МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
Кафедра конструкції літальних апаратів

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
д.т.н., проф.
______________Сергій ІГНАТОВИЧ
«_____»____________2022 рік

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

Тема: «Аванпроект середньо-магістрального пасажирського літака місткістю до 150 осіб»

Виконав: ____________ **Антон ДЕМЧЕНКО**

Керівник: канд.техн.наук, доцент ____________**Володимир КРАСНОПОЛЬСЬКИЙ**

Нормоконтролер: канд.техн.наук, доцент ____________ **Сергій ХИЖНЯК**

Київ 2022

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

PERMISSION TO DEFEND
Head of the department
Dr.Sc., Professor
__________ Sergiy IGNATOVYCH
«___»________2022

BACHALOR DEGREE THESIS
ON SPECIALTY
"AVIATION AND AEROSPACE TECHNOLOGIES "

Topic: «Preliminary design of a mid-range passenger aircraft with up to 150 passenger capacity»

Prepared by: ___________ **Anton DEMCHENKO**

Supervisor: PhD, associate professor ___________ **Volodymyr KRASNOPOLSKY**

Standard controller: PhD, associate professor ___________ **Sergiy KHIZHNYAK**

Kyiv 2022

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty

Department of Aircraft Design

Academic Degree «Bachelor»

Specialty: 134 "Aviation and Aerospace Technologies"

APPROVED BY
Head of the Department
Dr.Sc., Professor
__________Sergiy IGNATOVYCH
«___»_________2022

TASK
for the bachelor degree thesis

DEMCHENKO ANTON

1. Topic: «Preliminary design of a mid-range passenger aircraft with up to 150 passenger capacity» confirmed by Rector's order № 489/ст from 10.05.2022.

2. Thesis term: from 23.05.2022 to 19.06.2022.

3. Initial data: cruise speed V_{cr}=850 kmph, flight range L=4200 km, operating altitude H_{op}=11 km, 150 passengers.

4. Contents of the explanatory note: analysis of prototype aircraft; selection of design parameters; analysis of reliability indicators of prototype aircraft, calculation of aircraft masses; determination of the basic geometrical parameters of the aircraft; development of aircraft layout; calculation of aircraft alignment; development of a design of knots of a sample of ailerons, procedure of service of ailerons.

5. List of obligatory graphic material: general view of the aircraft (A1×1); aircraft layout

(A1×2); aileron attachment points (A1×1).

Graphic (illustrative) material is made using AutoCAD.

6. Thesis schedule:

Task	Time limits	Done
Task receiving, processing of statistical data	23.05.2022–28.05.2022	
Aircraft geometry calculation	28.05.2022–31.05.2022	
Aircraft layout	31.05.2022–03.06.2022	
Aircraft centering	03.06.2022–05.06.2022	
Graphical design of the parts	05.06.2022–12.06.2022	
Completion of the explanation note	12.06.2022–14.06.2022	
Defense of diploma work	14.06.2022–19.06.2022	

7. Date: 23.05.2022

Supervisor ____________ Volodymyr KRASNOPOLSKY

Student ____________ Anton DEMCHENKO

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Аерокосмічний факультет

Кафедра конструкції літальних апаратів

Освітній ступінь «Бакалавр»

Спеціальність 134 «Авіаційна та ракетно-космічна техніка»

Освітньо-професійна програма «Обладнання повітряних суден»

ЗАТВЕРДЖУЮ
Завідувач кафедри, д.т.н, проф.
___________Сергій ІГНАТОВИЧ
«_____»______________2022 р.

ЗАВДАННЯ
на виконання дипломної роботи студента

АНТОН ДЕМЧЕНКО

1. Тема роботи: «Аванпроект середньо-магістрального пасажирського літака місткістю до 150 осіб», затверджена наказом ректора № 489/ст від 10 травня 2022 року.

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

3. Вихідні дані до роботи: максимальна кількість пасажирів 150, дальність польоту з максимальним комерційним навантаженням 4200 км, крейсерська швидкість польоту 850 км/год, висота польоту 11 км.

4. Зміст пояснювальної записки: аналіз літаків-прототипів; вибір проектних властивостей; аналіз показників надійності літаків-прототипів; розрахунок мас літака; визначення основних геометричних параметрів літака; розробка компонування літака; розрахунок центрування літака; розробка конструкції вузлів навішування елеронів, процедура обслуговування елеронів.

5. Перелік обов'язкового графічного матеріалу: загальний вигляд літака (А1 × 1); компонування літака (А1 × 2); вузли навішування елеронів (А1 × 1). Графічний (ілюстративний) матеріал виконаний за допомогою AutoCAD.

6. Календарний план-графік:

Завдання	Термін виконання	Відмітка про виконання
Вибір вихідних даних, аналіз льотно-технічних характеристик літаків-прототипів	23.05.2022–28.05.2022	
Вибір та розрахунок параметрів проєктованого літака	28.05.2022–31.05.2022	
Виконання компонування літака	31.05.2022–03.06.2022	
Розрахунок центрування літака	03.06.2022–05.06.2022	
Виконання креслень літака	05.06.2022–12.06.2022	
Оформлення пояснювальної записки та графічної частини роботи	12.06.2022–14.06.2022	

Захист дипломної роботи	14.06.2022–19.06.2022	

7. Дата видачі завдання: 23.05.2022 рік

Керівник дипломної роботи ___________ Володимир КРАСНОПОЛЬСЬКИЙ

Завдання прийняв до виконання ___________ Антон ДЕМЧЕНКО

Format	№	Designation	Name	Quantity	Notes
			General documents		
A4	1	NAU 22 01 00 00 00 83 TW	Task for work	1	
	2	NAU 22 01 00 00 00 83	Mid-range passenger aircraft	2	
A1		Sheet 1	General view		
A2		Sheet 2	Fuselage layout		
A4	3	NAU 22 01 00 00 00 83 EN	Mid-range passenger aircraft	29	
			Explanatory note		
A1	4	NAU 22 01 00 00 00 83 AD	Clamp drawing	1	

			NAU 22 01 00 00 00 83 EN			
Done by	Demchenko A.O.		Preliminary design of a mid-range passenger aircraft with up to 150 passenger capacity	list	sheet	sheets
Checked by	Krasnopolsky V.S.				12	63
				134 AKF 402		
St.control.	Khyzhniak S.V.					
Head of dep.	Ignatovych S.R.					

CONTENT

Department of Aircraft Design				NAU 22 01 00 00 00 83 EN			
Performed by	Demchenko A.O.			Content	Letter	Sheet	Sheets
Supervisor	Krasnopolsky V.S.						
					402 AF 134		
Stand.contr.	Khizhnyak S.V.						
Head of dep.	Ignatovych S.R.						

Introduction

Ailerons (roll bars) are aerodynamic controls symmetrically located on the trailing edge of the wing panels in normal and ducking airplanes. Ailerons are designed primarily to control the roll angle of the aircraft, and ailerons are deflected differentially, that is, in opposite directions, when deflecting aileron changes curvature of the wing profile and the angle of attack. The lifting force of the half-wing with aileron down increases, while the lifting force of the half-wing with aileron up decreases and forces occur which tend to rotate the aircraft around its longitudinal axis (symmetry axis).

The increase in lifting force in a half wing with a dropped aileron is greater than the decrease in lifting force in a half wing with a raised aileron, as the angle of attack α increases in a half wing with a dropped aileron, then at a large angle of attack close to the critical one, when a deflection down the aileron may not increase the lifting force of the half wing, but its sharp decrease. This is because when the aileron is lowered, the angle of attack of the given half wing will become larger than the critical angle, beyond which it is known that the lift decreases sharply and therefore the lift decreases. In order to avoid such cases, aileron control is made differential, in which the rising aileron is deflected by a larger angle than the descending one.

Ailerons are located on the tail of the wing. Each half-wing has an inner and outer aileron. It is important to design ailerons and aileron mounts that can face all the challenges to which the medium-range aircraft is subjected.

INITIAL DATA AND SELECTED PARAMETERS

Passenger Number 150
Flight Crew Number 2
Flight Attendant or Load Master Number 4
Mass of Operational Items 1423.26 kg
Payload Mass 18468.00 kg

Cruising Speed 850 km/h
Cruising Mach Number 0.7966
Design Altitude 11km
Flight Range with Maximum Payload 4200 km
Runway Length for the Base Aerodrome 2.55km

Engine Number 2
Thrust-to-weight Ratio in N/kg 2.8
Pressure Ratio 35
Assumed Bypass Ratio 5.5
Optimal Bypass Ratio 5.5
Fuel-to-weight Ratio 0.21

Aspect Ratio 9.0
Taper Ratio 2.8
Mean Thickness Ratio 0.110
Wing Sweepback at Quarter Chord 28.0 degrees
High-lift Device Coefficient 1.050
Relative Area of Wing Extensions 0.140
Wing Airfoil Type Supercritical
Winglets Yes
Spoilers Yes

Fuselage Diameter 3.9 m
Finess Ratio 9.2
Horizontal Tail Sweep Angle 30 degree
Vertical Tail Sweep Angle 35 degree

CALCULATION RESULTS

Optimal Lift Coefficient in the Design Cruising Flight Point 0.40504

Induce Drag Coefficient 0.00901

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

Cruising Mach Number 0.79660
Wave Drag Mach Number 0.80734
Calculated Parameter Dm 0.1074

Wing Loading in kPa (for Gross Wing Area):
At Takeoff 4.705
At Middle of Cruising Flight 4.094
At the Beginning of Cruising Flight 4.531

Drag Coefficient of the Fuselage and Nacelles 0.008
Drag Coefficient of the Wing and Tail Unit 0.009

Drag Coefficient of the Airplane:
At the Beginning of Cruising Flight 0.02784
At Middle of Cruising Flight 0.02688
Mean Lift Coefficient for the Ceiling Flight 0.40504

