$B_{cabin(first\ class)} = 250 * 2 + 2 * 1200 + 500 * 2 = 3900\ [mm] \qquad (1.20)$$

The number of rows and passenger capacity in each class is represented in table 1.2.

Table 1.2 – The split of passengers in each class

first class	business class	economy class
n_{pas}=20	n_{pas}=30	n_{pas}=177
n_{rows}=5	n_{rows}=5	n_{rows}=30

The length of passanger cabin is equal:

$$Length\ (first\ class)\ =\ 1200\ +\ (5-1)*\ 1000+300\ =$$
$$5500\ (mm) \approx \approx 7937\ [\text{mm}] \quad (1.21)$$

$$Length\ (business) =\ 1200\ +\ (5-1)*870+300\ =\ 4980\ [mm] \approx$$
$$\approx 8878\ [mm] \quad (1.22)$$

$$Length\ (economy\ first\ floor) =\ 1200\ +\ (30-1)*810+300 =$$
$$= 24990\ [mm] \quad (1.23)$$

$$L_{total} = 46300\ [\text{mm}] \quad (1.24)$$

The placement of cargo and mail compartments is usually located under the floor of the passenger compartment. The cargo accommodation depends on the center of gravity of the fuselage. Therefore, in case of incorrect placing of cargo and passengers, we can observe an emergency situation in flight.

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

The area of cargo compartment is determined:

$$S_{cargo} = \frac{M_{bag}}{0.4K} + \frac{M_{cargoandmail}}{0.6K} = \frac{20*227}{0.4*600} + \frac{15*227}{0.6*600} = 28.38\ [m^2] \quad (1.25)$$

Volume of the cargo compartment is equal:

$$V_{cargo} = \nu * n_{pass} = 0.2*227 = 45.4\ [m^3] \quad (1.26)$$

Luggage compartment design is similar to the prototype.

1.3.3 Tail unit design parameters

The selection of the correct location of the tail unit plays an important role in the task of the aerodynamic layout. When it has overloading conditions, the center of gravity of the tail must be located in front of the focus of the aircraft to ensure longitudinal stability.

Consider the determination of the geometric parameters of the tail.

Area of vertical tail unit is calculated, using this formula:

$$S_{VTU} = \frac{l_W * S_W}{L_{VTU}} * A_{VTU} = \frac{36.72*162.42}{16.41} * 0.09 = 32.71\ [m^2] \quad (1.27)$$

Area of horizontal tail unit is determined:

$$L_{HTU} = 3.25 * 5.049 = 16.41\ [m] \quad (1.28)$$

$$L_{VTU} = L_{HTU} = 16.41\ [m]$$

$$S_{HTU} = \frac{b_{MAC} * S_W}{L_{HTU}} * A_{HTU} = \frac{5.049*162.42}{16.41} * 0.7 = 34.98\ [m^2] \quad (1.29)$$

Values L_{htu} and L_{vtu} depend on several factors. First of all, their value are influenced by: the length of the nose part and tail part of the fuselage, sweptback and wing location, as well as the conditions of stability and controllability of the aircraft.

Determination of the area and direction of the elevator:

Altitude elevator area:

$$S_{el} = 0.33*S_{HTU} = 0.33*34.98 = 11.543\ [m^2] \quad (1.30)$$

Rudder area:

$$S_{rud} = 0.35*S_{VTU} = 0.35 * 32.71 = 11.449\ [m^2] \quad (1.31)$$

Select the aerodynamic balance area. If the speed of the flight M≥0.75, than

S_{abea}≈ S_{abed}=(0.18..0.2)S_e= $0.18 * 11.543 = 2.078\ [m^2]$ (1.32)

To avoid excessive rudder balance, to consider the direction elevator area:

S_{ed}=(0.2..0.22)S_{VTU}= $0.2 * 32.71 = 6.542\ [m^2]$ (1.33)

The area of altitude elevator trim tab for directional elevator of the aircraft with two engines S_{ttea}=(0.04..0.06)S_{ea}.

In the first approach we may count that $L_{HTU} \approx L_{VTU}$ and we may find it from the dependences:

Length of the horizontal tail unit can be calculated by the next formula:

$$L_{HTU} = 3.25 * b_{MAC} = 3.25 * 5.049 = 16.41\ [m] \quad (1.34)$$

Elevator balance area is equal:

$$S_{eb} = 0.276 * S_{HTU} = 0.276 * 34.98 = 9.654\ [m^2] \quad (1.35)$$

Rudder balance area is equal:

$$S_{rb} = 0.233 * S_{VTU} = 0.233 * 32.71 = 7.621\ [m^2] \quad (1.36)$$

The area of altitude elevator trim tab:

$$S_{te} = 0.08 * S_{el} = 0.08 * 11.543 = 0.92344\ [m^2] \quad (1.37)$$

Area of rudder trim tab is equal:

$$S_{tr} = 0.06 * S_{rud} = 0.06 * 6.542 = 0.39252\ [m^2] \tag{1.38}$$

Root chord of horizontal stabilizer is:

$$b_{0HTU} = \frac{2S_{HTU} * \eta_{HTU}}{(1+\eta_{HTU}) * l_{HTU}} = \frac{2*34.98*4.59}{(1+4.59)*16.41} = \frac{321.1164}{91.7319} = 3.500\ [m] \tag{1.39}$$

Tip chord of horizontal stabilizer is:

$$b_{0HTU} = \frac{b_{0HTU}}{\eta_{HTU}} = \frac{3.500}{4.59} = 0.763\ [m] \tag{1.40}$$

Root chord of vertical stabilizer is:

$$b_{0VTU} = \frac{2S_{VTU} * \eta_{VTU}}{(1+\eta_{VTU}) * l_{VTU}} = \frac{2*32.71*1.56}{(1+1.56)*16.41} = \frac{102.0552}{42.0096} = 2.429\ [m] \tag{1.41}$$

Tip chord of vertical stabilizer is:

$$b_{0VTU} = \frac{b_{0VTU}}{\eta_{VTU}} = \frac{2.429}{1.56} = 1.557\ [m] \tag{1.42}$$

Tapper ratio of horizontal and vertical TU we need to choose:

For my airplane η_{HTU}=4.59 η_{VTU}=1.56

Determination of TU chords b_{end}, b_{root}:

$$b_{end} = \frac{2S_{HTU}}{(\eta_{HTU}+1) l_{HTU}} = \frac{2*34.98}{(4.59+1)*16.41} = \frac{69.96}{91.7319} = 0.763\ [m] \tag{1.43}$$

$$b_{root} = b_{end} * \eta_{HTU} = 0.763 * 4.59 = 3.500\ [m] \quad (1.44)$$

Relative width of the profile:

For horizontal and vertical TU in the first approach, $\overline{C}_{TU} \approx 0.8\overline{C}_{w}$.

For more accurate: for transonic $\overline{C}_{TU} = 0.07$

If the stabilizations fixation is on the fin we need to use upper limit of $\overline{C}_{TU}$, to provide fixation base on the fin.

TU sweptback is taken in the range 3..5˚, and not more than wing sweptback. We do this to ensure control of the aircraft during impact stalls on the wing.

1.3.4 Landing gear design

The landing gear is tricycle type, each main support has a four-wheeled trolley, nose support has pair of wheels on the strut like in prototype B-757 (figure 1.3 and 1.4).

Figure 1.3 – Boeing -757 in flight

Figure 1.4 - Nose and main landing gears

At the initial design process stage, when the position of the center of gravity of the aircraft is not determined and there is no general view of the aircraft, only part of the landing gear parameters can be found.

According to the statistic data, the distance from center of gravity to main strut is:

$$e = 0.236 * b_{MAC} = 0.236 * 5.049 = 1.19156\ [m] \quad (1.45)$$

With a big wheel base, it is difficult to take off the front landing gear and with a short wheel base, the aircraft is subjected to overturn and subjected to strike ground during the turn.

The wheelbase of the landing gear comes from the expression:

$$B = (0.3..0.4) l_f = 0.3834 * 58.155 = 22.297\ [m] \quad (1.46)$$

The last equation means that the nose support carries 6 ... 10% of the weight of the aircraft.

The axial displacement of the front wheels will be equal to:

$$d_{ng} = B - e = 22.297 - 1.19156 = 21.105\ [m] \quad (1.47)$$

Wheel track is:

$$T = (0.7..1.2) B = 0.7801 * 22.297 = 17.394\ [m] \quad (1.48)$$

On a condition of the prevention of the side nose-over the value K should be > 2H, where H – is the distance from runway to the center of gravity.

Wheels for the landing gear are selected according to the size and running load on it from the take-off weight; for the front support we also take into account the dynamic load.

The type of tires and the pressure in it is determined by the surface of the runway to be used. We install breaks on the main wheel.

We may assume CG by height. For the low wing CG is placed relatively lower than fuselage horizontal, on the distance:

$$Y_{CG} = 0.1831 * d_f = 0.1831 * 4.54 = 0.831274$$

(1.49)

The load on the wheel is determined: K_g = 1.5...2.0 – dynamics coefficient.

Nose wheel load is equal:

$$P_{NLG} = \frac{(9.81 * e * k_g * m_0)}{(B * z)} = \frac{(9.81 * 1.19156 * 1.57604 * 104398)}{(22.297 * 2)} = \frac{1923288.07}{44.594} = 43128.853\ [N] \quad (1.50)$$

Main wheel load is equal:

$$P_{MLG} = \frac{(9.81 * (B - e) * m_0)}{(B * n * z)} = \frac{(9.81 * (22.297 - 1.19156) * 104398)}{(22.297 * 2 * 4)} = \frac{21615017.8}{178.376} = 121176.715\ [N] \quad (1.51)$$

According to the loads on nose and main struts and also speed for takeoff and landing, we choose the tires from the catalog (table 1.3).

