МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Кафедра конструкції літальних апаратів

ДОПУСТИТИ ДО ЗАХИСТУ

Завідувач кафедри

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«_____» ___________ 2020 р.

ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ

"БАКАЛАВР"

Тема: «Аванпроект середньомагістрального літака пасажиромісткістю до 190 осіб»

Виконав: __________ В.В. Савенок

Керівник: канд. техн. наук, доцент ___________ С.С. Юцкевич

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Київ 2020

MINISRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

Department of Aircraft Design

AGREED
Head of the Department
Professor, Dr. of Sc.
_________S.R. Ignatovych
«___» _______ 2020 y.

DIPLOMA WORK

(EXPLANATORY NOTE)

OF ACADEMIC DEGREE
«BACHELOR»

Theme: «Preliminary design of middle range aircraft with a capacity of up to 190 passengers»

Performed by: **__________V.V. Savenok**

Supervisor: PhD, associate professor **__________ S.S.Yutskevich**

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

Kyiv 2020

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty

Department of Aircraft Design

Academic Degree «Bachelor»

Speciality: 134 "Aviation and Rocket-Space Engineering"

APPROVED
Head of the Department
Dr. Tech. Sciences, Prof.
__________ S.R. Ignatovich
"__" ___________2020

TASK
for bachelor diploma work

Vladyslav Savenok

1. Subject: **"Preliminary design of a medium-range passenger aircraft with a capacity of up to 190 passanger"**
2. Project implementation period:
3. Initial data for the project: aircraft statistics: Boeing 737-800, A320, A319; number of passengers 100-200 passenger; crew 2 people; cruising speed 850-900 km / h; altitude of cruising flight 10-12.5 km; flight range with a maximum commercial load of 5-7 thousand km.
4. Contents of the explanatory note: analysis of flight technical and mass characteristics of prototype passenger aircraft; selection of parameters of the designed aircraft; calculation of mass, flight technical characteristics and centering of the aircraft; design development and calculation of the strength of the load on the passenger seats; labor and environmental protection measures.
5. List of the graphical materials: general view of the airplane (A1×1); layout of the airplane (A1×1); cargo fitting (assembly drawing A1x1).

6. Calendar Plan

Task	Execution period	Signature
Task receiving, processing of statistical data	14.04.2020–18.04.2020	
Aircraft take-off mass determination	19.04.2020–22.04.2020	
Aircraft layout	23.04.2020–03.05.2020	
Aircraft centering determination	04.05.2020–14.05.2020	
Graphical design of the parts	15.05.2020–24.05.2020	
Completion of the explanation note	25.05.2020–02.06.2020	
Preliminary defence	16.06.2019–17.06.2020	

7. Task issuance date: 02.06.2020 y.

Supervisor of diploma work ___________ S.S. Yutskevich

Task for execution is given for ___________ V.V. Savenok

ABSTRACT

Explanatory note to the diploma work **«Preliminary design of middle range aircraft with a capacity of up to 190 passengers»**

42 sheets, 9 figures, 10 tables, 9 references and 3 drawings

Object of the design is development a medium-range passenger aircraft with the possibility to accommodate up to 190 passengers or relayout of passenger cabin to the cargo solution.

The aim of the diploma work is the preliminary design of the aircraft and its design characteristic estimation.

The method of design is analysis of the prototypes and selections of the most advanced technical decisions, analysis of center of gravity position.

The diploma work contains drawings of the middle-range aircraft with capacity up to 190 passengers, calculations and drawings of the aircraft layout and re-equipment for cargo cabin transportation.

The practical significance of the result of the bachelor's thesis project is to increase the reliability and efficiency of passenger and cargo air transportation. The materials of the bachelor's thesis project can be used in the educational process and in the practical activities of designers of specialized design institutions.

PASSENGER AIRCRAFT, NARROW-BODY AIRCRAFT, LAYOUT, CENTER OF GRAVITY POSITION, RE-EQUIPMENT CARGO CABIN

INTRODUCTION

The family of narrow-body aircraft makes the largest number of flights, both from point to point on the medium range, and with the possibility of refueling to perform flights over longer distances. For the diploma work there were selected prototypes: Boeing 737-800, Airbus 319 and Airbus 320. This airplanes are the most popular aircraft in the world, namely due to their high reliability and efficiency. Those aircrafts incorporating the latest technologies in the field of avionics and composite materials, due to their small empty weight, its allow transporting more passengers and cargo on board. Namely, purpose of a designed aircraft is to be able to carry passengers, cargo, total take-off mass up to 90,000 kg on the middle-range passenger traffic. Therefore, it is on these types of narrow-body aircraft and their performance data will be developed and further calculations during diploma work.