Mean Lift-to-drag Ratio 15.06886

Landing Lift Coefficient 1.605

Landing Lift Coefficient (at Stall Speed) 2.407
Takeoff Lift Coefficient (at Stall Speed) 1.986
Lift-off Lift Coefficient 1.449
Thrust-to-weight Ratio at the Beginning of Cruising Flight 0.621
Start Thrust-to-weight Ratio for Cruising Flight 2.616
Start Thrust-to-weight Ratio for Safe Takeoff 2.748

Design Thrust-to-weight Ratio 2.858

Ratio $D_r = R_{cruise} / R_{takeoff}$ D_r= 0.952

SPECIFIC FUEL CONSUMPTIONS (in kg/kN*h):
Takeoff 34.8553
Cruising Flight 57.4325
Mean cruising for Given Range 59.2800

FUEL WEIGHT FRACTIONS:
Fuel Reserve 0.03541
Block Fuel 0.21368

WEIGHT FRACTIONS FOR PRINCIPAL ITEMS:
Wing 0.13310
Horizontal Tail 0.01168
Vertical Tail 0.01151
Landing Gear 0.04053
Power Plant 0.08855
Fuselage 0.08397
Equipment and Flight Control 0.012914
Additional Equipment 0.01284
Operational Items 0.01715
Fuel 0.24908
Payload 0.22253

Airplane Takeoff Weight 82992 kg
Takeoff Thrust Required of the Engine 118.59 kN

Air Conditioning and Anti-icing Equipment Weight Fraction 0.0222
Passenger Equipment Weight Fraction 0.0158
(or Cargo Cabin Equipment)
Interior Panels and Thermal/Acoustic Blanketing Weight Fraction 0.0068
Furnishing Equipment Weight Fraction 0.0125
Flight Control Weight Fraction 0.0060
Hydraulic System Weight Fraction 0.0167
Electrical Equipment Weight Fraction 0.0322
Radar Weight Fraction 0.0031
Navigation Equipment Weight Fraction 0.0047
Radio Communication Equipment Weight Fraction 0.0023
Instrument Equipment Weight Fraction 0.0054
Fuel System Weight Fraction 0.0073

Additional Equipment:
Equipment for Container Loading 0.0078
No typical Equipment Weight Fraction 0.0050
(Build-in Test Equipment for Fault Diagnosis,
Additional Equipment of Passenger Cabin)

TAKEOFF DISTANCE PARAMETERS
Airplane Lift-off Speed 259.33 km/h
Acceleration during Takeoff Run 21.16 m/s^2
Airplane Takeoff Run Distance 1195 m
Airborne Takeoff Distance 578 m
Takeoff Distance 1774 m

CONTINUED TAKEOFF DISTANCE PARAMETERS

Decision Speed 246.36 km/h
Mean Acceleration for Continued Takeoff on Wet Runway 0.21 m/s^2
Takeoff Run Distance for Continued Takeoff on Wet Runway 2256.56 m
Continued Takeoff Distance 2834.94 m
Runway Length Required for Rejected Takeoff 2938.15 m

LANDING DISTANCE PARAMETERS

Airplane Maximum Landing Weight 69050 kg
Time for Descent from Flight Level till Aerodrome Traffic Circuit Flight 21.8 min
Descent Distance 51.38 km
Approach Speed 241.75 km/h
Mean Vertical Speed 1.96 m/s
Airborne Landing Distance 514 m
Landing Speed 226.75 km/h
Landing run distance 707 m
Landing Distance 1220 m
Runway Length Required for Regular Aerodrome 2038 m
Runway Length Required for Alternate Aerodrome 1733 m

ECONOMICAL EFFICIENCY

THESE PARAMETERS ARE NOT USED IN THE PROJECT

РЕФЕРАТ

Пояснювальна записка до дипломної роботи «Аванпроект середньо-магістрального пасажирського літака місткістю до 150 осіб»:

63 с., 8 рис., 9 табл., 12 літературних джерел.

Об'єкт проектування – пасажирський середньомагістральний літак.

Мета роботи: спроектувати середньо-магістральний пасажирський літак місткістю до 150 осіб.

Методи проектування: порівняльний аналіз літаків-прототипів, аналіз льотно-технічних характеристик літаків, розрахунок мас літака, розрахунок геометричних параметрів літака, обробка літературних джерел.

Результати дипломної роботи рекомендується використовувати для магістерських робіт та у навчальному процесі.

АВАНПРОЕКТ, СЕРЕДНЕМАГІСТРАЛЬНИЙ ЛІТАК, КОМПОНОВКА, ЦЕНТРОВКА, ПОВЕРХНІ УПРАВЛІННЯ, ЕЛЕРОНИ, ВУЗЛИ НАВІСКИ

ABSTRACT

Bachelor thesis "Preliminary design of a medium-range passenger aircraft with up to 150 passenger capacity" consists of:

63 sheets, 8 figures, 9 tables, 12 literature sources.

Object of study – medium-range passenger aircraft.

Purpose of the work: to design a medium-range passenger aircraft with a capacity of up to 150 people.

Design methods: comparative analysis of prototype aircraft, analysis of flight characteristics of aircraft, calculation of aircraft masses, calculation of geometric parameters of the aircraft, processing of literature sources.

It is recommended to use the results of the thesis for master's theses and in the educational process.

AVANPROJECT, MEDIUM-RANGE AIRCRAFT, LAYOUT, CENTERING, SURFACE CONTROLS, AIRCRAFT, MOUNTING UNITS

1 Analysis of prototype aircraft, selection of design parameters of the designed aircraft

1.1 The purpose of the designed aircraft and the analysis of prototype aircraft

The designed aircraft is designed for commercial transportation of passengers, baggage, cargo and mail on medium-haul lines in the field of civil aviation. The project is based on the following basic requirements:

- ensuring the necessary cost-effectiveness of transportation;
- ensuring maximum safety of passenger transportation;
- ensuring the necessary living conditions for passengers during the flight and maximum comfort;
- ensuring the possibility of performing flights in conditions of poor visibility and in instrument flight conditions.

During the design process, the necessary scope for fulfilling these requirements must comply with the standards defined in the Aviation Regulations and ICAO documents.

The main prototypes for the designed aircraft were the Boeing 737-200, Boeing 727, Tu-154M aircraft, the operational and technical characteristics of which are presented in Table 1.1, and the geometric characteristics in Table 1.2. To determine the initial data of the designed aircraft, we analyze the data of prototype aircraft.

Table 1.1 - Operational and technical data of prototype aircraft

Characteristics names	Prototypes		
	B-737-200	B-727	Tu-154M
Maxinum payload, kg	19000	17400	18000
Crew / flight attendance	2	3	4
Passengers	130	189	164
Wing load , kg/m^2	586	631	555
Average cruise quality	-	-	-
Flight range, km	3100	2780	3500
The altitude of flight, m	9,5-11	9,5-11	9,5-11
Vcr. Max, km/h	950	982	880
Vcr. econ., km/h	850	883	850
Thrust-to-weight ratio , kN/kg	0,00285	0,0022	0,003
Number of engines and their type	2 turbofan engines	3 turbofan engines	3 turbofan engines
Takeoff thrust , kN	119,23	70,3	110
Cruise thrust , kN	30,2	21	27,5
Specific fuel consumption at takeoff, kg/h	-	65,8	58
Specific fuel consumption at cruise speed, kg/h	-	85	65
Pressure ratio	30	18	19
Bypass ratio	5	1,05	2,4
Home airfield class	C	B	B
Landing speed, km/h	230	220	230
Takeoff speed, km/h	250	250	270
Takeoff run , m	1200	1200	1200
Run length , m	1000	1000	1000
Takeoff distance, m	2682	3033	2080
Landing distance, m	1420	1494	2300
Takeoff weight, kg	52390	95000	100000
Landing weight, kg	46720	72575	80000

Table 1.2. Geometrical parameters of prototype aircrafts

Characteristics	Prototypes		
	B-737-200	B-727	Tu-154M
Wingspan, m	28,35	32,92	37,5
Wing Sweepback at Quarter Chord	35	32	35
Mean Geometrical chord, m	4,6	5,7	4,6
Aspect Ratio	8,99	7,2	7,83
Taper ratio	2,94	2,91	3,48
Fuselage length, m	30,48	41,51	42,33
Fuselage Diameter, m	3,88	4	3,8
Fuselage elongation, m	7,61	10,38	11,15
Passenger cabin length, m	20,88	28,25	32,5
Passenger width, m	3,52	3,56	3,51
Cabin height, m	2,18	2,11	2,8
Cabin volume, m^3	131,3	188,3	218
Luggage compartment volume, m^3	24,76	43,1	
Seats placement, m	0,762	0,762	
Passage width, m	0,46		
Horizontal tail span, m	10,97	10,9	13,4
Horizontal Tail Sweepback at Quarter Chord	35	35	38
HT relative area	0,322	0,232	0,201
HT elongation	4,18	3,4	4,41
HT narrowing	2,75	2,67	1,83
Relative area of rudder	-	0,253	0,208
Vertical tail height, m	6,3	5,1	5,65
Vertical Tail Sweepback at Quarter Chord	45	55	54
Relative area of Vertical tail	0,233	0,219	0,157
VT elongation	-	0,79	1
VT narrowing	-		
Relative area of VT	-	0,185	0,233
Chassis base, m	11,4	19,28	18,92
Chassis track, m	5,26	5,72	11,5

1.2 Selection of parameters and justification of the aircraft design

The layout of the aircraft is determined by the relative position of the units, their number and shape. Its aerodynamic and technical and operational properties depend on the scheme and aerodynamic layout of the aircraft.