Table 1.3 – Aviation tires for designing aircraft

Main gear				
Wheel size	Ply rating	Rated speed	Rated load	Maximum braking load
30x11.5-14.5	26	220K	26,600 Lbs	38570 Lbs

1.3.5 Engine selection and description

The power plant consists of two Rolls-Royce RB211-535C turbofan engines suspended on pylons under the wing. The Rolls-Royce RB211 is a high-bypass turbofan engine made by Rolls-Royce company (figure 1.5).

RB211-535E4 is a more reliable and quieter engine. The engines are capable of delivering of thrust from 41,030 to 59,450 lbf (182.5 to 264.4 kN). Visible differences include a mixed exhaust nozzle and a bigger fan cone. The engine also features a first for a wide chord fan, which improves efficiency, reduces noise and provides additional protection against foreign object damage.

Figure 1.5 - RB211 structure

The advantages of the Rolls-Royce RB211 engine:

- 40,000 hours of autonomous work on the wing over nine years of operation;
- 69 million flying hours;
- 1250 engines delivered;
- 20000 overhaul repairs.

1.4 Airplane centre of gravity calculation

Keeping the aircraft within weight and balance is critical to flight safety. Excessive weight reduces flight performance. During overloading, the aircraft may have a longer take-off run, lower maximum altitude, higher takeoff speed, reduction of maneuverability, longer landing roll, cruising speed decreasing, excessive weight on the nose or tail wheel.

Therefore, in my work, I calculate the center of gravity to make sure that my plane is not overloaded.

The center of gravity (CG) is the point about which the aircraft would balance if it could be paused at that point. This is the center of mass of the aircraft, or the theoretical point at which the entire weight of the aircraft is supposed to be concentrated. The CG is a three-dimensional point with longitudinal, lateral and vertical position in an airplane.

1.4.1 Trim sheet of equipped wing

There are several parameters, such as the mass of its structure, the mass of the fuel, the mass of the equipment placed in the wing, which influence the total mass of the equipped wing. The main landing gear are included in the weight of the equipped wing, regardless of where they are attached. The trim sheet for wing structure consists of equipment of systems, the mass of the wing structure, the mass of the fuel, and their center of gravity coordinates.

The recommendation was taken into account for the position of the center of mass according to the leading edge of the MAC (mean aerodynamic chord), positive aft direction or (tail direction), and negative direction from the leading edge of the MAC towards the nose of the aircraft. All wing masses of the projected aircraft are presented in Table 1.4. To calculate the coordinates of the center of gravity of the equipped wing, we use the formula:

$$X_w^{/} = \frac{\Sigma m_i^{/} x_i^{/}}{\Sigma m_i^{/}} \quad (1.52)$$

Table 1.4 - Trim sheet of equipped wing

N	Object name	Mass		C.G coordinates Xi, м	Moment of mass
		units	total mass m(i)		
1	Wing	0,09799	10229,96	0,45 C_{MAC}=2.17	22199,0132
2	Fuel system	0.0080	835,184	0,45 C_{MAC} =2.17	1812,34928
3	Flight control system, 30%	0,00177	184,78446	0,6 C_{MAC}=3.0294	559,786043

4	Electrical equipment, 10%	0,00313	326,77	0,1 C_{MAC}=0.5049	164,984022
5	Anti-ice system , 50%	0,0117	1221,46	0,1 C_{MAC}=0.5049	616,713437

Ending of the table 1.4 – Trim sheet of equipped wing

6	Hydraulic systems , 70%	0,01162	1213,10476	0,6 C_{MAC} =3.0294	3674,97956
7	Engines (-fuel system)	0,08959	9353,01682	-4,5	37412,0672
	Equipped wing without landing gear and fuel	0,2238	23364,2724	2,843	66439,8928
8	Nose landing gear (10-15%)	0,00595	621.168	X_{MLG}-B=-19,2676	11968,4166
9	Main landing gear (85-90%)	0,03370	3518,21	X_{MLG} =0,5….0,6C_{MAC} =3,0294	10658,065
10	Fuel	0,26892	28074,71	0,42….0,45 C_{MAC} =2,17	60922,1207
	Equipped wing with landing gear and fuel	0,53237	55578,36326	3,0294	149988,487

1.4.2 Trim sheet of equipped fuselage

The origin of coordinates is chosen in the projection of the fuselage nose on the horizontal axis. The X-axis shows the constructional part of the fuselage. An approximate list of objects for aircraft, the engines of which are installed under the wing, are given in Table 1.5.

The CG coordinates of the FEF are calculated using formulas:

$$X_f = \frac{\Sigma m_i^/ X_i^/}{\Sigma m_i^/}; \qquad (1.53)$$

After we found the C.G. of the fully equipped wing and fuselage, we create the moment equilibrium equation relatively in reference to the fuselage nose:

$$m_f x_f + m_w (x_{MAC} + x_w^/) = m_0 (x_{MAC} + C) \qquad (1.54)$$

From here we made the calculation of the wing MAC leading edge position relative to fuselage, which means $\boldsymbol{X_{MAC}}$ value by formula:

$$X_{MAC} = \frac{m_f x_f + m_w \cdot x_w^{/} - m_0 C}{m_0 - m_w} \quad (1.55)$$

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

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

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

The values trim sheet of the equipped fuselage is represented in table 1.5.

Table 1.5 - Trim sheet of equipped fuselage

N	Objects names	Mass		C.G coordinates Xi, м	Moment of mass
		units	total mass		
1	fuselage	0.09573	9994.021	29.0775	290601,1323
2	horizontal tail	0.00941	982.385	55	54031,1849
3	vertical tail	0.00929	969.857	53	51347,11232
4	navigation equipment	0,003	313,194	3.5	1096,179
5	radio equipment	0.0022	229.6756	1.3	298.57828
6	radar	0.0030	313.194	3.5	1096,179
7	instrument panel	0.0052	542.8696	1.3	705.73048
8	Flight control system 70%	0.00413	431.16374	29.0775	12537.1636
9	hydraulic system 30%	0.00498	519.90204	40.7085	21164.4322
10	anti ice system, 25%	0.00585	610.7283	46.524	28413.5234
	airconditioning system, 25%	0.00585	610.7283	29.0775	17758.4521
11	electrical equipment, 90%	0.02817	2940.89166	29.0775	85513,77724
12	lining and insulation	0,00284	296,1426747	29.0775	8611,088622
13	Not typical equipment	0.0028	292.3144	29,0775	8499,771966
14	Additional equipment (emergency equipment)	0,01146	1196,40108	29,0775	34788,3524
15	Operational items	0,02099	2191,31402	20	43826,2804
16	Furnishing:				
	lavatory1, 20%	0,00091	94,98860826	15,905	1510,793814
	lavatory 2, 8%	0,00091	94,98860826	27,117	2575,80609

	lavatory 3, 8%	0,00091	94,9886082	27,117	2575,80609
	lavatory 4, 8%	0,00091	94,98860826	47,965	4556,12859

Ending of the table 1.5 - Trim sheet of equipped fuselage

lavatory 5, 8%	0,00091	94,98860826	47,965	4556,128595
galley 1, 30%	0,00114	118,7349773	16,5	1959,127126
galley 2, 30%	0,00114	118,7349773	25,589	3038,309335
galley 3, 10%	0,00114	118,7349773	25,589	3038,309335
galley 4, 10%	0,00114	118,7349773	46,145	5479,025529
galley 5, 10%	0,00114	118,7349773	46,61	5534,237294
galley 6, 10%	0,00114	118,7349773	46,61	5534,237294
Passenger equipment:				
passenger seats (economy class) block of 3 passenger seats (economy class) block of 5	0,00335 0,00718	350 750	37,235 37,235	13032,25 27926,25
passenger seats (business class) *1 seat/block of 2/block of 3* 8-10kg/14-18kg/20-25kg	0,00383	400	20,126	8050,4
First class *1 seat/block of 2* 10-12kg/18-22 kg	0,003132	327	11,906	3893,262
seats of flight attendances	0,0003	32	4	128
seats of pilots	0,0003	30	2,5	75
equipped fuselage without payload	0,24574	25656,24868	47,965	754033,884
Baggage, cargo, mail nose	0,03985	4160,2603	9	37442,3427
Baggage, cargo, mail tail	0,03985	4160,2603	9	37442,3427
Passengers	0,14133	14755	28,155	415427,025
crew	0,00143	150	7,5	1125
TOTAL	0,468196 1,000566	48881,76928	47,965	1245470,594

1.4.3 Calculation of center of gravity positioning variants

The list of masses of objects for calculating the center of gravity option, given in Table 1.6, and the options for calculating the center of gravity, given in Table 1.7, are completed on the basis of both previous tables.