Due to the situation in the world, with the Covid-19, airlines are considering the possibility of re-equipment passenger aircraft into cargo and narrow-body aircraft are no exception. Therefore, in the diploma work considered the possibility of re-equipment the passenger compartment into a so called cargo cabin, namely the possibility of transporting cargo on passenger seats in accordance with the requirements and calculations for strength.

Diploma work presented a preliminary design of the aircraft, designed for operation on the passenger and medium-range routes. Preliminary design performed with the airworthiness requirements of large aircrafts (CS-25),

Calculation of the characteristics of the aircraft was carried out in the

				NAU 20 12 S 00 00 00 39 EN
Performed by	*Savenok V.V.*			*Introduction*
Supervisor	*Yuskevych S.S*			*Letter* / *Sheet* / *Sheets*
Instructor				
N. contr	*Khizhnyak S.V.*			*AF 402 134*
Head of Dep	*Ignatovich S.R*			

computer laboratory room of the department with the help of the developed at the department computer program.

Calculation of the re-equipment of the aircraft was carried out on the guidelines “Transport of cargo in passenger compartment” and airworthiness requirements of large aircrafts (CS-25).

CONTENT

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Performed by	Savenok V.V.			CONTENT	Letter	Sheet	Sheets
Supervisor	Yuskevych S.S						
Instructor					AF 402 134		
N. contr	Khizhnyak S.V.						
Head of Dep	Ignatovich S.R						

1. PROJECT PART

1.1 Analysis of prototypes and short description of designing aircraft

The aircraft is designed to carry passengers, cargo baggage, mail, on main international airlines with a middle range passenger traffic. The main aim markets are: Europe and the CIS countries, Africa, Asia, Latin America, Middle East and some countries in the Far East.

1.1.1. Choise of the projected data

The selecting of the optimum design parameters of the aircraft is the multidimensional optimization task, aimed at forming a "look" promising aircraft.

In its configuration mean the whole complex flight-technical, weight, geometrical, aerodynamic and economic characteristics. In forming the "Appearance of the plane" in the first stage is widely used statistics methods transfers, approximate aerodynamic and statistical dependence. The second stage uses a full aerodynamic calculation; aircraft specified formulas of aggregates weight calculations, experimental data.

Prototypes of the aircraft, taking for aircraft designing were in class 160-190 passengers. Such aircraft like Boeing 737-800, Airbus 320 and Airbus 319 will compete with projected aircraft in this market segment. Statistic data of prototypes are presented in table 1.1.

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Supervisor	*Yuskevych S.S*						
Instructor					*AF 402 134*		
N. contr	*Khizhnyak S.V.*						
Head of Dep	*Ignatovich S.R*						

Table 1.1 – Operational-technical data of prototypes

PARAMETER	PLANES		
	B 737-800	A320	A319
The purpose of airplane	Passenger	Passenger	Passenger
Crew/flight attend. persons	2/4	2/4	2/3
Maximum take-off weight, m_{tow}, kg	78245	77000	75 500
Most pay-load, $m_{к.max}$, kg	18260	18000	15000
Passenger's seat	189	180	156
The height of the flight $V_{w.\ ек.}$, m	12400	12000	11900
Range $m_{к.max}$, km	6050	6100	6800
Take off distance $L_{зл.д.}$, m	2307	2090	1950
Number and type of engines	2xCFM56	2xCFM56	2xCFM56
The form of the cross-section fuselage	circular	circular	circular
Extension of the fuselage	9,4	9,2	8,38
Extending the nose and tail unit part	5,64	5.62	4,2
Sweepback on 1/4 chord, ^{0}	25	25	25

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

1.1.2 Brief description of the main parts of the aircraft

Designed plane is twin-engine narrow-body low-winged aircraft with straight angle wing and classical type of the empennage.