A well-chosen scheme improves the safety and regularity of flights, and the economic efficiency of the aircraft. The choice of the scheme of the designed aircraft is preceded by the study and analysis of the schemes of aircraft taken as prototypes. Justification is subject to:

I. the location of the wing and tail relative to the fuselage, as well as the choice of their shape

II. location of engines, their number and type, if it is not specified in the design assignment;

III. type and location of landing gear.

Justification of the aircraft scheme should be carried out on the basis of information given in the literature.

The designed aircraft is made according to the low-wing scheme.

This aircraft is designed according to the normal scheme, that is, the GO is located behind the wing. This scheme has become widespread on civil aviation aircraft.

The main advantages of the normal scheme are:

• the possibility of effective use of wing mechanization;

• easy balancing of the aircraft with extended flaps;

• Placing the empennage behind the wing, which makes it possible to make the nose of the fuselage shorter, which not only improves the pilot's view, but also reduces the area of the aircraft, since the shortened nose of the fuselage causes a smaller destabilizing ground moment;

• the possibility of reducing the areas of VT and HT, since the arms of VT and HT are much larger than those of other schemes.

Naturally, the considered scheme is also characterized by disadvantages:

• HT creates negative lift in almost all flight modes, which leads to a decrease in the lift of the entire aircraft;

• HT operates in a disturbed air flow behind the wing.

When choosing a place for installing engines, the features of the general layout of the aircraft, operating conditions and ensuring the maximum engine life are taken into account, to obtain the lowest frontal resistance of the power plant, to minimize air loss in the air intake. In this scheme of the aircraft, the engines are placed under the wing on pylons, which provides the above advantages. One of the disadvantages of this arrangement of engines on the wing is that as the bypass ratio increases, the diameter of the engine increases. Therefore, when arranging engines under the wing, it is necessary to increase the height of the chassis to ensure a rated distance from the engine nacelle bypass to the ground.

The designed aircraft has a tricycle landing gear with a nose support. Such a scheme of the landing gear provides the aircraft with high stability during the takeoff run and run, good controllability when moving on the ground and effective wheel braking due to the lack of a cowling.

Aircraft on which such a chassis scheme is implemented have a horizontal position of the longitudinal axis, both in the parking lot and when moving along the airfield, therefore, for pilots, visibility from the cockpit is improved and comfort for passengers is increased. A three-bearing scheme of the landing gear with a nose leg can greatly simplify the take-off and landing of an aircraft in a crosswind, if all three legs of the landing gear are made self-orienting and equipped with self-oscillation dampers.

The most important task in the design of an aircraft is the maximum reduction in fuel consumption, both due to the aerodynamic layout, and due to the rational choice of the type of power plant.

At this stage, the number of engines is set according to statistical data, taking into account the degree of pressure increase of the prototype aircraft engines. For the designed aircraft, we accept the following parameters of two turbojet engines with a thrust-to-weight ratio of 2.8 N/kg with a pressure ratio of 35 and a bypass ratio of 5.5.

Among the main parameters of the wing are the type of profile and its relative thickness, sweep χ of 0.25 chords, elongation λ, narrowing η, transverse angle V of the wing and the specific load on the wing P, the shape of the wing in plan.

Wing aspect ratio is a parameter that significantly affects the value of inductive resistance and the maximum quality of the wing and aircraft. In addition, λ affects the weight and stiffness characteristics of the wing structure.

Subsonic transport aircraft have wings with zero and low sweep. The elongation of such wings lies in a fairly wide range λ= 8...12, and large values of the elongation, as a rule, refer to large-sized aircraft with a large estimated flight range. Increased wing aspect ratios are sometimes chosen for aircraft with a short flight range in connection with the desire to improve their takeoff and landing characteristics.

For an approximate estimate of the wing elongation of the designed aircraft, the following formula can be used: λ=10.5•cos2χ. The resulting aspect ratio value is corrected based on data on the wing parameters of analogue aircraft.

The narrowing of the wing has a contradictory effect on the aerodynamic, weight and stiffness characteristics of the wing.

An increase in taper η favorably affects the distribution of external loads, stiffness and weight characteristics of the wing. It also leads to an increase in the construction height and volume of the central part of the wing, which facilitates the placement of fuel and various units, and an increase in the wing area served by mechanization significantly increases its efficiency.

However, the increase in narrowing also has negative sides. The main one is the tendency of a wing with a large narrowing to end stall with a simultaneous decrease in the effectiveness of the ailerons. In connection with the indicated circumstances, the narrowing of the straight wings of subsonic aircraft is usually filled with a small amount and amounts to η = 2...2.5, which provides close to the minimum induced drag of the wing and high values of CYmax post.

The angle of the transverse V wing, as is known, serves as a means of ensuring the degree of lateral stability of the aircraft. Its value and sign depend in an eye way on the aircraft layout, and for aircraft with swept wings, it also depends on the sweep angle. For straight wings of subsonic aircraft, the values of the transverse angle V lie in the range from + 5°...7°- for a low-wing scheme, to -1°...-2°- for a high-wing aircraft.

Sweep increases the lateral stability of the wing and therefore swept wings should be given a negative transverse V.

However, layout and other requirements (for example, landing with a roll) can lead to a positive V swept wing. This will entail the installation of automatic yaw dampers in the control system and will require some increase in the vertical tail area.

We select the following main parameters of the wing:

$\lambda = 9$; $\eta = 2,8$; $C = 0.11$; $\chi_{0.25} = 28°$.

The aerodynamic and weight characteristics of the fuselage significantly depend on its shape and dimensions, which are determined by such geometric parameters as the cross-sectional shape, aspect ratio λf and fuselage diameter Df. It should be noted that the elongation and length of the fuselage are specified during the subsequent layout of the aircraft from the conditions of providing the necessary volumes for accommodating the crew, passengers and cargo, as well as acceptable arms LVO and LGO of the horizontal and vertical tail of the aircraft. The elongation of the fuselage and its parts (nose λ_{nch} and tail λ_{hch}) are selected based on considerations of aerodynamics and fuselage weight.

When choosing L_f of the designed aircraft, one can be guided by the following statistical data of modern aircraft.

At $M_k < 0,7$:

$\Lambda_f = 7...8$ - passenger aircraft MVL and BMS;

$\Lambda_f = 8...9$ – medium-range aircraft.

При $M_k < 0,9$:

$\Lambda_f = 9...10$ - large passenger aircraft;

$\Lambda_f = 10...13$ - long range aircraft.

Their final values are specified when performing the layout drawing of the fuselage. The fuselage diameter of passenger aircraft is determined mainly by the number of passenger seats placed in one transverse row, and the cabin class, which determines the width of the seats with armrests, as well as the width and number of aisles.

A preliminary estimate of the fuselage diameter should be made based on statistical data and prototype parameters.

We select the following main parameters of the fuselage:

$$D_f = 3{,}9 \text{ m}, \lambda_f = 9{,}2.$$

1.3 Brief description of the designed aircraft

The projected aircraft is a cantilever low-wing aircraft with two turbojet engines placed in nacelles under the wing, with a tricycle chassis with a nose support.

The wing of the aircraft is trapezoidal, of high elongation with a supercritical wing profile. The leading edge of the wing is equipped with retractable slats; three-slotted flaps and slotted ailerons with axial compensation are installed on the trailing edge.

1.3.1 Description of the fuselage

The fuselage is round in cross section.

Plumage - single tail with a fixed stabilizer installed in the tail section of the aircraft.

The fuselage of the aircraft is an all-metal semi-monocoque with a longitudinal set of stringers and beams, a transverse set of frames and working skin with reinforcements in the areas of cutouts for hatch openings, doors, glazing and aircraft equipment.

The fuselage is conditionally divided along the length into the nose, middle and tail sections.

In the forward part of the fuselage is the cockpit, which is separated by a partition from the passenger cabin. In front of the cockpit there is a lantern with vents, in the upper part there is an emergency hatch. The entrance to the cockpit is carried out from the passenger cabin by stairs, through the hatch in the floor of the cockpit. Under the floor of the cockpit there is a technical compartment, in which there is a niche for the front landing gear, closed by doors, and a shaft with a lower emergency hatch that opens outwards.

Glazing of the cockpit canopy provides sufficient visibility for pilots in flight. Windshields and their mounts can withstand a normal bird strike.

1.3.2 Description of the wing

The projected aircraft is made according to the low-wing scheme, which is the least advantageous from the point of view of aerodynamics and layout, because in the wing-fuselage connection zone the smoothness of the flow is disturbed and additional resistance arises through the interference of the wing-fuselage system. This drawback can be significantly reduced by setting fairings, providing a diffuser effect. The need to maintain a higher position of the fuselage is associated in low-wing aircraft with ensuring that the wingtip does not touch the runway surface during a roll landing, as well as ensuring the safe operation of the control system when placing engines on the wing.

The low-wing scheme is most often used for passenger aircraft, because it provides greater safety than other options for emergency landing on soil and water. When landing on the ground with the landing gear retracted, the wing absorbs the impact energy, protecting the passenger cabin. When landing on the water, the aircraft is immersed in water up to the wing, which gives the fuselage additional buoyancy and simplifies the organization of work related to the evacuation of passengers.

An important advantage of the low-wing scheme is the smallest mass of the structure, because the main landing gear is most often associated with the wing and their dimensions and weight are less than in the high-wing.

The low-wing scheme includes: carrying caisson; docking points with the fuselage; docking points with consoles.

The composition of each cantilever part includes: the middle part of the wing (MPW); detachable part of the wing (DPW); non-removable nasal compartment; non-removable tail compartment; wingtip; wing box - two-spar design, made of high-strength aluminum alloy, fittings docking with the fuselage; low-wing docking points with MPW; mounting brackets for propulsion systems; docking points of MPW with DPW; flap attachment points; slat attachment points; interceptor attachment points; aileron attachment points; end brackets.

The low-wing caisson is a built-in fuel side. Fasteners connecting the components of the structure provide tightness. The system of sealing covers for inspection manholes is made easily replaceable and does not require additional use of sealant.