Table 1.6 - Calculation of C.G. positioning variants

Name	Mass, Kg	Coordinate	Mass moment
Object	m_i	C.G., M	Kg.m
equipped wing (without fuel and landing gear)	23364,3	33,0294	771707,8988
Nose landing gear (extended)	621,1681	10,7324	6666,624516
main landing gear (extended)	3518,213	33,0294	116204,4513
fuel/fuel reserve	28074,71	32,17	903163,4258
equipped fuselage (without payload)	25655,2	47,965	754033,884
passenger seats (economy class) block of 3	350	37,235	13032,25
passenger seats (economy class) block of 5	750	37,235	27926,25
passenger seats (business class)	400	20,126	8050,4
First class	327	11,906	3893,262
Baggage, cargo, mail nose	4160,26	9	37442,3427
Baggage, cargo, mail tail	4160,26	9	37442,3427
crew	150	7,5	1125
nose landing gear (retracted)	621,1681	2,5	1552,92025
main landing gear (retracted)	3518,213	25	87955,315
reserve fuel	28074,71	28	786091,8845

Table 1.7 - Airplanes C.G. position variants

№	Variants of the loading	Mass, kg	Moment of the mass, kg*m	Center of mass, m	Centering

1	take off mass (L.G. extended)	104398	3259660,513	31,2234	0,338891967
2	take off mass (L.G. retracted)	104398	3248061,895	31,1123	0,308116343

Ending of the Table 1.7 - Airplanes C.G. position variants

3	landing weight (LG extended)	91532,1	2817743,47	30,7842	0,2172
4	ferry version	81384,6	2519538,44	30,9584	0,2654
5	parking version	52159,2	1648612,85	31,6073	0,3183

Conclusions to the part

In the preliminary design process, the next results have been received:

- preliminary design of the mid-range aircraft with 227 passengers;
- the fuselage layout of the middle range aircraft with 227 passengers;
- calculation of the center of gravity of the aircraft;
- the calculation of the basic geometric parameters of the landing gear;
- selection of wheels that meet the requirements;
- nose landing gear design.

The selected design is a low-wing aircraft with two engines suspended on pylons under the wing, which makes the possibility to provide the wing aerodynamic characteristics, and reduce the passenger cabin noise level.

The installation of high-bypass turbofan engines guarantees high cruising speed, increases efficiency, reduces noise, and provides additional protection against damage from foreign objects.

2. CONCEPTUAL DESIGN OF THE PASSENGER DOOR

2.1 General requirements for the passenger doors

During aircraft designing it is necessary to solve some tasks:

- to provide required geometrical parameters of passenger door;
- to provide required strength characteristics;
- provide safety characteristics to prevent the door from being opening during flight.
- to determine if my design can withstand load 1335 N, using von Mises stress as failure criterion.

According to CS 25.783 airworthiness standards, the main requirements for a fuselage door are:

(1) Each door must have a way of protection against opening in flight as a result of mechanical failure or the failure of any individual structural member.

(2) Each door that could pose a hazard when opened must be constructed so that unlocking during flight under pressure and without pressure from a fully closed, latched, and locked state is extremely unlikely. This must be confirmed by a safety analysis.

(3) Each element of each door operating system must be designed or, if not possible, clearly and permanently marked to minimize the possibility of improper assembly and adjustment that could lead to malfunction.

(a) For doors in pressurized compartments: it should generally not be possible to open the door when the pressure drop across the compartment exceeds 13.8 kPa (2 psi). The ability to open the door will depend on the operating mechanism of the door, the handle design, its position, and the operating force. Working force in excess of 136 kg (300 pounds) is enough to prevent the door from opening. It is recognized that during the approach, takeoff, and landing, when the pressure drop in the compartment is lower, the deliberate opening is possible; however, these stages are short and all passengers are expected to be seated with their seat belts fastened.

2.2 Cutouts as the stress concentrator in the fuselage airframe

Fuselages of modern aircraft most often have a thin-walled shell, riveted by a discrete power set. Therefore, the formation of various cutouts, which are often impossible to do without in structures, leads to significant changes in the loading and operation of the power elements of the fuselage.

The most characteristic zones where cutouts are formed on the fuselage of transport aircraft are entrance, service and emergency doors, hatches, window panels in passenger compartments, hatches for luggage, cargo, technical compartments, wheel well for placing the landing gear in the retracted position (figure 2.1).

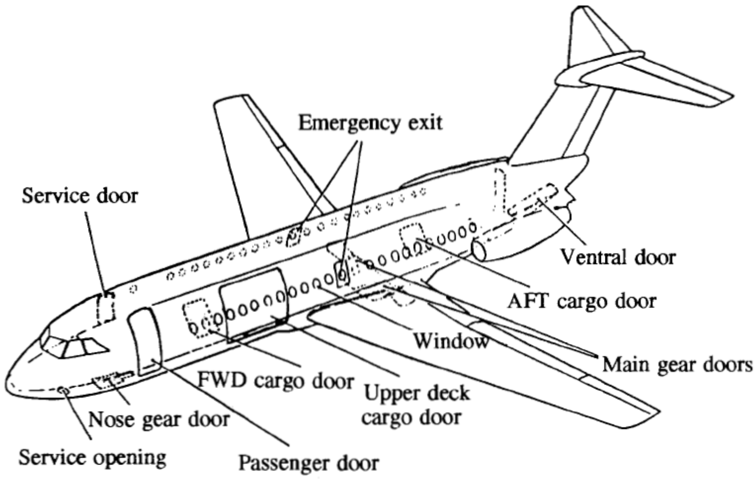


Figure 2.1 - Main cutouts of the fuselage

One of the disadvantages of the cutouts is the weakening of the strength of the fuselage shell, which, as a result, requires force compensation. For example, the installation of power hatches, which are included in the operation of the frame of the fuselage using power locks. However, if the hatches are to be opened in flight, then they are forced to perform non-power. Non-power hatches include landing gear doors and cargo hatches for transport aircraft. In the places of the cutout, the load-bearing shell of the fuselage is reinforced with the load-bearing elements of the transverse set (reinforced frames along the cutout borders) and longitudinal beams (beams and spars).

Cutouts in the fuselage structure lead to a significant redistribution of loads not only in its sections, but also in the areas adjacent to it.

Although the cutout holes are required, they should be as small as possible to meet the minimum standard requirements for commercial airplanes (figure 2.2).

Figure 2.2 - Commencial standarts of main door sizing

Depending on the small, large, short and long dimensions of the cutout, different methods of analyzing the operation of the fuselage elements in the cutout area are used.

Doors refer to large cutouts and relatively short ones (($l \leq d_f$), where l is beam length), which lead to a change in the main structure scheme and the nature of the fuselage, especially during torsion. In short cuts, shear plays a major role, and normal stresses are concomitant.

According to the requirements of CS 25.783 and on base of statistic data of the prototype about dimensions of passenger entry doors we consider the next geometry of doors for designing aircraft. The figure 2.3 shows the main dimensions of the passenger entry doors.

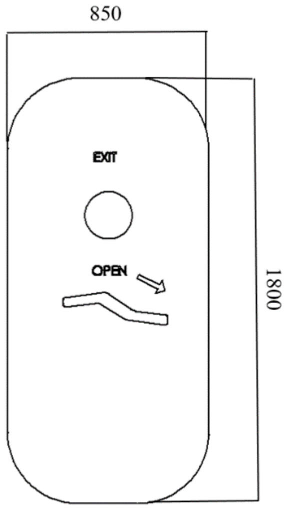


Figure 2.3 – The main dimensions of the designed door

After the choice of geometrical parameters of the door and taking into account the value of differential pressure at the altitude 10 km, we can perform the stress analysis of the passenger entry door.

One of the factors that influence the door cutout is the load caused by the pressure in the fuselage cabin. Since the door is located between the main fuselage frames, the fuselage tensile loads between the cutout are transferred to the edge frames through shear flow in the panels between primary and secondary structure elements as shown in fig. 2.4.

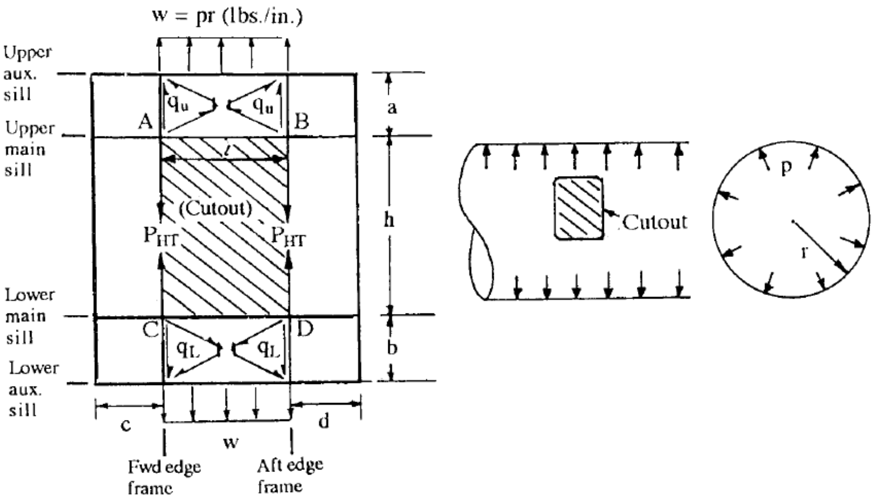


Figure 2.4 - Hoop loads during pressurization

The fuselage tensile loads between the cutout can be calculated by the next formula:

$$w = pr = 0{,}0593 * 2270 = 134.6\ \frac{N}{mm} \tag{2.1}$$

where w is a hoop tension running load, p is cabin pressurization and r is a radius.