Engines provide the thrust needed to fly, correspond to the weight and needed thrust the designed aicraft has 2 engines installed under the wing. Today, there are many different types of engines, but all perform the same basic function of taking the air that’s in front of the aircraft, pushing and give the accelerating out behind the aircraft. It’s performed by compressing the air using turbines, with help of fan or propeller.

The **fuselage** has a circular cross section, a semi-monocoque construction. Accommodates a pressurized cabin for the crew and passengers. The fuselage combine advantages of parts shape and its elongation, has a minimum resistance and a high critical value of the number M. Fuselage interior includes: passenger cabin, flight compartment, galleys, lavatories, cargo compartment, electronic compartment.

The **wing** provides lift required for flight. Its shape is specifically designed for the aircraft to which it is attached. Design aircraft has sweepback wing for better aerodynamic characteristics and high durability and mechanization of the wing are presented of Krueger flaps in comparing with slats. Inside the wing located the fuel tank.

The **rudder** controls the flight attitude of the airplane about the vertical axis. The rudder hinges installed at the aft of the rear spar of the vertical stabilizer.

The **elevators** control the pitch attitude of the airplane about the lateral axis. The elevators are on the trailing edge of the horizontal stabilizer.

The **flight controls systems** keep the airplane at the necessary attitude during flight. They have movable surfaces on the wing and the empennage.

Primary flight control system moves the airplane about three axes: lateral, longitudinal, and vertical, which include ailerons, elevator, rodder. Secondary flight controls improve the lift and handling properties of the airplane, includes leading edge devices , trailing edge flaps, spoilers and speedbrakes, horizontal stabilizer

The **landing gear** provides support for the airplane static and ground maneuvering conditions. The landing gear also reacts to airplane load forces that are generated during airplane movement. A designed airplane has two main gear and single nose gear.

1.1.3. Technical description of the aircraft

The aircraft will be a sample of the Boeing 737 which will consist of 189 passengers.

The aircraft has a "normal" design or "classic", i.e. the horizontal stabilizer is located behind the wing.

Designed a 2-engine aircraft according to the task and some analogues.

As a design scheme of the aircraft taken low-wing airplane with swept-back wings and two engines on pylons under the wings.

Applicable classic tail unit does not require additional mounting points, except directly to the fuselage.

This configuration provides a high aerodynamic efficiency, the required lifting efficiency of the wing for the standardized characteristics of stability and controllability under all anticipated operating conditions.

Were used the tricycle landing gear with nose wheel and two main bearings, located under the wing, and retractable into the fuselage.

The applicable chassis with three main bearings allows to operate the aircraft with a runway capable of accepting a light aircraft. It does not require any reconstruction of the runway of the airfield.

The wing with a sweep of 25 degrees combined with the fuselage diameter of almost 4 meters, is characterized by high aerodynamic perfection, provides high aerodynamic quality of the aircraft at cruising speed, the corresponding value of M = 0.75, as well as on the takeoff and landing.

The designed model of the aircraft will embody a high level of flights safety, their comfort, high operational efficiency and adaptability in production.

1.1.4. Selection and justification of the scheme of the aircraft

Chosen the scheme "low-wing airplane" because it is the most common passenger aircraft:

- it provides a higher security in emergency landing on the ground and water;
- under this scheme the mass of the structure will be the lowest since the main landing gear is connected with the wing and its size and weight is lower than a " high-wing airplane."

Chosen the standard (classical) scheme with the aerodynamic configuration of the horizontal stabilizer located behind the wing because:

- it easily provides the balance with lowered flaps;
- this scheme allows you to make the nose of the fuselage shorter, which improves the view of the pilots, reduces the square of vertical unit as a shortened nose of the fuselage causes less destabilizing yawing moment;
- it gives the opportunity to reduce the square and horizontal and vertical units, as their shoulders are much farther than in other designs.

Chosen sweep-shaped wing as the aircraft speed exceeds the number of M> 0,6. It’s provide better aerodynamic characteristics and high durability for designed aircraft speed.

Chosen turbofan engine on the designed plane because we deal with a high-speed passenger plane and this type of the engine provides needed thrust and high fuel efficiency. The engines are placed under the wing.