The composition of the middle part of the wing includes: power caissons; fixed nasal compartments; non-removable tail compartments.

Power caisson includes: front and rear spars; top and bottom panels of monolithic construction; typical, power and sealed ribs of a beam structure; mounting brackets for power plants; hinge points of movable surfaces; docking points with a low-wing aircraft and DPW.

The structure of the low-wing structure includes: upper and lower panels of a monolithic structure, consisting of a set of elements; front and rear spars; beam structure ribs; fuselage docking fittings; docking points with MPW. Access inside the MPW caisson is carried out through the upper removable panels. Manholes and manholes are made on the upper panels of the caisson tanks for maintenance of the fuel system units.

The structure of each removable part of the wing includes: bearing power caisson; non-removable nasal compartment; non-removable tail compartment; removable ending.

Power caisson includes: front and rear spars; three upper and three lower panels of a monolithic design; standard, power and sealed ribs; slat attachment points; aileron attachment points; ending hinge brackets.

The composition of the bow compartment includes: the design of a fixed bow;

deflected toe design; controllable slat design.

The design of the fixed nose parts is made to exclude the accumulation of moisture and has appropriate drainage holes.

The gaps between the slats and the nose are sealed.

The design of the slat section and the deflected toe is prefabricated and riveted.

The nose part of the wing is of a prefabricated structure, it consists of three-layer construction panels with the use of PCM (Polymer Composite materials) and longitudinal beams.

The composition of the tail section of the wing includes: tail section of the wing; flaps; ailerons; spoilers.

The tail part of the wing consists of upper and lower panels of a three-layer construction using PCM.

Flaps - sliding, double-slotted. The flap section includes the main and tail links. The ailerons are made in the form of a prefabricated structure using PCM. Interceptors are made of PCM.

1.3.3 Description of the plumage

The plumage of the aircraft is made cantilever, in the classical scheme with one centrally located keel.

The stabilizer is made mainly of composite materials (CM) and consists of: a fully molded CM frame with external three-layer panels; nose and tail parts; endings; metal prestabilizer of prefabricated-riveted design.

Elevator (Elevator) is made two-link, two-section and made mainly of KM. There are removable covers for the RV suspension units for structural inspection, repair and maintenance, as well as replacement of all mechanical parts.

The keel is made mainly of composite materials and consists of: a one-piece molded frame of their KM with external three-layer panels; bow; tail section; equipment fairing.

The junction of the keel with the fuselage is made by means of fittings, which are made by machining aluminum alloy stampings.

The rudder (RN) is made of two-link, three-section (lower, upper and middle sections) and is made mainly of KM. Removable covers are made for the LV hinge points for structural inspection, repair and maintenance, as well as replacement of all mechanical parts.

The plumage is provided with structural protection against reduction or loss of strength when exposed to the environment in all expected operating conditions, and there are ventilation and drainage in all compartments.

1.3.4 Chassis description

The designed aircraft has a tricycle landing gear with a nose support. Such a scheme of the landing gear provides the aircraft with high stability during the takeoff run and run, good controllability when moving on the ground and effective wheel braking due to the lack of a cowling. Aircraft on which such a chassis scheme is implemented have a horizontal position of the longitudinal axis, both in the parking lot and when moving along the airfield, therefore, for pilots, visibility from the cockpit is improved and comfort for passengers is increased.

The landing gear of the aircraft consists of two underwing main pylons and one front pylon.

Each main support consists of shock struts, on which four wheels with hydraulic disc brakes and a wheel cooling system are mounted.

The main supports are retracted into the fairing compartments in the direction of the plane of symmetry of the aircraft. When harvesting, the wheels of the main supports are automatically braked.

The nose support consists of a controlled shock strut with two non-brake wheels. The front support is retracted into the front compartment of the fuselage landing gear.

The aircraft landing gear is equipped with the following systems: retraction and release; wheel braking; temperature control and wheel cooling control; steering wheels of the front support.

The landing gear retraction and extension system provides:

- cleaning and landing gear in the main mode;

- release of racks and closing of landing gear compartment doors in standby mode;

- release of racks and closing of shutters of the main support by means of hydromechanical system;

- issuing a signal to the braking system to brake the wheels

the main supports when retracting the landing gear (post-takeoff braking);

- cleaning with an incomplete release and release with an incomplete cleaning cycle.

The design of the system provides for blocking the cleaning of the chassis on the ground with compressed shock absorbers.

The retraction and release of the nose gear and the main landing gear are carried out from separate electro-hydraulic subsystems.

In case of failure of the main and reserve landing gear extension modes, the following are provided: hydromechanical extension of the main landing gear struts, mechanical extension of the nose gear, mechanical closing of the doors of the main landing gear compartments.

The wheel braking system is designed for parking, taxiing and aircraft run braking. The wheel braking system is of an electrohydromechanical type, with continuous-discrete anti-skid automatics and a built-in automatic performance monitoring system.

2 Aircraft layout and alignment

2.1 Aircraft layout

The layout process combines the following interrelated processes: aerodynamic, volumetric-mass and structural-force layouts, and centering calculations.
Fulfillment of each of these conditions is aimed at obtaining high economic efficiency of the aircraft.
Aerodynamic layout must ensure that the aerodynamic requirements are met, which boils down to solving the problems of ensuring:
- large range of velocities V from takeoff-landing to Vmax maximum with minimum transition time from one velocity to another in the initial and final flight modes of the aircraft;
- maximum aerodynamic quality of the aircraft in cruising flight at a given speed. This requirement includes ensuring minimum drag and, in particular, minimum balancing losses;
- for takeoff and landing as much as possible of the aircraft's Su;
- in all flight modes of the aircraft the standardized (required) reserves of stability and controllability;
- on the aircraft the most favorable conditions for the operation of the power plant, determined by the best possible losses at the entrance of the air to the engines and at the exit of the gases from the exit nozzles of the engines;
- The safety of the airplane to reach extreme flight conditions (e.g., high speeds or large angles of attack) without causing flutter, flutter, stall, deep stalls, and other extremely dangerous phenomena.

2.1.1 Calculation of geometric characteristics and wing layout

The geometric characteristics of the wing are determined based on the takeoff weight m_0 and the specific load on the wing P_0 In the beginning we find thearea of the wing:

Find the wing area:

$$S_{кр} = \frac{m_0 \cdot g}{P} = \frac{82992 \cdot 9.8}{4.705 \cdot 10^3} \approx 173 m^2$$

Calculate the wingspan:

$$l_{кр} = \sqrt{S_{кр} \cdot \lambda_{кр}} = \sqrt{173 \cdot 9} = 39.5m\ ;$$

According to preliminary calculations $L_ф = D_ф \cdot \lambda_ф = 3{,}9 \cdot 9{,}2 = 35.88 м$.

For example, the Boeing 737-800 (160 passengers) has a wingspan of 34.3m with a fuselage length of 39.5 m and a wing area of 125 m^2 .

Based on the prototype planes, we take a wingspan of 35.9 m and accordingly reduce the wing area to 143 m^2 .

We determine the wing root chord:

$$b_0 = \frac{2 \cdot S_{kr} \cdot \eta}{(1+\eta) \cdot l} = \frac{2 \cdot 143 \cdot 2.8}{(1+2.8) \cdot 35.9} \approx 5.87m$$

Determine the end chord of the wing:

$$b_k = \frac{b_0}{\eta} = 2.1m$$

On-board chord:

$$b_d = b_0 \cdot \left(1 - \frac{\eta - 1}{\eta} \cdot \frac{D_f}{l}\right) = 5.87 \cdot \left(1 - \frac{2.8 - 1}{2.8} \cdot \frac{3.9}{35.9}\right) = 5.46м$$

where D_f is taken from the previous calculations.

When selecting the power scheme of the wing, determine the number of spars and their position, as well as the places of the wing segmentation.

On modern airplanes, a caisson-type two- or three-spar wing is used; the spar wing is inherent in light sports, sanitation and other airplanes.

The relative position of the wing spars along the chord is

where X is the distance , the i-th spar from the nose of the wing, b is the chord.

In a wing with two spars: X_i = 0,2; X_i = 0,6.

This determines the width of the caisson and the capacity of the fuel tanks.

The value of bmac - the mean aerodynamic chord of the wing is determined by geometric method. The definition of bmac =4.3 m is presented in Appendix B. After determining the geometric characteristics of the wing, proceed to the evaluation of the geometry of ailerons and wing mechanization.

The geometric parameters of the aileron are determined in the sequence:

- aileron span l_{ail} = (0.3. 0.4) l/2 = 6.3 m;
- aileron area S_{ail} = (0.05.. 0.08) Sw /2 = 5.19 m2 .

Aileron axial compensation:

$S_{comp.ail.}=0.25S_{ail}$; $S_{comp.ail.}=1.3$ m^2;

Aileron deflection range: up $б_{ail}=25$ degrees; down $б_{ail}=15$ degrees.

Increasing lail and bail beyond the recommended values is not rational. Increasing lail above these values increases the aileron moment coefficient and decreases the mechanization range. Increasing bail decreases the width of the caisson.

On third-generation aircraft, a tendency to reduce the relative span and area of ailerons has been revealed. Due to this the aileron span and aileron area can be increased, which improves the takeoff and landing characteristics of the aircraft.

2.1.2 Fuselage layout

When selecting the shape and dimensions of the fuselage cross-section, it is necessary to proceed from the requirements of aerodynamics (streamlining and cross-sectional area). For subsonic passenger and transport aircraft (V < 800 km/h), the wave drag is almost unaffected. Therefore, the shape should be chosen to provide the lowest values of frictional resistance CYf and profile resistance CXp respectively.

For supersonic aircraft, the nose part of the fuselage should be:

$L_{np}= (2...3)\ D_f =9.75$

where D_f – fuselage diameter.