$q_u = 0$, on the top panel but the center changes to $q_u = \frac{w\ l}{2a} = \frac{pr\ l}{2a}$ at the edge frame and it’s equal:

$$q_u = \frac{w\ l}{2a} = \frac{pr\ l}{2a} = \frac{134.6*850}{2*445} = 128.6\ \frac{N}{mm} \tag{2.2}$$

$q_L = 0$, on the bottom panel and the center changes to $q_L = \frac{w\ l}{2b} = \frac{pr\ l}{2b}$ at the edge frame and it equals:

$$P_{HT} = \frac{w\ l}{2} = \frac{134.6*850}{2} = 57205\ \frac{N}{mm^2} \tag{2.3}$$

Calculation for determining the redistributed internal load in structures surrounding the cutout for a cutout from an aluminum alloy with dimensions 1800 mm X 850 mm with a radius, r = 2270 [mm] (figure 2.5).

Considering the load conditions along the centerline of the cutting surface:

1) Constant shear flow, q_0 = 204,1 [kg]
2) The axial loads on the stringer are shown in the figure, caused by the bending moment of the fuselage (figure 2.6).
3) Cabin pressurization, p = 59,3 kPa

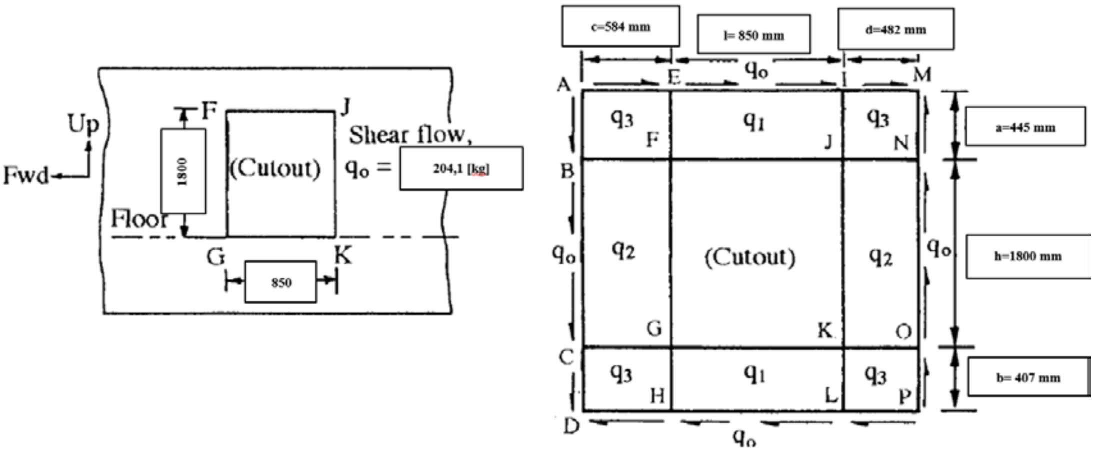


Figure 2.5 - Main dimensions of cutout and redistribution of shear flows q_1, q_2, q_3

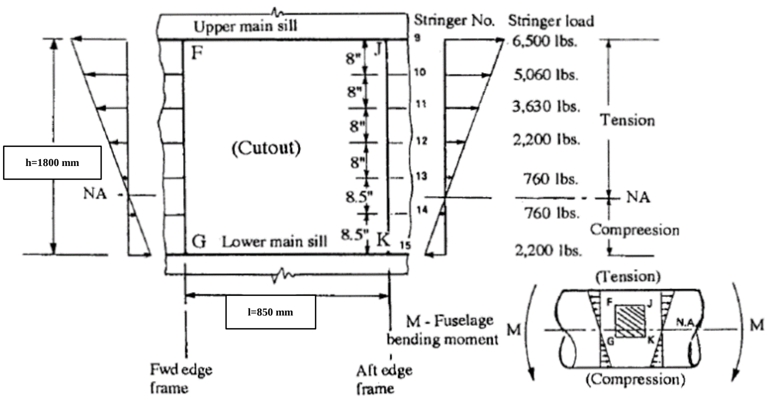


Figure 2.6 - Stringer axial load due to the fuselage bending moment

Designing process:

- Suppose there are two stringer bays between the primary and secondary sills.
- Suppose there is one frame compartment on each side of the cutout (between the edge frame and the adjacent frame).

With a shear flow q_0 = 204.1 kg. (assume that there is a constant shear flow in the cutout):

$$q_1 = \left(1 + \frac{h}{a+b}\right) q_0 = \left(1 + \frac{1800}{445+407}\right) * 204.1 = 635.3 \text{ [kg]} \quad (2.4)$$

$$q_2 = \left(1 + \frac{l}{c+d}\right) q_0 = \left(1 + \frac{850}{584+482}\right) * 204.1 = 366.8 \text{ [kg]} \quad (2.5)$$

$$q_3 = \left[\left(\frac{l}{c+d}\right)\left(\frac{h}{a+b}\right) - 1\right] q_0 = \left[\left(\frac{850}{584+482}\right)\left(\frac{1800}{445+407}\right) - 1\right] * 204.1 = 139.6 \text{ [kg]} \quad (2.6)$$

Using the results of the cutout shear flows calculation and how they are redistributed on the cutout’s zone, we can do the next conclusions: on the forward and aft edge frame the shear flow will be greater near areas that are closer to the cut zones (q_1).

2.3 Conceptual design of the passenger entry door for designing airplane

My plane has three passenger doors No 1, 2 and 4 on each side of the fuselage. Usually the doors on the left side of the fuselage are for the entry of passengers and crew. The doors on the right side of the fuselage are for service personnel (figure 2.7).

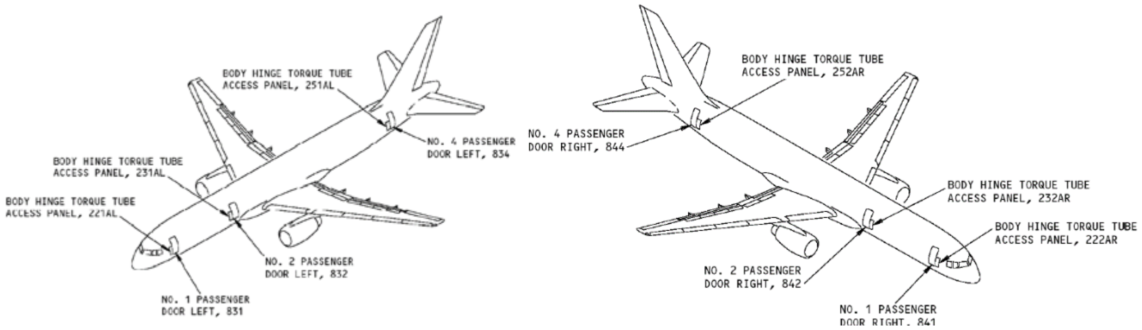


Figure 2.7 - Passenger doors № 1,2 and 4 overview

Passenger door is an assembly drawing. It consists of upper lining, mode selector lever, interior handle, exterior handle, assist handle, window, retractable door, cover (door-mounted escape system behind) (figure 2.8).

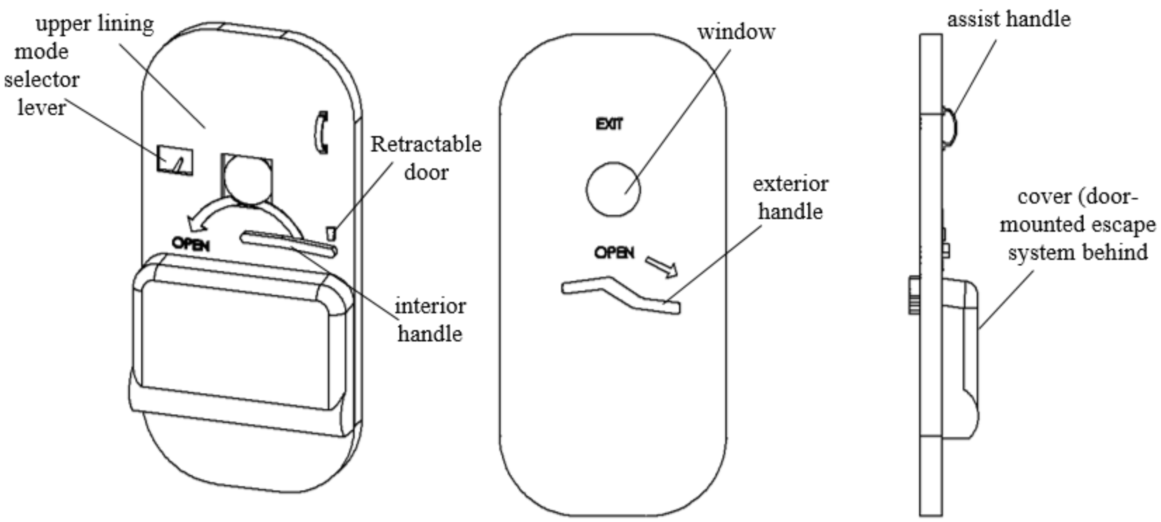


Figure 2.8 - Door construction

The passenger doors are hinged, open outward and sealed. The doors open from the inside or outside of the aircraft.

Doors have upper and lower gates that open when the doors are closed and locked. When the door is unlocked, the gate folds inward so that the door can pass through the doorway. The bolt pushers connect the bolt to the latch torque tube. The gate opens when any handle is turned to lock / unlock the door.

The doors have a torsion tube mounted on the door. The door torsion tube opens the door to the cocked position when any handle is turned to unlock the door.

The doors are locked by closed four roller latches. The latch roller cranks are mounted on the latch torsion tubes. The latch torsion tubes are connected to the handle box by latch pushers. Either handle operates the latch torque tube to lock/unlock the door.

The door has a lining that covers the mechanisms and the evacuation system. An auxiliary handle is installed on the lining which helps to close the door from the inside. A window in the lower lining provides visual access to the pressure gauge of the inflatable bladder.