1.2. Geometry calculations for the main parts of the aircraft

Layout of the aircraft consists from composing the relative disposition of its parts and constructions, and all types of the loads (passengers, luggage, cargo, fuel, and so on).

Choosing the scheme of the composition and aircraft parameters is directed by the best conformity to the operational requirements.

1.2.1. 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:

$$S_{wfull} = \frac{m_0 \cdot g}{P_0} = (90759 \cdot 9.8)/6425.6 = 138.42\ [m^2];$$

Relative wing extensions area is 0.1

Wing area is:

$$S_w = 124.58\ [m^2];$$

Wing span is:

$$l = \sqrt{S_w \cdot \lambda_w} = \sqrt{9.45 \cdot 124.58} = 34.31\ [m];$$

Root chord is:

$$b_0 = \frac{2 \cdot S_w \cdot \eta_w}{(1+\eta_w) \cdot l} = \frac{2 \cdot 124.58 \cdot 0.15}{(1+0.15) \cdot 34.31} = 7.87\ [m];$$

Tip chord is:

$$b_t = \frac{b_0}{\eta_w} = \frac{7.87}{0.15} = 1.25\ [m];$$

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

$$c_i = c_w \cdot b_t = 0.11 \cdot 1.25 = 0.137\ [\mathrm{m}];$$

The a geometrical method of mean aerodynamic chord determination was used (figure 2.1):

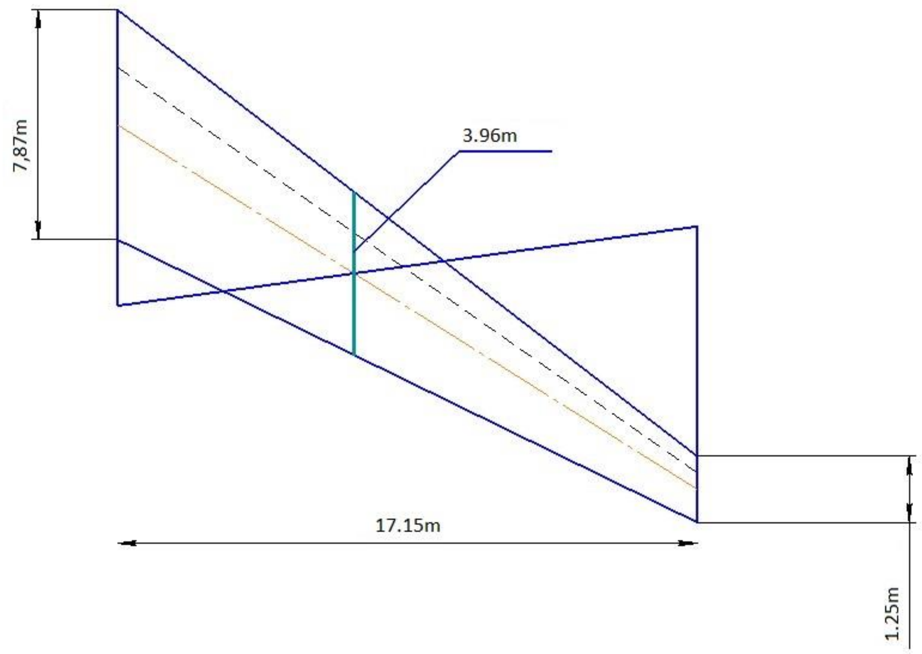


Figure 2.1. – Determination of mean aerodynamic chord

Mean aerodynamic chord is equal:

$$b_{MAC} = 3.96 \text{ [m]};$$

Estimation of the ailerons geometrics and high-lift devices:

Ailerons span:

$$l_{ai} = 0,375 \cdot \frac{l_w}{2} = 0.375 \cdot (34.31/2) = 6.433 \text{ [m]};$$

Aileron area:

$$S_{ail} = 0.065 \cdot \frac{S_w}{2} = 0.065 \cdot (124.52/2) = 4.05 \ [m^2];$$

Aerodynamic balance of the aileron.

Hinge balance:

$$S_{axinail} \le (0.25\ldots0.28) \cdot S_{ail}$$

$$S_{ail} = 0,26 \cdot 4.05 = 1.053 \ [m^2];$$

Area of ailerons trim tab.