In addition to the aerodynamic requirements, when selecting the shape of the section, the layout conditions and strength requirements should be taken into account.

To ensure minimum weight, the most expedient form of the fuselage cross-section should be the circular cross-section. In this case, the thickness of the fuselage skin is the smallest. As a variation of such a section, a combination of two or more circles can be used both vertically and horizontally.

For transport aircraft when choosing the shape of the cross section of the fuselage aerodynamics issues do not become paramount and the shape of the section can be performed rectangular or close to it.

The geometric parameters of the fuselage include: fuselage diameter Df ;

fuselage length, Lf ; fuselage extension λ_f, fuselage nose extension λ_{np}, fuselage tail extension λ_{tp}, respectively fuselage nose length L_{nl} and tail length L_{tl} The length of the fuselage is determined taking into account the aircraft scheme, layout and alignment features, as well as the condition of ensuring the landing angle of attack $\alpha_{landing}$.

Let's define the following parameters of the fuselage:

$L_f = \lambda_f * D_f = 9.2*3.9 = 35.88$ m

$L_{np} = \lambda_{np} * D_f = 1.2*3.9 = 4.68$ m

$L_{np} = \lambda_{tp} * D_f = 2.1*3.9 = 8.2$ m

Analyzing the prototype planes, with the accepted wingspan of 35.9 m it is reasonable to increase the fuselage length by 4 m. Thus we accept the fuselage length Lf =39,9 m.

When determining the diameter of the fuselage, the goal is to have a minimum midsection Sm-cs on the one hand and to meet layout requirements on the other.

For passenger and transport aircraft, the fuselage midline is primarily determined by the dimensions of the passenger cabin or cargo compartment.

One of the main parameters determining the midsection of a passenger aircraft is the height of the passenger compartment.

We take the height of the passenger cabin h = 2.2 m; width of the aisle 0.6 m; distance from the window to the floor 1m; height of the luggage room 1.2 m.

Note that finding the required width of the passenger compartment does not yet allow us to find the optimum dimensions of the fuselage cross section.

From a structural point of view, it is rational to have a circular cross-section of the fuselage, because in this case it will be the strongest and lightest. However, to accommodate passengers and cargo, this shape may not always be optimal.

The spacing of the normal fuselage frame members is between 360...600 mm, depending on the size of the fuselage and the passenger compartment layout class.

Layout of passenger and domestic equipment in the fuselage. The size of the passenger cabin is determined by the number of passengers in a standard seating arrangement.

In terms of comfort, passenger planes are divided into three classes: first class, business class, and economy class. The greatest comfort for passengers is provided in first class, the least in economy class.

To determine the diameter of the fuselage it is necessary to select the number of seats in one row from the prototypes and determine the required width of the passenger cabin.

Passenger cab width

$B_{cab} = mb_{seat} + k_1 b_{aisle} + 2\delta$,

Where m - width of the block from three seats, bкр - number of blocks in one row, k1 - number of aisles, bпрох - width of the aisle, δ - the gap between the seat and the inner surface of the cabin wall.

$B_{cab} = 2 \cdot 1420 + 1 \cdot 500 + 2 \cdot 200 = 3800$ mm

The length of the passenger cabin when done as a single cabin is defined:

$$\iota_{kab} = 1200 + \left(\frac{n}{m} - 1\right) \cdot t_{kr} + (235..250) mm$$

$$\iota_{kab} = 1200 + \left(\frac{n}{m} - 1\right) \cdot t_{kr} + (235..250) = 1200 + \left(\frac{162}{6} - 1\right) 870 + 250 = 24070 mm$$

where n - number of passengers; m - number of seats in one row, t - seat

The length of the cabin in two cabins is determined separately for business

class (12 passengers) and separately for economy class (150 passengers).

The length of the cab of the business class:

$$\iota_{kab} = 1200 + \left(\frac{12}{4} - 1\right) 1050 + 250 = 3550 mm$$

Economy class cabin length:

$$\iota_{kab} = 1200 + \left(\frac{150}{6} - 1\right) 870 + 250 = 22330 mm$$

Long cabins look uncomfortable and then they are divided into separate cabins. The length of each cabin is determined in the same way as the cabs. In the case of cabins with different passenger classes (e.q. first and business class) it is obligatory to divide them with a hard partition into cabins.

After determining the length of the cabin to check the requirements for the volume per passenger.

$$v_{каб} = \iota_{каб} \frac{\pi (d_{ф} - 0.240)^2}{4} = 24{,}07 \frac{\pi (3{,}9 - 0{,}240)^2}{4} \approx 253{,}1 m^3$$

$$v_{пасс} = \frac{v_{каб}}{n} = 1.56 m^3$$

Per passenger - the condition is met.

The greater the range, the greater the specific volume must be. If the requirements for νкаб are not met, the size of the cabin must be increased.

When laying out the passenger cabin, care should be taken to create proper comfort and safety for the passengers.

The Aviation Regulations stipulate that when flying with H=3500 m, the cabin must be sealed, the cabin overpressure must be at least 567 mm Hg (2400 m), the cabin pressure change rate must not exceed 0.18 mm Hg/s, the fresh air supply must be at least 24 kg/h per passenger, the temperature in the cabin must be 18...22°C and the humidity must be 30 60%.

The height of the passenger cab in the passageway area should not be less than 1900...2000 mm. The passenger cab is designed with a single floor level and must not have any protrusions or depressions, and the front door must not have a threshold.

2.1.3 Cockpit layout

The cockpit should occupy as little volume as possible, but at the same time provide normal working and resting conditions for the flight crew. The most stringent requirements are imposed on the pilot's workplace. In addition to comfort they should provide a good overview. The size of the cockpit depends on the crew.

On intercontinental and long-haul lines the crew consists of 3...5 people, on medium and short-haul lines of 3...4 people, on local lines of 2...3 people.

For the designed aircraft, the crew consists of two people, the commander and co-pilot. Depending on the flight route, the crew may vary. The flight crew cabin is separated from other rooms by a rigid partition with a lockable door.

2.1.4 Baggage facilities

Baggage facilities are usually located in the pressurized part of the fuselage under the cockpit floor. To improve economy of transportation, it is necessary to make maximum use of the volumes of the tail section of the fuselage by placing luggage racks, aircraft equipment, etc. in them.

Given that the specific load on the floor of the trunks is K=400...600 kgf/m2 and the non-compactness of the luggage, the area of the trunks is determined:

$$S_{б} = \frac{m_{бп}}{0.4K} + \frac{m_{гр}}{0.6K} = \frac{25}{0.4 \cdot 600} + \frac{5}{0.6 \cdot 500} = 0{,}11[m]$$

Where mбп, mгр - weight of luggage and mail, cargo, respectively. The required volume of luggage space:

$$v_b = (0.20...0.24) n_{pass} = 0{,}22 \cdot 162 = 35{,}64 м^3$$

The luggage compartments are designed like the prototype in the underground part of the passenger compartment.

2.1.5 Kitchens and buffets

To cater for passengers on medium-haul lines with 162 passengers, we provide a kitchen and a buffet, a buffet behind the crew cabin and a kitchen at the end of the passenger cabin. Kitchens and buffets must always be located at the door, preferably between the crew cabin and the passenger cabin, or have a separate cargo door. Buffets and kitchens should not be placed near restrooms or combined with dressing rooms. Total volume of kitchens:

$$v_к = (0.10...0.12) \cdot n_{пас} = 0.10 \cdot 162 = 16.2 м^3$$

and its area:

$$S = \frac{V_к}{h_к} = \frac{16{,}2}{1{,}5} = 10{,}8 м^2$$

Where hк = 1.5 m - height of the kitchen. Sк = 10.8 m2

The amount of food per passenger: breakfast, lunch and dinner - 800 grams; tea and water - 400 grams.

If meals are provided once, a set No. 1 weighing 620 grams is given. Meals are given to passengers every 3.5 ... 4 hours of flight.

The buffet and the kitchen are designed similar to the prototype.

2.1.6 Lavatories

The number of toilets is determined by the number of passengers and the duration of the flight: at t > 4 hours one toilet for 50 passengers. As the projected plane is designed to carry 162 passengers with a flight time of more than 4 hours, then we provide 3 toilets, 1 in the nose and 2 in the tail of the fuselage. The area of one toilet Sтуал = 1,5...1,6 m2 with the width not less than one meter. The norms stipulate to have stock of water and chemical liquid in the toilets per person: at t > 4 hours q = 2,0 *kg*, , total stock of water and chemical liquid: $m_l = q*n_{pas} = 2*162 = 324$ kg.

The toilets are designed like the prototype.

2.1.7 Normal and emergency outputs

Normal doors for entering and exiting the crew are made on the left side of the aircraft. The door height depends on the fuselage diameter and is equal to 1400...1830 mm. Door width shall be not less than 860 mm, at wide-bodied aircraft to reduce the entry and exit time the doors are often made so wide that they could be entered by 2 people simultaneously. Threshold at the door is not allowed, the doorway from below is limited to the floor plane.

Emergency exits are made for emergency exit of the aircraft, the main door counts as an emergency door. The number of emergency exits depends on the number of passengers.

According to the requirements, the number and size of the emergency hatches should be such that when training on the ground (checking to leave the aircraft), with all exits open at 50%, including the main ones, or separately all the left and all the right exits, evacuation was done in 90 seconds. It was found that with two normal exits on the port side and two emergency exits on the starboard side 120...160 passengers left the plane in 30 seconds. It is desirable to have at least two emergency hatches on lowplanes. The airworthiness standards require at least one door that is easily accessible from the outside. According to ICAO regulations, the size of the escape hatch should be such that an ellipse of at least 483x660 mm can be fit inside it.

In the crew accommodation area there should be either one exit on each side of the fuselage at least 480x510 mm, or one overhead hatch at least 500...700 mm, or a round hatch 0.610 m.