The handle mechanism is installed on the door which consists of the handle box assembly and the interior and exterior operating handles (figure 2.9 and 2.10).

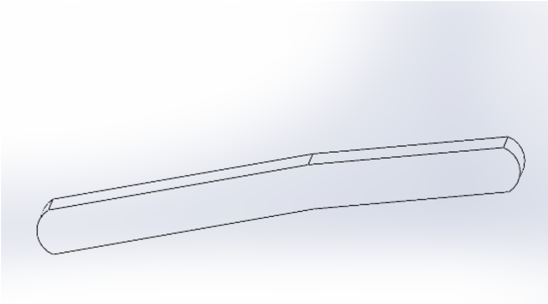


Figure 2.9 - Interior door

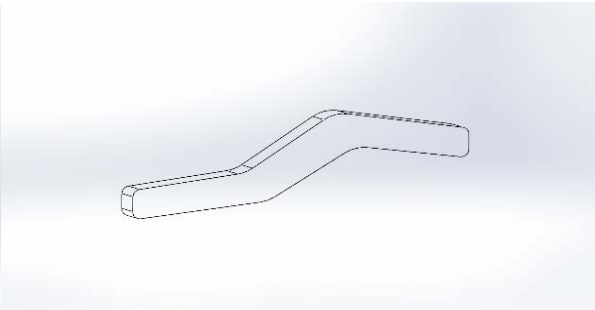


Figure 2.10 - Exterior door

The box handle mechanisms operate the latch mechanism and door cocking movement. When the door is opened with an outside handle, the handle box mechanism will automatically disarm the system. The outside handle does not work when the door is opened with the inside handle. The interior handle is connected directly to the control cam via a stub shaft. Using the inner handle will not deactivate the evacuation system.

The step-by-step mechanism for opening the door from the inside.

Before opening the door, you should disable the door emergency systems. The retractable door above the inner handle is retracted into the door trim. Then you should make the rotation of the interior handle and push the handle in order to help the door being opened.

The process of opening the door from the outside.

Firstly, you should press down on the handle latch, take the ends of the two outer handles, and pull the outer handles out of the handle recess to the fully unfolded (depressed) position. Continue to slowly rotate the outer handles no more than 30 degrees and then on the additional 60 degrees. And after finishing this rotation, turn the outer door to the closed position.

2.4 Stress analysis of the passenger door

Passenger door designing process contains several stages such as:

- Door’s construction development in accordance with requirement geometrical parameters and safety requirements;
- Experimental door’s static strength testing performed by the simulation program.

Stress-strain analysis of the passenger door is based on the linear stress analysis presented in Solidworks. Solidworks Simulation linear stress analysis enables designers and engineers to verify product quality performance and safety throughout the design creation process. Solidworks Simulation integrates easily with the design process, allowing to run linear stress analysis directly from your Solidworks CAD model resulting in fewer expesive prototypes, decreased rework and delays and more time and cost efficiency.

Using linear stress analysis, we can calculate geometry stress and strains with three basic assumptions:

- The selected part or assembly will deform under load with small rotations and displacements.
- Any product load will remain static (neglecting inertia) and remain constant over time.
- The material has a constant stress / strain ratio (Hooke's law).

For a more detailed analysis of the door strength the next data are taken for the static stress test:

- static strength of the door frame in the longitudinal direction (figure 2.11) where the inner part of the door frame was fixed (figure 2.13) and on the external part of the door frame,
- the force of 1335 N (300 pounds) was applied (figure 2.14).
- aluminum alloy 2024 was used for the testing object (table 2.1 and figure 2.12).

Using this operating force we can practically validate and ascertain that such loading on the door will prevent the door from opening during flight. Aluminum alloy 2024 is widely used in aircraft structures, especially wing and fuselage primary structure elements subjected to tension, due to its high strength and fatigue resistance.

The next figure 2.11 shows stress distribution of the door structure under the action of loads in longitudinal direction and scale of equivalent stresses at different points of the door, estimated by the von Mises formula.

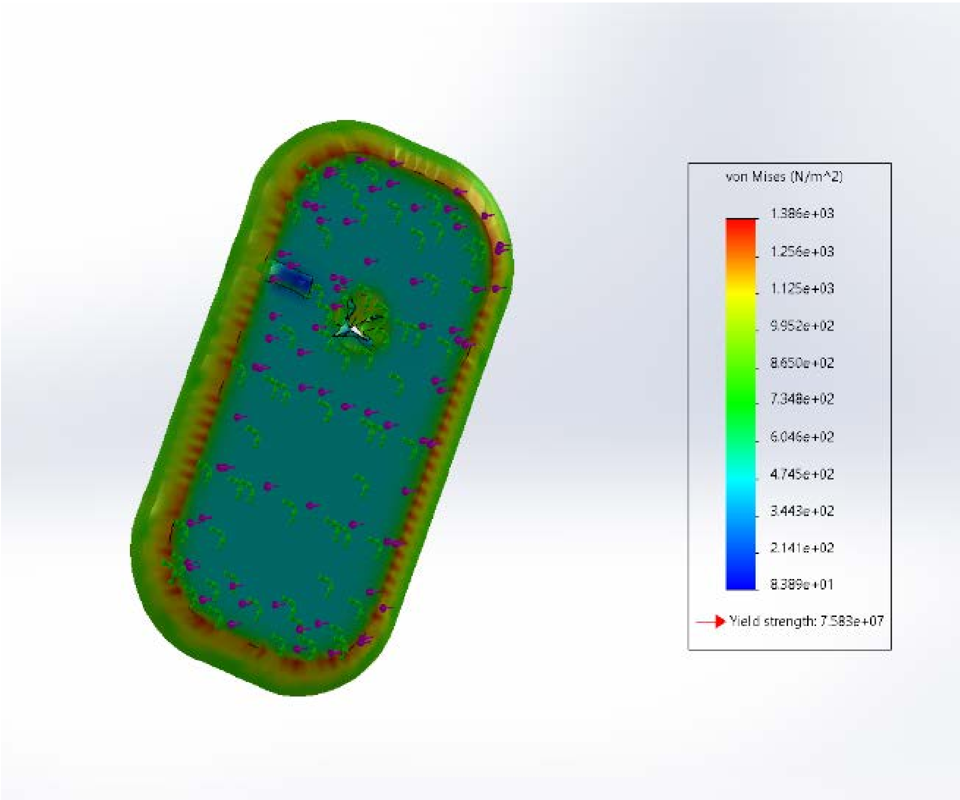
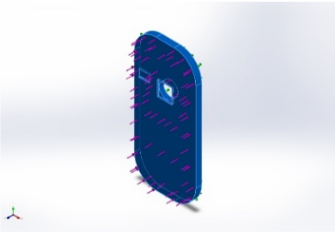


Figure 2.11 - Stress distribution of the door structure under the action of loads in longitudinal direction

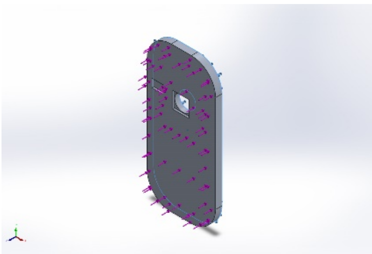
The main properties of the Aluminum alloy 2024, which is taken for the door structure, are presented in table 2.1.

Table 2.1 - Material properties

Model Reference	Properties	Components
 Figure 2.12 - material properties	Name: 2024 Alloy Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 75.82 MPa Tensile strength: 186.126 MPa Elastic modulus: 73000 MPa Poisson's ratio: 0.33 Mass density: 2,800 kg/m^3 Shear modulus: 28000 MPa Thermal expansion coefficient: $2.3\ 10^{5}$ /Kelvin	SolidBody 1 (Cut-Extrude3 - static stress test)
Curve Data:N/A		

Operating force 1335 N can be presented as the main force in the z-direction and other x and y directions.

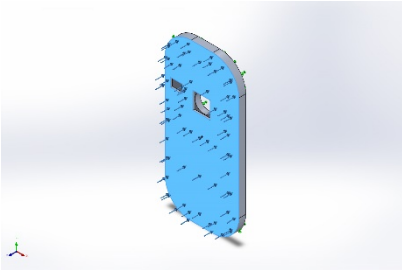
Table 2.2 - Loads and fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1	 Figure 2.13 – Fixed plane	Entities: 1 face(s) Type: Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	**2.48235e-05**	**0.000444725**	**1,335**	**1,335**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Ending the table 2.2 - Loads and fixtures

Load name	Load Image	Load Details
Force-1	 Figure 2.14 – Inner door part with normal force applying	Entities: 1 face(s) Type: Apply normal force Value: 1,335 N

The main mesh information which make possibility to obtain more detailed values for static strain analysis, are presented in table 2.3.

Table 2.3 – Mesh information

Total Nodes	14032
Total Elements	8135
Maximum Aspect Ratio	11.733
% of elements with Aspect Ratio < 3	98.7
Percentage of elements with Aspect Ratio > 10	0.0369

Resultant summing values of the x, y and z directions with operating force 1335 N are represented in table 2.4.

Table 2.4 – Resultant forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	2.48235e-05	0.000444725	1,335	1,335

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.000584864	-0.000453325	0.0038461	0.00391664

Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

The design has to be strong enough to withstand the daily stresses or it won't make it to production. So how do calculate the possibility of the structure to withstand designing loads?

For solving this problem in SolidWorks, the most common failure criteria used for static stress are von Mises.