For two engine airplane:

$S_{tail} = 0,05...0,06 \cdot S_{ail} = 0,05 \cdot 4.05 = 0.162$ [m^2];

Range of aileron deflection:

- Upward $\delta'_{ail} \geq 20^{\circ}$;
- Downward $\delta''_{ail} \geq 10^{\circ}$.

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

Before doing following calculations it is necessary to choose the type of airfoil due to the airfoil catalog, specify the value of lift coefficient $C_{y\max bw}$ and determine necessary increase for this coefficient $C_{y\max}$ for the high-lift devices outlet by the formula: $\Delta C_{y\max} = (\frac{C_{y\max l}}{C_{y\max bw}})$.

Where $C_{y\max l}$ is necessary coefficient of the lifting force in the landing configuration of the wing by the aircraft landing insuring (it is determined during the choice is the aircraft parameters).

b_f = 0.3..0.4 – for three slotted flaps and Krueger flaps;

1.2.2 Fuselage layout

For transonic airplanes fuselage nose part has to be:

$$l_{nfp} = 2.1 \cdot D_f = 2.1 \cdot 4.02 = 8.442 \text{ [m]};$$

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 length is equal:

$$l_f = \lambda_f \cdot D_f = 9.45 \cdot 4.02 = 38.02 \text{ [m]};$$

Fuselage nose part aspect ratio is equal:

$$\lambda_{fnp} = \frac{l_{fnp}}{D_f} = \frac{8.442}{4.02} = 2.11$$

Length of the fuselage rear part is equal:

$$l_{frp} = \lambda_{frp} \cdot D_f = 2.11 \cdot 4.02 = 8.442 \text{ [m]}$$

Cabin height is equal:

$$H_{cab} = 1.48 + 0.17 B_{cab} = 1.48 + 0.17 \cdot 3.54 = 2.2\ [m];$$

For economic salon with the scheme of allocation of seats in the one row (3 + 3) determine the appropriate width of the cabin:

$$B_{cab} = n_{3chblock} \cdot b_{3chblock} + b_{aisle} + 2\delta = 2 \cdot 1500 + 450 + 2 \cdot 50 = 3.5\ [m];$$

The length of passanger cabin is equal:

$$L_{cab} = L_1 + (n_{raws} - 1) \cdot L_{seatpitch} + L_2 = 30.02\ [m];$$

1.2.3 Luggage compartment

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

The area of cargo compartment is defined:

$$S_{cargo} = \frac{M_{bag}}{0.4 \cdot K} + \frac{M_{cargo}}{0.6 \cdot K} = \frac{20 \cdot 189}{0.4 \cdot 600} + \frac{15 \cdot 189}{0.6 \cdot 600} = 23.6\ [m^2];$$

Cargo compartment volume is equal:

$$V_{cargo} = v \cdot n_{pass.} = 0.2 \cdot 189 = 37.8\ [m^3];$$

1.2.4 Galleys and buffets

International standards provide that if the plane made a mixed layout, be sure to make two dishes. If flight duration less than 3 hours at this time of food to passengers not issued in this case provided cupboards for water and tea. Tickets to the flight time less than one hour buffets and toilets can not be done.[CS-25]

Volume of buffets(galleys) is equal:

$$V_{galley} = 0.1 \cdot n_{pass.} = 0.1 \cdot 189 = 18.9\ [m^3];$$

Area of buffets(galleys) is equal:

$$S_{galley} = \frac{V_{galley}}{H_{cab}} = \frac{18.9}{2.2} = 8.59\ [m^2];$$

1.2.5 Lavatories

Number of toilet facilities is determined by the number of passengers and flight duration: with t> 4:00 one toilet for 40 passengers, at t = 2 ... 4 hours and 50 passengers t <2 hours to 60 passengers [2].

$$n_{lav} = 3;$$

Area of lavatory:

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

Width of lavatory: 1m.

1.2.6 Layout and calculation of basic parameters of tail unit

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

$$m_x^{C_y} = \overline{x}_T - \overline{x}_F < 0$$

Where m^{Cy}_x –is the moment coefficient; $x_{T.}$ x_F- center of gravity and focus coordinates. If $m^{Cy}_x=0$, than the plane has the neutral longitudinal static stability, if $m^{Cy}_x>0$, than the plane is statically instable. In the normal aircraft scheme (tail unit is behind the wing), focus of the combination wing – fuselage during the install of the tail unit of moved back.