Main doors - 900x1650 mm (2 pieces on the port side in the nose and tail of the fuselage). Emergency doors - 510x1000 mm (3 on starboard and 1 on port side). All doors can be used as emergency doors.

2.1.8 Calculation of basic parameters and chassis layout

During the course design scheme of the chassis, the number of wheels on the supports, the basic parameters of the chassis (base, outreach main and supports, track) and the characteristic angles, as well as the selection of chassis pneumatics.

A feature of this scheme of landing gear is the location of the main struts within the range of alignment in such a way that all the flight positions of the centers of mass are ahead of the axes of the main struts, and the center of mass of an empty and equipped aircraft - behind.

At the initial stage of design, when the alignment has not yet been made and there are no drawings of the general view of the aircraft, only some of the parameters of the landing gear are determined.

The outreach of the main wheels of the chassis is:

$$e = (0,15...0,20)\ b_{mac} = 0,18 \cdot 4,7 = 0,846\ m$$

Too much overhang will make it difficult to lift off the front leg on takeoff, and too little may cause the airplane to tip over on the tail when the rear compartments and baggage compartments are loaded first. In addition, the load on the nose support will be too low and the airplane will be unstable when traveling on a slippery runway and in a side wind.

The base of the undercarriage is from the expression: B = (0,3-0,4) L_f = 12,56 m

The outreach of the front support will be: d = B - e = 12,56-0,846 = 11,71 m

The undercarriage track is calculated using the formula: $K = (0{,}7...1{,}2)\ B \leq 12m$

We take the track of the chassis 5.7 m.

From the condition of preventing lateral drift, K>2H. Here H is the distance from the runway to the center of mass (CM) of the aircraft. The position of the CM can be taken by altitude.

The wheels of the landing gear are selected by the value of the parking load on them from the take-off weight of the aircraft; when selecting the wheels of the nose support, dynamic loads are taken into account. The type of pneumatics (balloon, half-balloon, arch) and the pressure in them are determined by the runway surface on which the aircraft is intended to operate. Brake wheels are installed on the main and sometimes on the nose support. The load on the wheels is determined by:

$$P_{гл} = \frac{(B-e)m_0 \cdot 9.8}{B \cdot n \cdot z} = \frac{(12.56-0.846)\cdot 82992 \cdot 9{,}8}{12{,}56 \cdot 2 \cdot 2} = 189634{,}73H$$

$$P_{нос} = \frac{e \cdot m_0 \cdot 9.8 \cdot K_{д}}{B \cdot z} = \frac{0{,}846 \cdot 82992 \cdot 9{,}8 \cdot 1{,}5}{12{,}56 \cdot 2} = 41086{,}98\,\text{H}$$

where n and z are the number of supports and wheels on one support, respectively;

$K_д$ = 1,5...2,0 - dynamic coefficient..

According to the calculated value of wheel load Pmain and Pnose . and the value of takeoff Vtakeoff and landing Vlanding speeds select the pneumatics catalog, meeting the conditions:

$$P_к > P_{гл}\ ;\ P_к > P_{нос}\ ;\ V_{к\ пос} > V_{пос}\ ;\ V_{к\ взл} > V_{взл}$$

From the catalog of Michelin select the following wheels:

The base support – H44.5x16.5-21/28PR in inches (brake); H44 –дwheel diameter in inches, which corresponds to 1117,6 mm, 16,5 inches wheel width – 419 мм, 21 inch =533,4 mm rim diameter, 28 Ply rating –tire marking.

The nose support - 27x7,75-R15/12PR/225Speed MPh (non-braked).

After determining the alignment of the aircraft and drawing the side and front view of the aircraft on millimeter paper, graphically determine the other parameters of the landing gear. The landing gear should be mounted so that the conditions are met:

$\varphi^0 > \alpha_{noc} - \alpha_{ycm} - \alpha_{cm}$

φ > 10... 18° - rollover angle to the tail;

$\gamma^1 > \varphi+(1...2°)$ - angle of the main landing gear legs;

γ^2>90° - condition of overturning to the nose support of the landing

2.1.9. Layout and calculation of the main parameters of the fins

One of the most important tasks of aerodynamic design is the choice of location of the horizontal tail, to ensure the longitudinal static stability of the aircraft on overload its CM should be ahead of the aircraft focus and the distance to these points, referred to the value of the mean aerodynamic chord (AX) of the wing, determines the degree of longitudinal stability, ie.i.e., $t_{Cy} = X_t - X_f$, <0, where t_{Cy} is the moment coefficient, Xt and Xf are the relative coordinates of the CM and focus, respectively. If $t_{Cy} = 0$, the aircraft has neutral longitudinal static stability and, if t_{Cy} >0, the aircraft is statically unstable. In the normal scheme of the aircraft (wingtip behind the wing), the focus of the wing-fuselage combination is shifted backward when the horizontal wingtip is installed. Usually the areas of vertical S_{hor} and horizontal S_{ver} are as follows:

S_{hor} = (0,18...0,25) S_{wing}=0,25 143=35,75 m^2;

S_{ver} = (0,12...0,20) S_{wing}=0,2 143=28,6 m^2.

A more precise determination can be made:

$$S_{ГО} = \frac{b_{сах} \cdot S}{L_{ГО}} \cdot A_{ГО}$$
$$S_{ВО} = \frac{l \cdot S}{L_{ВО}} \cdot A_{ВО}$$

Where L_{hor}, L_{ver} - horizontal and vertical shoulder, l and S - wingspan and area, A_{hor} =0,75; A_{ver} =0,1 - coefficients of static moments. The value of L_{hor} and L_{ver} depends on a number of factors. First of all, their value is influenced by: the length of the fuselage nose and tail, the sweep and location of the wing, as well as the conditions for ensuring the stability and controllability of the aircraft.

In the first approximation we can assume that $L_{hor} \approx L_{ver}$ and depending on thedesign features find them from the relations:

- with the normal scheme of the aircraft and trapezoidal wing shape in plan $L_{hor} \approx L_{ver}$ = (2,5...3,5) b_{mac}=3 4,3=12,9 m.

$$S_{ГО} = \frac{b_{сах} \cdot S}{L_{ГО}} \cdot A_{ГО} = \frac{4{,}3 \cdot 143}{12.9} \cdot 0{,}75 = 32.75 м^2$$
$$S_{ВО} = \frac{l \cdot S}{L_{ВО}} \cdot A_{ВО} = \frac{35{,}9 \cdot 143}{12.9} \cdot 0{,}1 = 26.8 м^2$$

Take, S_{hor}=33 m^2, S_{ver}=26 m^2.

Determination of rudder height and direction areas. The rudder height area is usually taken as:

$$S_{rudder} = (0{,}3...0{,}4)S_{hor} = 11.5\ m^2.$$

Directional rudder area:

$$S_{rudder} = (0{,}35...0{,}45)\ S_{ver} = 9.8\ m^2.$$

Aerodynamic compensation area:

$S_{акрв}$=(0,22…0,25) $S_{рв}$=2,54 м^2, $S_{акрн}$=(0,2…0,22) $S_{рн}$=2 m^2.

Trimmer area for rudder height $S_{тррв}$=(0,08…0,12)$S_{рв}$=1,15m^2, $S_{тррн}$=(0,04…0,06) $S_{рн}$=0,5 m^2.

Determination of the horizontal tail span.

The wingspan and the wingtip of the airplane are related by the static dependence $l_{го}$= (0,32...0,5) $l_{кр}$= 0,45 35,9=15 м.

The height of the vertical tail Нво is determined depending on the location of the wing relative to the fuselage and the location of the engines on the aircraft. Taking into account the above, take:

- when the engines are placed at the root of the wing,

$h_{во}$ = (0.13...0,18) $l_{кр}$ =0.18 35.9=6.5 m

Taper of horizontal and vertical plumage should be chosen:

- for aircraft with $M<1$ $\eta_{го}= 2...4$ и $\eta_{во}= 2...5$.

Consider: $\eta_{го}=2.5$ и $\eta_{во}=3.6$.

Plumage lengthening can be recommended:

$\lambda_{го}$ = 6 and $\lambda_{во}$ = 1,9.

Determination of chords of the fins $b_{конц}$, $b_{сах}$, $b_{корн}$ is carried out by the formulas:

For Horizontal tail:

$$b_{конц} = \frac{2\cdot S_{го}}{(1+\eta_{го})\cdot l_{го}} = \frac{2\cdot 33}{(1+2.5)\cdot 15} = 1.25м$$

$$b_{сах} = 0{,}88\frac{\eta_{го}^2+\eta_{го}+1}{1+\eta_{го}} = 2.45м$$

$$b_{корн} = b_{конц}\cdot\eta_{го} = 1.25\cdot 2.5 = 3.125м$$

For vertical tail:

$$b_{конц} = \frac{2\cdot S_{во}}{(1+\eta_{во})\cdot h_{во}} = \frac{2\cdot 26}{(1+3.6)\cdot 6.5} = 1.74м$$

$$b_{сах} = 0{,}88\frac{\eta_{во}^2+\eta_{во}+1}{1+\eta_{во}} = 3{,}36м$$

$$b_{корн} = b_{конц}\cdot\eta_{го} = 1{,}74\cdot 3{,}6 = 6.26м$$

We take the tip sweep $\chi_{го}$=30˚; $\chi_{во}$=35˚.