The von Mises stress is a quantity used to determine whether a given material will deform or fail. It is basically used for ductile metals like aluminum. The von Mises yield criterion approves that if the material von Mises stress under the action of the load will be equal to or greater than the yield strength of the same material under tension, then the material will make possibility to yield.

The equation for von Mises stress is shown below.

$$\sigma = \sqrt{0.5\left[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2\right] + 3(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)} \tag{2.7}$$

where the σ is the normal stress value and the τ is the shear stress value.

Using the linear stress analysis it has been determined the von Mises stresses, resultant displacement values and equivalent strain.

Figure 2.15 and table 2.5 are represented the maximum, medium, and minimum von Mises stress values.

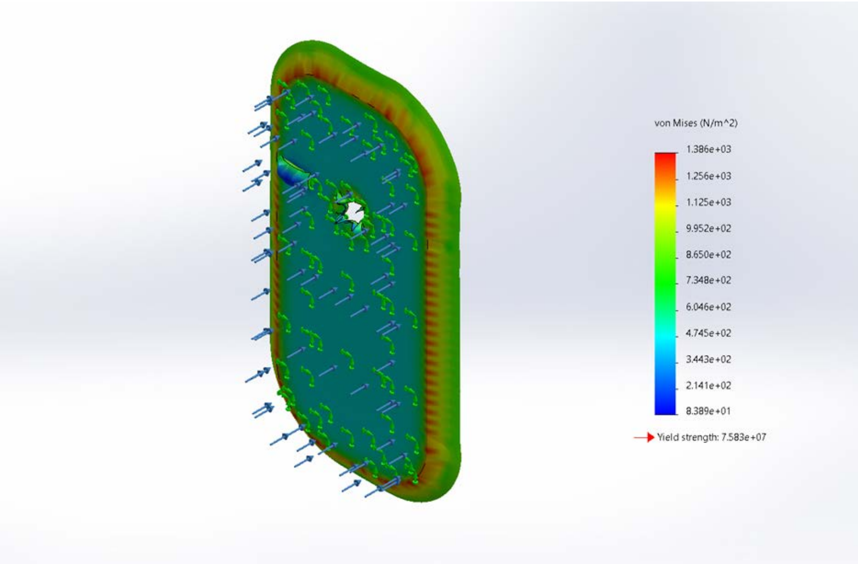


Figure 2.15 - Static stress test – von Mises stress values

Table 2.5 – The values of von Mises stress

Name	Type	Min	Max
Stress 1	von Mises Stress	0,00008389 MPa Node: 7153	0,001386 MPa Node: 13572

It can be observed that the max applied value (0,001386 MPa) is located on the edge of the door surface but this value is not critical, so it can't lead to actually strong deformation.

The minimum value (0,00008389 MPa) of von Mises stress is represented in the internal side of the door frame, where the mode selector lever takes place. And mid-values are shown along the entire length of the door excluding edges.

Having considered the effect of stress on the tested door and using the max, mid, and min values of von Mises stress, it can make the conclusion that the door was analyzed successfully on the static stress analysis and it can withstand the normal force applied.

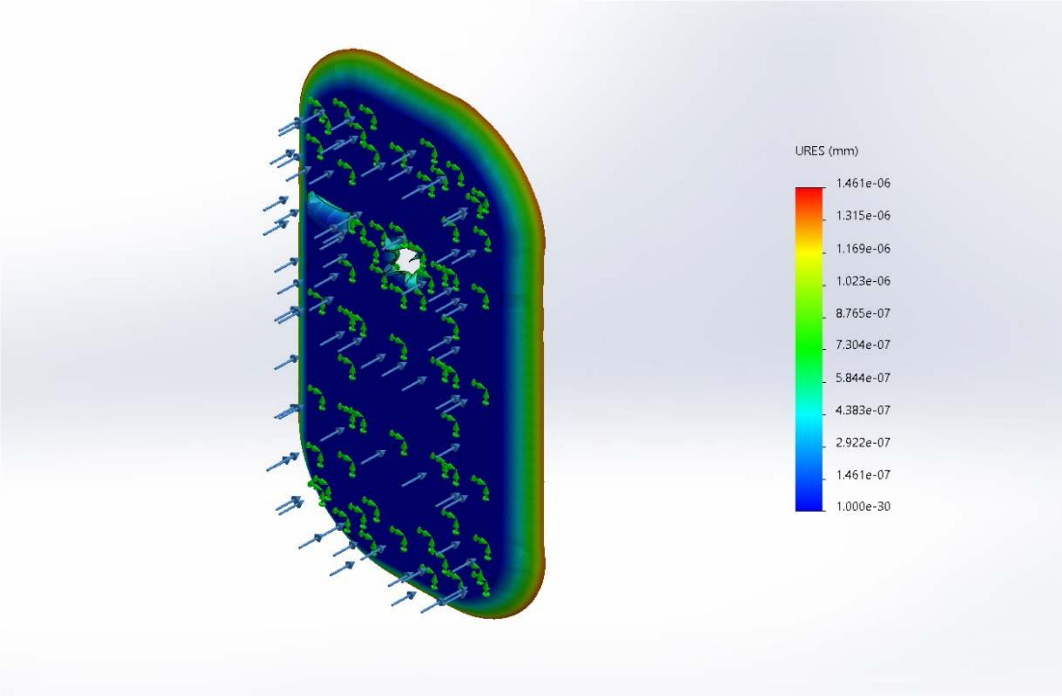


Figure 2.16 - static stress test – Resultant displacement values

Table 2.6 – Resultant displacement values

Name	Type	Min	Max
Displacement 1	URES: Resultant Displacement	0,001385 MPa Node: 8	1.46 MPa Node: 11904

Figure 2.16 and table 2.6 is shown the maximum, medium, and minimum URES: Resultant Displacement values. URES shows how many millimeters the object was displaced during linear stress analysis and is calculated by squaring each of the terms adding them and taking the square root.

$$URES = \left|\vec{U}\right| = \sqrt{(U_x)^2 + (U_y)^2 + (U_z)^2} =$$

$$= \sqrt{(U_{2.48235e-05})^2 + (U_{0.000444725})^2 + (U_{1,335})^2} = 1{,}335 \quad (2.8)$$

Where $\vec{U}$ is strain energy dencity.

The minimum value of URES displacement is located along the entire length of the door surface and in the figure 2.17 it is indicated in blue color. The middle value is represented along the edge of the part and is shown in the figure in green and yellow color. The maximum URES displacement value occupies a small area at the very edge of the part and is shown in the figure in red.

Summing up the results of URES displacement test, it can conclude that the data from this test are allowable and the max displacement value is very low.

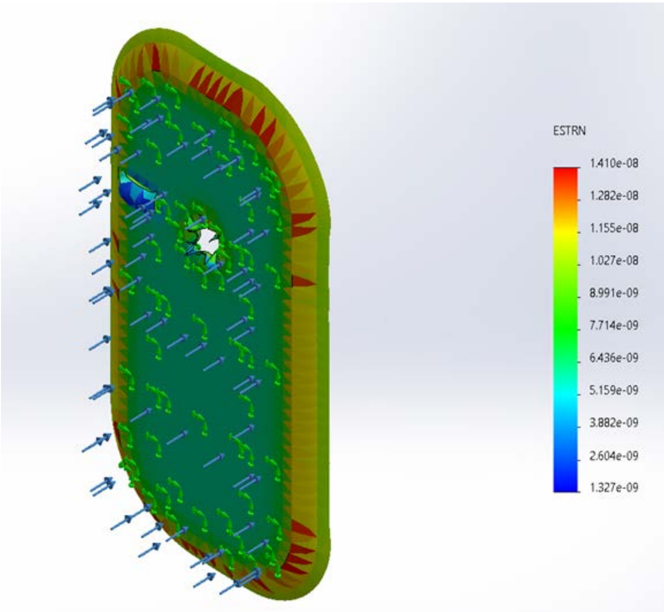


Figure 2.17 – Static stress test – Equivalent Strain values

Table 2.7 - Equivalent Strain values

Name	Type	Min	Max
Strain 1	ESTRN: Equivalent Strain	1.327 MPa Element: 2186	1.41 MPa Element: 3918

ESTRN: Equivalent Strain is a scalar quantity which also called equivalent von Mises strain is often used to describe the state of deformation in solids.

After examining the effect of the strain state of solids on the testing door and using the maximum, average, and minimum ESTRN: Equivalent Strain values (table 2.7), it can conclude that the door has successfully passed the static stress analysis and can withstand the normal applied force.

To sum up, the obtained maximum stress along the edge of the door structure is less than allowable yield strength (75.82 MPa) and allowable tensile strength (186.126 MPa) which was set as material properties by Solidworks for aluminum alloy 2024.

The stress analysis of the passenger door confirms that the most stressed sections of the cutout are the places found along the edges of the cut, and it proves the calculation for the determination of redistribution shear flow in the cutout.

Conclusions to the part

In the special part of the diploma work, the preliminary design of the main passenger door is presented. A brief description of the main parts of the fuselage door and their operational functions has been described.

The static strength tests of the experimental door were carried out using Solidworks. The material used for testing was 2024 aluminum alloy. This material has several advantages such as high strength and excellent fatigue resistance. After examining the effect of stress on the tested door and using the maximum, average and minimum von Mises stresses, URES: Resultant Displacement and ESTRN: Equivalent Strain, it can conclude that the door has successfully passed the static stress analysis and can withstand a normal force of 1335 N.