2.1.10 Engine selection

For the designed aircraft, we choose the CFM56-7BE turbofan engine produced by CFM International (an association of the American private company General

Electric and the French company SNECMA), the specifications of which are given in Table 2.1

Table 2.1 - Technical data of the CFM 56-7 BE engines

Characteristics	CFM 56 – 7 BE
Thrust, kgf	14165
Bypass ratio	6,60
Full degree of pressure rise	31,5
Air consumption, kg/s	466
Thrust, kgf	2996
Specific fuel consumption, (kg/h)/kgf	0,545

2.2 Aircraft alignment

To ensure the desired degree of statistical stability and controllability of the aircraft its center of gravity should be within a certain range along the length of the MAC of the wing. The position of its center of gravity may change in the course of aircraft operation: in this particular flight, as fuel is exhausted, as well as due to the differencesin loading options of the aircraft. The main requirements are as follows:

- the layout of the aircraft should provide for the convenience of control and maintenance of these main systems of aggregates, as well as the convenience of removing and installing removable parts and assemblies;

- technological division of the structure should provide for a wide scope of work in the production and convenience of the general assembly of the aircraft;

- the power circuit should provide (with the possible full fulfillment of the preliminary requirements) a lower weight of the structure with sufficient strength and hardness.

The basic principles of aircraft layout boil down to the following. The operational and technical requirements for the aircraft layout are reflected in accordance with their importance for the designed aircraft. The most important requirements are fulfilled first, and others as far as possible. Contradictions in the requirements are resolved by compromise solutions.

In addition to this, a number of other principles are laid down in the power scheme of the aircraft:

- the transfer and balancing of all the main force factors over the elements of the force scheme should be carried out in the shortest possible way;
- The transfer of concentrated forces should preferably be carried out by stretching or compressing the force elements rather than by bending;
- it is advisable to transmit bending moments at the greatest possible building height, and torsional moments - along the closed contour of the largest possible area.

The main tasks of aircraft layout:

- placement of units and cargoes inside the aircraft, provided the necessary range of alignment is ensured;
- development and interconnection of power diagrams of aircraft parts (wings, tail, fuselage, engine nacelles, pylons, landing gear).

When placing units and cargoes inside the aircraft, it should be taken into account that all cargoes to be placed can be divided into two main groups: 1. Cargoes that require a well-defined place on the aircraft. 2. Cargoes, the arrangement of which is not bound by strict requirements to any specific place on the aircraft.

When laying out the aircraft, it is first necessary to place the cargoes consumed in flight (fuel) and the cargoes whose weight may vary from flight to flight (passengers, baggage, mail, etc.). In this case the centers of gravity of these cargoes when they are consumed or change the loading of the aircraft should remain near the desired position of the center of gravity of the entire aircraft. Then other cargoes of the first group are placed, e.g. crew with pilot-navigational equipment, antennas of radio-electronic stations, etc. This is guided by the requirements of creating the best working conditions for the crew and the fullest use of the technical capabilities of the equipment.

In the placement of cargo of the second group, seek to make the most efficient use of the volume of the fuselage and other parts of the airframe, to reduce the length of communications, to ensure ease of operation.

In a series of successive approximations, the layout and alignment are adjusted to best meet the economic and technical requirements for the designed aircraft.

At present, aircraft alignment calculations are carried out by the method of successive approximation until a positive result is obtained either by changing the layout, or by rearranging the mass objects, or using both the first and second ways at the same time.

2.2.1 Determination of the center of mass of the loaded wing

The weight of the loaded wing includes the weight of its structure, the weight of equipment placed in the wing, and the weight of fuel. Regardless of the place of attachment (to the wing or fuselage), the main landing gear supports, as well as the nose landing gear support are included in the weight list of an equipped wing. In the statement of masses are entered names of objects, masses, the masses themselves and the coordinates of their centers of mass. The beginning of specifying the coordinates of the centers of gravity of masses, is selected in the projection of the point of the beginning of MAC on the area xOy. Positive values of coordinates of centers of weight of objects are taken towards the tail of the aircraft. The X-axis forms an angle of wing installation with the MAC. The center of mass of the fuel in each tank is taken: along the wing chord - in the middle of the caisson, along the span - at a distance of 0.45×lб from the wall of the tank, which is closer to the axis of the aircraft. Here lб is the length of the fuel tank along the span of the spar. It is advisable to place the fuel left as an aeronautical reserve in one pair (or one) of tanks. The center list of weights of the loaded wing is given in Table 2.2.

The coordinates of the center of mass of the equipped wing are determined by the formula:

$$X'_{к} = \frac{\sum m_i' \cdot x_i'}{\sum m_i'}.$$

Таблица 2.2. - Centering list of the masses of the loaded wing

№ п/п	Name of the object	Mass m'_i		Coordinate of the center of gravity x_i, m	Momentum ofmass, m_I, x_i,.
		relative	General		
1	Wing (design)	0,1331	11046,235	1,849	Wing (design)
2	Fuel system	0,0073	605,841	1,849	Fuel system
3	Aircraft control, 30%	0,0018	149,3856	2,58	Aircraft control, 30%
4	Electrical equipment, 30%	0,00966	801,70272	0,43	Electrical equipment, 30%
5	Anti-obl. system, 50%	0,0111	921,21	0,43	Anti-obl. system, 50%
6	Hydraulic system, 50%	0,00835	692,98	2,58	Hydraulic system, 50%
7	Force installation	0,06940	5760,14	-1	Force installation
8	Loaded wing without fuel and landing gear	0,240716	19977,50	0,9359	Loaded wing without fuel and landing gear
9	Undercarriage nose support	0,008106	672,733	-15,36	Undercarriage nose support
10	Main chassis support	0,032424	2690,93	1,075	Main chassis support
11	Fuel	0,24908	20671,647	1,075	Fuel
12	Wing loaded with fuel and landing gear	0,5303	44012,815	1,185	Wing loaded with fuel and landing gear

2.2.2 Determining the center of mass of an equipped fuselage

The origin is the projection of the fuselage nose to the horizontal axis. The construction horizontal of the fuselage is taken as the X-axis. Calculations of the center of mass of the loaded fuselage are recorded in Table 2.3. Coordinates of the center of mass of the loaded fuselage are determined by the formulas:

$$X'_{\phi} = \frac{\sum m_i' \cdot x_i'}{\sum m_i'} .$$

Таблиця 2.3 - Centering list of fuselage weights

№ п/п	Name of the object	Mass		Coordinate of weigh tcenter X	Momentum of mass $X_i m_i$
		Relative	total, kG		
1	2	3	4	5	6
1.	Fuselage	0,08397	6968,8382	20,2	140770,5
2.	GO	0,01168	969,34	38	36835,169
3.	VO	0,01151	955,237	38,2	36490,08
4.	Locating equipment	0,0031	257,27	1,6	411,64
5.	Radio communications equipment	0,0023	190,88	4,5	858,96
6.	Dashboard	0,0054	448,15	4,2	1882,258
7.	Aeronautical equipment	0,0047	390,06	3,5	1365,2184
8.	Toilet 1	0,000602	50	5,8	290
9.	Toilet 2.3	0,0012	100	32,5	3250
10.	Buffet	0,0012	100	5,8	580
11.	Kitchen	0,01009	837,4	32,5	27215,5
12.	Trunk equipment	0,0078	647,33	27,1	17542,84
13.	Aircraft control,70%	0,0042	348,56	20	6971,32
14.	Electrical equipment, 70%.	0,02254	1870,63	19	35542,15
15.	Hydraulic system, 50%	0,00835	191,167	24	4588,008
16.	High-Rise Equipment	0,00555	460,6	21	9672,71
17.	Decor. trim and TZI	0,0068	564,34	20,5	11569,08
18.	Anti-obl. system, 25%	0,00555	460,60	28	12896,95
19.	WSU	0,011844	982,95	37	36369,41
20.	Additional equipment	0,0066	500	6	3000
21.	Atypical equipment	0,005	414,96	4,5	1867,32
22.	Workload	0,00716	594,6	6,5	3864,9
19.	Emergency equipment.	0,0018	150	20	3000

20.	Crew seats	0,000433	36	5	180
21.	On-board seats. 1,2	0,00019	16	6,48	103,68
22.	On-board seats. 3,4	0,00019	16	34	544
23.	Business class armchairs	0,00289	240	9	2160
24.	Economy class chairs	0,02168	1800	23	41400
25.	Loaded fuselage without commercial load	0,25319	20510,98	21,43	439596,8

Продолжение таблици 2.3.

1	2	3	4	5	6
26.	Economy Class Passengers	0,14459	12000	23	276000
27.	Business Class Passengers	0,011567	960	9	8640
28.	Food, water	0,006024	500	5,5	2750
29.	Crew	0,0019278	160	5	800
30.	Flight attendants 1.2	0,0014459	120	6,48	777,6
31.	Flight attendants 3.4	0,0014459	120	34	4080
32.	Passenger luggage, cargo	0,0555259	4608,20	15,1	69583,96
33.	Fuselage loaded with a commercial load	0,47572	38979,19	20,58	802228,35

Having determined the centers of weight of the equipped wing and fuselage, we add the equation of moment equilibrium relative to the fuselage toe:

$$m_{сн.ф} \cdot X_{ф} + m_{сн.кр} \cdot \left(X_{сах} + X'_{к}\right) = m_{o} \cdot \left(X_{сах} + C\right);$$

From this equation we determine the position of the nose of the MAC wing relative to the nose of the fuselage, i.e. the value Xcax behind the formula:

$$X_{сах} = \frac{m_{сн.ф} \cdot X_{ф} + m_{сн.кр} \cdot X'_{к} - m_{o} \cdot C}{m_{o} - m_{сн.кр}};$$

where: $m_{сн.ф}$ - is the weight of the loaded fuselage;

$m_{сн.кр}$ - is the weight of the loaded wing;

C – the distance from the toe of the MAC to the center of the weight of the aircraft is chosen by the designer;

$C = (0{,}22...0{,}25) \cdot b_{сах} = 0{,}22 \cdot 4{,}3 = 0{,}946$ - for low-wing planes;

Determine the position of the nose of the MAC wing relative to the nose of the fuselage, that is, the value X_{CAX} by the formula:

$$X_{cax} = \frac{44012{,}81 \times 1{,}185 \ + 38979{,}19 \times 20{,}58 - 82992 \times 4{,}3 \times 0{,}25}{82992 - 44012{,}81} = 19{,}63 м$$

2.2.3 Calculation of aircraft alignment for different loading options

Knowing the position of the wing relative to the fuselage on the layout drawing, the power elements of the wing and fuselage are coordinated. After arranging the wing and fuselage, the center of gravity is calculated. The center of gravity is the relative position of the center of mass of the aircraft from the nose of the nose, expressed as a percentage:

$$\bar{X}_m = \bar{X}_c = \frac{X_{цт} - X_{cax}}{b_A} \cdot 100\% = \frac{C}{b_A} \cdot 100\% \ ;$$

Calculation of alignment options is shown in tables 2.4 and 2.5.