Based on calculations of shear flow in the door cutout, it was found that due to the fact that the weak areas are areas that are closer to the cut zones, these more loaded places require reinforcing elements such as the strap. A fail-safe strap (doubler) is attached to the cap of the frame edges around the cutout to give the necessary outer layer to redistribute extreme loads in addition to ensuring a fail-safe load path.

French company Latécoère was chosen as the company that will manufacture our passenger door which perfectly machining large parts, mastering part distortion, simulation crack propagation.

GENERAL CONCLUSIONS

The main task of the diploma was the preliminary design of a medium-range airplane with a larger passenger capacity than in the main prototypes: B737, Lockheed L-1011 Tristar and Tu-204.

All geometrical parameters have been calculated such as wing geometry calculation, fuselage layout, tail unit design, landing gear design. The general view of the designed plane has been conducted. It was based on the geometry calculations and on the results of centre of gravity position with correct attachment of the wing to the fuselage.

The airplane center of gravity calculation was presented in the main part, and the result of this computation showed that the aircraft has a uniformly loaded cabin without overloading.

In the special part of the bachelor's work, the preliminary design of the main passenger door was constructed. A brief description of the main parts of the fuselage door are presented. Design and sizing of the passenger enter door as a cutout in the fuselage airframe has been designed and tested for the action of differential pressure in cabin. For the structure of the door aluminum alloy 2024 was taken. The analysis carried out in Solidworks. The application of 1335 N to the door structure showed that the door frame has successfully passed the strength analysis and the material is able to withstand normal working loads. During the stress strain analysis, the von Mises method was taken for the equivalent stress evaluation. Resultant displacement and equivalent strain values were presented. Video simulation in Solidworks shows the action of von Mises stress on the door.

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Appendix A

П Р О Е К Т

С А М О Л Е Т А С Т Р Д Д

НАУ, кафедра К Л А

ПРОЕКТ diploma Расчет выполнен 15.10.2020

Исполнитель Anna Borysova Руководитель Maslak

ИСХОДНЫЕ ДАННЫЕ И ВЫБРАННЫЕ ПАРАМЕТРЫ

Количество пассажиров	227.
Количество членов экипажа	2.
Количество бортпроводников или сопровождающих	6.
Масса снаряжения и служебного груза	2191.72 кг.
Масса коммерческой нагрузки	23222.10 кг.
Крейсерская скорость полета	850. км/ч
Число "М" полета при крейсерской скорости	0.7870
Расчетная высота начала реализации полетов с крейсерской экономической скоростью	10.00 км
Дальность полета с максимальной коммерческой нагрузкой	5000. км.
Длина летной полосы аэродрома базирования	3.30 км.
Количество двигателей	2.
Оценка по статистике тяговооруженности в н/к	3.1100
Степень повышения давления	32.50
Принятая степень двухконтурности двигателя	4.50
Оптимальная степень двухконтурности двигателя	4.50
Относительная масса топлива по статистике	0.3600
Удлинение крыла	8.30
Сужение крыла	4.74
Средняя относительная толщина крыла	0.112
Стреловидность крыла по 0.25 хорд	27.0 град.
Степень механизированности крыла	1.050
Относительная площадь прикорневых наплывов	0.050
Профиль крыла - Суперкритический	
Шайбы УИТКОМБА - установлены	
Спойлеры - установлены	
Диаметр фюзеляжа	4.54 м.
Удлинение фюзеляжа	12.00
Стреловидность горизонтального оперения	30.0 град.
Стреловидность вертикального оперения	35.0 град.

Р Е З У Л Ь Т А Т Ы   Р А С Ч Е Т А

НАУ,   КАФЕДРА   "К Л А"

Значение оптимального коэффициента подъемной силы в расчетной точке крейсерского режима полета	Су	0.44790
Значение коэффициента	Сх.инд.	0.00907

ОПРЕДЕЛЕНИЕ КОЭФФИЦИЕНТА Dм = Мкрит - Мкрейс

Число Маха крейсерское	Мкрейс	0.78701
Число Маха волнового кризиса	Мкрит	0.79591
Вычисленное значение	Dм	0.00890

Значения удельных нагрузок на крыло в кПА(по полной площади):

при взлете	5.984
в середине крейсерского участка	5.160
в начале крейсерского участка	5.782

Значение коэффициента сопротивления фюзеляжа и гондол	0.00821
Значение коэфф. профиль. сопротивления крыла и оперения	0.00910
Значение коэффициента сопротивления самолета:	
в начале крейсерского режима	0.02843
в середине крейсерского режима	0.02734
Среднее значение Су при условном полете по потолкам	0.44790
Среднее крейсерское качество самолета	16.38382
Значение коэффициента Су.пос.	1.602
Значение коэффициента (при скорости сваливания) Су.пос.макс.	2.403
Значение коэффициента (при скорости сваливания) Су.взл.макс.	1.983
Значение коэффициента Су.отр.	1.447
Тяговооруженность в начале крейсерского режима	0.567
Стартовая тяговооруженность по условиям крейс. режима Ro.кр.	2.122
Стартовая тяговооруж. по условиям безопасного взлета Ro.взл.	2.767
Расчетная тяговооруженность самолета Ro	2.906
Отношение Dr = Ro.кр / Ro.взл Dr	0.767

УДЕЛЬНЫЕ РАСХОДЫ ТОПЛИВА (в кг/кН*ч):

взлетный	37.5179
крейсерский (характеристика двигателя)	59.9968
средний крейсерский при заданной дальности полета	63.7136

ОТНОСИТЕЛЬНЫЕ МАССЫ ТОПЛИВА:

аэронавигационный запас	0.03500
расходуемая масса топлива	0.23391

ЗНАЧЕНИЯ ОТНОСИТЕЛЬНЫХ МАСС ОСНОВНЫХ ГРУПП:

крыла	0.09799
горизонтального оперения	0.00940
вертикального оперения	0.00928
шасси	0.03964
силовой установки	0.08959
фюзеляжа	0.09572
оборудования и управления	0.13451
дополнительного оснащения	0.01146
служебной нагрузки	0.02099
топлива при Lрасч.	0.26891
коммерческой нагрузки	0.22244

Взлетная масса самолета "М.о" = 104398. кГ.

Потребная взлетная тяга одного двигателя 151.66 kH

Относительная масса высотного оборудования и противообледенительной системы самолета	0.0234
Относительная масса пассажирского оборудования (или оборудования кабин грузового самолета)	0.0175
Относительная масса декоративной обшивки и ТЗИ	0.0058
Относительная масса бытового (или грузового) оборудования	0.0173
Относительная масса управления	0.0059
Относительная масса гидросистем	0.0166
Относительная масса электрооборудования	0.0313
Относительная масса локационного оборудования	0.0030
Относительная масса навигационного оборудования	0.0044
Относительная масса радиосвязного оборудования	0.0022
Относительная масса приборного оборудования	0.0052
Относительная масса топливной системы (входит в массу "СУ")	0.0080
Дополнительное оснащение:	
Относительная масса контейнерного оборудования	0.0087
Относительная масса нетипичного оборудования	0.0028

[встроенные системы диагностики и контроля параметров, дополнительное оснащение салонов и др.]

ХАРАКТЕРИСТИКИ ВЗЛЕТНОЙ ДИСТАНЦИИ

Скорость отрыва самолета	292.68 км/ч
Ускорение при разбеге	2.21 м/с*с
Длина разбега самолета	1489. м.
Дистанция набора безопасной высоты	578. м.
Взлетная дистанция	2067. м.

ХАРАКТЕРИСТИКИ ВЗЛЕТНОЙ ДИСТАНЦИИ
ПРОДОЛЖЕННОГО ВЗЛЕТА

Скорость принятия решения	278.05 км/ч
Среднее ускорение при продолженном взлете на мокрой ВПП	0.23 м/с*с

Длина разбега при продолженном взлете на мокрой ВПП	2724.85 м.
Взлетная дистанция продолженного взлета	3303.23 м.
Потребная длина летной полосы по условиям прерванного взлета	3423.06 м.

ХАРАКТЕРИСТИКИ ПОСАДОЧНОЙ ДИСТАНЦИИ

Максимальная посадочная масса самолета	84726. кг.
Время снижения с высоты эшелона до высоты полета по кругу	19.9 мин.
Дистанция снижения	47.00 км.
Скорость захода на посадку	269.48 км/ч.
Средняя вертикальная скорость снижения	2.14 м/с
Дистанция воздушного участка	525. м.
Посадочная скорость	254.48 км/ч.
Длина пробега	871. м.
Посадочная дистанция	1396. м.
Потребная длина летной полосы (ВПП + КПБ) для основного аэродрома	2331. м.
Потребная длина летной полосы для запасного аэродрома	1982. м.

ПОКАЗАТЕЛИ ЭФФЕКТИВНОСТИ САМОЛЕТА

Отношение массы снаряженного самолета к массе коммерческой нагрузки	2.2349
Масса пустого снаряженного с-та приход. на 1 пассажира	228.63 кг/пас.
Относительная производительность по полной нагрузке	417.64 км/ч
Производительность с-та при макс. коммерч. Нагрузке	18781.0 кг*км/ч
Средний часовой расход топлива	3949.879 кг/ч
Средний километровый расход топлива	4.88 кг/км
Средний расход топлива на тоннокилометр	210.313 г/(т*км)
Средний расход топлива на пассажирокилометр	18.9838 г/(пас.*км)
Ориентировочная оценка приведен. затрат на тоннокилометр	0.2517 $/(т*км)

INITIAL DATA AND SELECTED PARAMETERS

Passenger Number	227.
Flight Crew Number	2.
Flight Attendant or Load Master Number	6.
Mass of Operational Items	2191.72 kg
Payload Mass	23222.10 kg
Cruising Speed	850. Km/h
Cruising Mach Number	0.7870
Design Altitude	10.00 km
Flight Range with Maximum Payload	5000. km
Runway Length for the Base Aerodrome	3.30 km
Engine Number	2.
Thrust-to-weight Ratio in N/kg	3.1100
Pressure Ratio	32.50
Assumed Bypass Ratio	4.50
Optimal Bypass Ratio	4.50
Fuel-to-weight Ratio	0.3600
Aspect Ratio	8.30
Taper Ratio	4.74
Mean Thickness Ratio	0.112
Wing Sweepback at Quarter Chord	27.0 degree
High-lift Device Coefficient	1.050
Relative Area of Wing Extensions	0.050
Wing Airfoil Type	Supercritical
Winglets	Installed
Spoilers	Installed

Fuselage Diameter	3.54 m.
Finess Ratio	12.00
Horizontal Tail Sweep Angle	30.0 degree
Vertical Tail Sweep Angle	35.0 degree

I. CALCULATION RESULTS

Optimal Lift Coefficient in the Design Cruising Flight Point	
Cy	0.44790
Induce Drag Coefficient	
Cx.ind	0.00907

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

Cruising Mach Number	Mcruise	0.78701
Wave Drag Mach Number	Mcrit	0.79591
Calculated Parameter D_m	Dm	0.00890

Wing Loading in kPa (for Gross Wing Area):	
At Takeoff	5.984
At Middle of Cruising Flight	5.160
At the Beginning of Cruising Flight	5.782
Drag Coefficient of the Fuselage and Nacelles	0.00821
Drag Coefficient of the Wing and Tail Unit	0.00910
Drag Coefficient of the Airplane:	
At the Beginning of Cruising Flight	0.02843
At Middle of Cruising Flight	0.02734
Mean Lift Coefficient for the Ceiling Flight	0.44790
Mean Lift-to-drag Ratio	16.38382
Landing Lift Coefficient	1.602
Landing Lift Coefficient (at Stall Speed)	2.403
Takeoff Lift Coefficient (at Stall Speed)	1.983
Lift-off Lift Coefficient	1.447
Thrust-to-weight Ratio at the Beginning of Cruising Flight	0.567
Start Thrust-to-weight Ratio for Cruising Flight	2.122
Start Thrust-to-weight Ratio for Safe Takeoff	2.767
Design Thrust-to-weight Ratio Ro	2.906
Ratio $D_r = R_{cruise} / R_{takeoff}$ Dr	0.767

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

Takeoff	37.5179
Cruising Flight	59.9968
Mean cruising for Given Range	63.7136

FUEL WEIGHT FRACTIONS:

Fuel Reserve	0.03500
Block Fuel	0.23391

WEIGHT FRACTIONS FOR PRINCIPAL ITEMS:

Wing	0.09799
Horizontal Tail	0.00941
Vertical Tail	0.00929
Landing Gear	0.03965
Power Plant	0.08959
Fuselage	0.09573
Equipment and Flight Control	0.13451
Additional Equipment	0.01146
Operational Items	0.02099
Fuel	0.26892
Payload	0.22246

Airplane Takeoff Weight	"M.o" =	104398. Kg.
Takeoff Thrust Required of the Engine		151.66 kN

Air Conditioning and Anti-icing Equipment Weight Fraction	0.0234
Passenger Equipment Weight Fraction (or Cargo Cabin Equipment)	0.0175
Interior Panels and Thermal/Acoustic Blanketing Weight Fraction	0.0058
Furnishing Equipment Weight Fraction	0.0173
Flight Control Weight Fraction	0.0059
Hydraulic System Weight Fraction	0.0166
Electrical Equipment Weight Fraction	0.0313
Radar Weight Fraction	0.0030
Navigation Equipment Weight Fraction	0.0044
Radio Communication Equipment Weight Fraction	0.0022
Instrument Equipment Weight Fraction	0.0052
Fuel System Weight Fraction	0.0080
Additional Equipment:	
Equipment for Container Loading	0.0000
No typical Equipment Weight Fraction (Build-in Test Equipment for Fault Diagnosis, Additional Equipment of Passenger Cabin)	0.0028

II. TAKEOFF DISTANCE PARAMETERS

III. Airplane Lift-off Speed	292.68 km/h
Acceleration during Takeoff Run	2.21 m/s*s
Airplane Takeoff Run Distance	1489. m.
Airborne Takeoff Distance	578. m.
Takeoff Distance	2067. m.

IV. CONTINUED TAKEOFF DISTANCE PARAMETERS

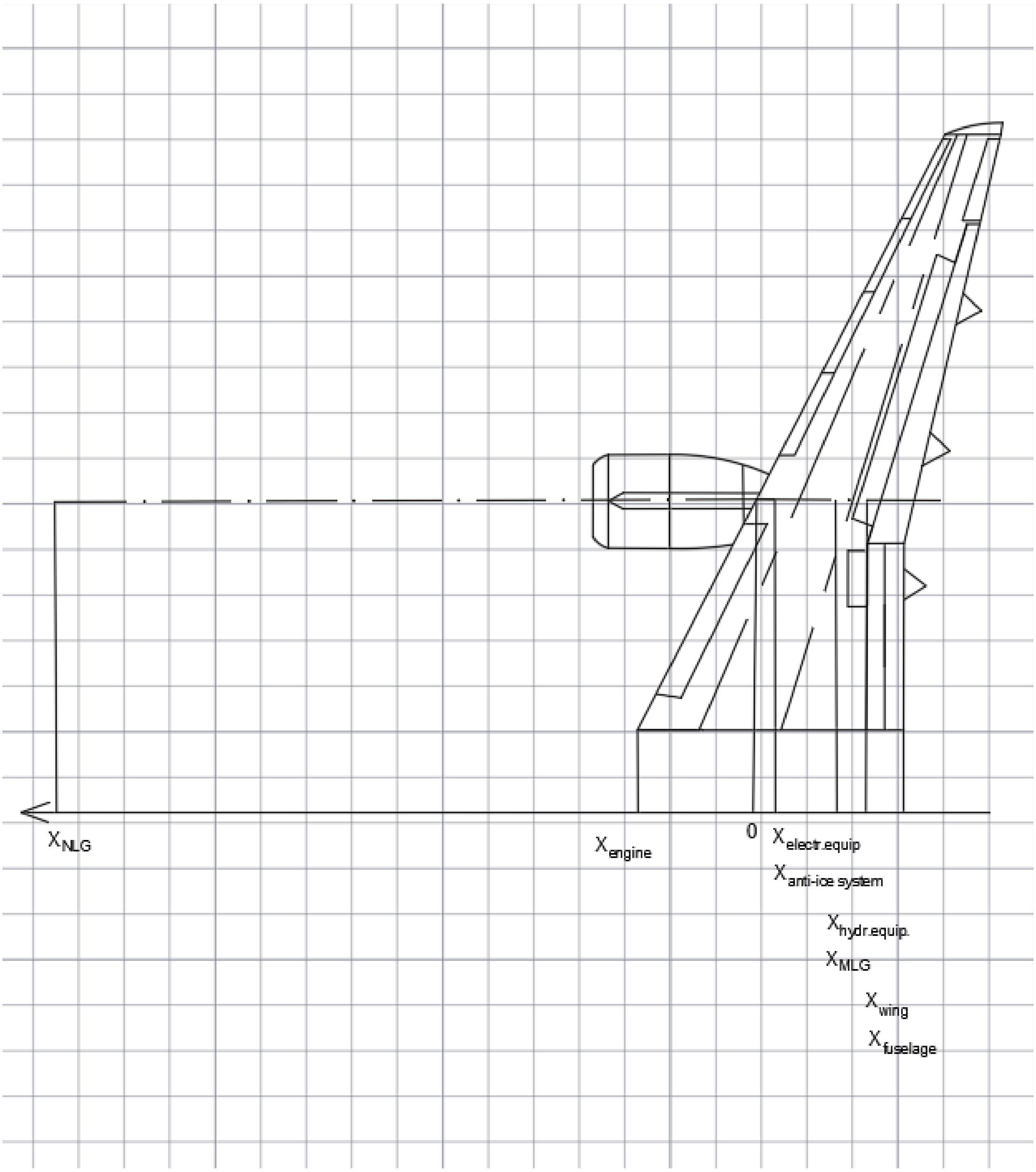
V. Decision Speed	278.05 km/h
Mean Acceleration for Continued Takeoff on Wet Runway	0.23 m/s*s
Takeoff Run Distance for Continued Takeoff on Wet Runway	2724.85 m.
Continued Takeoff Distance	3303.23 m.
Runway Length Required for Rejected Takeoff	3423.06 m.

VI. LANDING DISTANCE PARAMETERS

VII. Airplane Maximum Landing Weight	84726. kg.
Time for Descent from Flight Level till Aerodrome Traffic Circuit Flight	19.9 min.
Descent Distance	47.00 km.
Approach Speed	269.48 km/h.
Mean Vertical Speed	2.14 m/s
Airborne Landing Distance	525. m.
Landing Speed	254.48 km/h.
Landing run distance	871. m.
Landing Distance	1396. m.
Runway Length Required for Regular Aerodrome	2331. m.
Runway Length Required for Alternate Aerodrome	1982. m.

Appendix B

Centering drawing of the wing



Appendix C

Centering drawing of the fuselage