Table 2.4 - Summary centering list

№п/п	Name of the object	Mass total, kG	Coordinate of the weight center X_i	Moment of mass $m_i X_i$
1.	Loaded wing (without fuel and landing gear)	19977,5	20,56	410872,2
2.	Front chassis (released)	672,73	4,27	2873,08
3.	Main landing gear (issued)	2690,93	20,7	55717,8
4.	Fuel	20671,65	20,705	428022,1
5.	Fuselage loaded	20510,98	21,43	439596,8
6.	Economy Class Passengers	12000	23	276000
7.	Business Class Passengers	960	9	8640
8.	Food, water	500	5,5	2750

9.	Crew	160	5	800
10.	Flight attendants 1.2	120	6,48	777,6
11.	Flight attendants 3.4	120	34	4080
12.	Passenger luggage, cargo	4608,20	15,1	69583,96
13.	Front undercarriage (retracted)	672,73	3,27	2200,348
14.	Main landing gear (retracted)	2690,93	20,7	55717,8

Table 2.5. - Variants of aircraft alignment

№п/п	Name of the oblect	Mass, m_i kg	Moment of mass $m_i X_i$	Center of mass $X_{ЦМ}$	Centering X_C %
1	Takeoff weight (landing gear released)	82992	1699713	20,48	19,76
2	Takeoff weight (landing gear retracted)	82992	1699713	20,47	19,57
3	Landing variant (landing gear released)	65259,1	1332540,46	20,41	18,34
4	Transporter version (without commercial load, chassis removed)	64683,79	1337209,3	20,67	24,23
5	Parking variant (without commertial load, fuel, crew, landing gear released)	43852,15	909059,91	20,73	25,56

Conclusions to the design part

This section of the thesis was:

- the basic geometric parameters of the main parts of the designed airplane were obtained,
- the selection of engines has been made, namely the CFM56,
- layout of the passenger cabin, layout of household equipment
- the alignment of the airplane has been performed.

As a result of a certain amount of comparative computational, computational and research work, an airplane that meets the set requirements of aircraft construction, safety, practicality and economy has been designed.

3 Development of new clamps for the designed airplane

3.1 Usage of clamps in an airplane

An aircraft clamp is a device that usually consists of a metal ring and some elastic material to allow it to safely and reliably fix wires, ducts, hoses, and tubes in place. It cancels or reduces the vibrations and shock loads in the assemblies, which prolongs their service life and increases overall safety.

These are different types of clamps used on an airplane: loop clamp, band clamp, P-clamp, block clamp, and some other less common (see the pictures below). Loop clamp is the most popular clamp type. Loop clamp has a wider range of adjustments than other clamp types. It sits better around pipes and tubes and protects them from wear and other negative effects.

Clamps can be found in almost every part of the airplane. They prove to be extremely useful in flight control systems, hydraulic and electrical systems, fuel and propulsion systems, environmental control system, and in avionics.

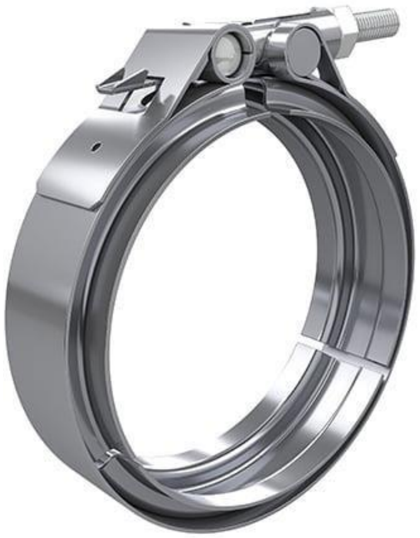

Fig.1

Department of Aircraft Design				NAU 22 01 00 00 00 83 EN			
Performed by	Demchenko A.O.			SPECIAL PART	Lit.	Sheet	Sheets
Supervisor	Ignatovich S. R.						
Counsel					402AF 134		
Stand.cont.	Khizhnyak S.V.						
Head of th Departmen t.	Ignatovich S. R.						

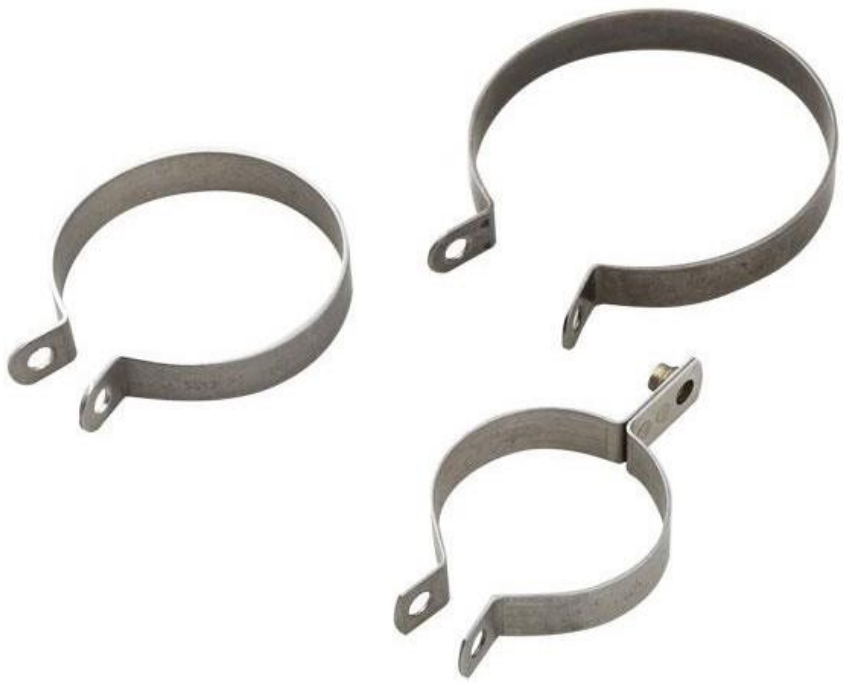

Fig.2

Loop clamps have a very simple design: cushion (1) is attached to the inner surface of metal clamp (2). Cushion may be manufactured heat-resistant, gasoline-resistant etc. depending on the system this clamp will be installed in. Cushion eliminates vibration, thus preventing line abrasion. Metal composition of a clamp itself may also vary.

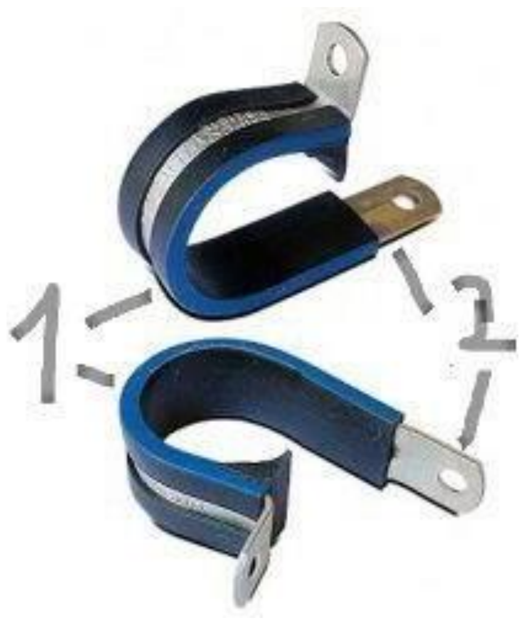

Fig.3

3.2. Problems associated with the use of clamps

As well as clamps currently used in an aircraft do their job, they still have some flaws. The biggest problems of most clamps are their cost of production, and time-consuming removal and installation.

The metal clamps need to use rivets, welding to connect some pieces of a clamp together. It often requires sophisticated precise machinery, which is expensive to maintain and buy initially. This results in higher prices for the finished product. Some other clamps are cheaper and simpler in production, but on average costs are pretty high.

Another problem is ease of removal and installation. Again, most clamps require precise tightening with dynamometric wrench, which may cause trouble for un-experienced personnel. Also dynamometric wrench is not a common tool, so mechanic does not always carry it with him. This little-by-little increases time spent in hangar, which is expensive.

3.3. Designing of new clamps

The fast-lock clamp has been designed. It can be made in pretty much all diameters and fit in most aircraft systems. The production of the clamp is using modern 3D-printing technology. The material of a clamp can be chosen accordingly to the task. For heat-stressed areas a heat-resistant plastic will be used. If the fast-lock clamp will be used in fuel system, it can be made out of plastic or resin that is not affected by chemicals.

The 3D- printing technology allows us to produce very complicated shapes without the need to design special molds or use post-processing. It lowers the costs significantly. Another benefit is that the design of a clamp can be improved constantly with no changes to the initial equipment. The testing of new designs will be inexpensive.

The fast-lock 3D-printed clamp is easy-to-install and can be removed or installed even by inexperienced personnel. Plus it can be easily produced in the shortest terms if needed, which may be crucial to get the airplane airborne ASAP.

The recommended use of these clamps is for fast repairs, as a temporary solution to keep airplane in service if factory-installed clamps fail, or as a substitute to existing clamps.

Conclusions to the special part:

- the design of the clamp was made

- the manufacturing process of a clamp has been suggested

- the recommendations on clamp application have been given