Static range of static moment coefficient: horizontal A_{htu}, vertical A_{vtu} given in the table with typical arm Htu and Vtu correlations. Using table we may find the first approach of geometrical parameters determination.

Determination of the tail unit geometrical parameters:

Area of vertical stabilizer is equal:

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

Area o horizontal stabilizer is equal:

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

Determination of the elevator area and direction:

$$0.3 \le M \le 0.6,\ S_{eb}=(0.22..0.28)S_{ea},\ S_{rb}=(0.2..0.24)S_{rd}$$

Altitude elevator area:

$$S_{el} = 0.2765 \cdot S_{HTU} = 9.07\ [m^2];$$

Rudder area:

$$S_{rud} = 0.2337 \cdot S_{VTU} = 6.18\ [m^2];$$

The area of altitude elevator trim tab:

$$S_{te} = 0.08 \cdot S_{el} = 0.72\ [m^2];$$

Area of rudder trim tab is equal:

$$S_{tr} = 0.06 \cdot S_{rud} = 0.3708\ m^2$$

Root chord of horizontal stabilizer is:

$$b_{0HTU} = \frac{2S_{HTU} \cdot \eta_{HTU}}{(1+\ \eta_{HTU}) \cdot l_{HTU}} = 1.948\ [m];$$

Tip chord of horizontal stabilizer is:

$$b_{0HTU} = \frac{b_{0HTU}}{\eta_{HTU}} = 0.79\ [m];$$

Root chord of vertical stabilizer is:

$$b_{0VTU} = \frac{2S_{VTU} \cdot \eta_{VTU}}{(1+\ \eta_{VTU}) \cdot l_{VTU}} = 5.82\ [m];$$

Tip chord of vertical stabilizer is:

$$b_{0VTU} = \frac{b_{0VTU}}{\eta_{VTU}} = 2.97\ [m]$$

1.2.7 Landing gear design

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

Main wheel axial offset is:

$$e = 0.2673 \cdot b_{MAC} = 0.2673 \cdot 3.96 = 1.0585 \text{ [m]};$$

Landing gear wheel is:

$$B = 0.4526 \cdot L_f = 0.4526 \cdot 34.46 = 15.6 \text{ [m]};$$

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

Front wheel axial offset will be equal:

$$d_{ng} = B - e = 14.542 \text{ [m]};$$

Wheel track is:

$$T = 0.6072 \cdot B = 0.6072 \cdot 15.6 = 5.71 \text{ [m]};$$

The load on the wheel is determined:

K_g = 1.5...2.0 – dynamics coefficient.

Nose wheel load is equal:

$$P_{NLG} = \frac{(9.81 \cdot e \cdot k_g \cdot m_0)}{(B \cdot z)} = \frac{9.81 \cdot 1.0585 \cdot 1.75 \cdot 90759}{15.6 \cdot 2} = 52781.86 \text{ [N]};$$

Main wheel load is equal:

$$P_{MLG} = \frac{(9.81 \cdot (B - e) \cdot m_0)}{(B \cdot n \cdot z)} = \frac{(9.81 \cdot (15.6 - 1.058) \cdot 90759)}{15.6 \cdot 2 \cdot 2} = 207461.98 \text{ [N]};$$

Table 1.2 – Aviation tires for designing aircraft [10];

Speed (MPH)	Main Gear		Nose Gear	
	Tire Size	Ply Rating	Tire Size	Ply Rating
225	H40*14.5-19	26	27*7.75-15	12
225	H42*14.5-19	26		
225	H40*16.0-21	24	27*7.75-15	12

1.2.8 Choice of power plant

Needed thrust for designed aircraft is 90kN. Compared with the CFM56-7, it has greater durability, 8% fuel burn improvement and a 15% reduction in maintenance costs. So, according to the requirements was chosen engine with following parameters in table 1.3

Table 1.3 – Parameters of chosen engine

Model	Thrust	Bypass ratio	Dry weight
CFM56-7B20	20,600 lbf (91.6 kN)	5.34	2370 kg

1.3 Center of gravity calculation

1.3.1 Trim-sheet of the equipped wing

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

The example list of the mass objects for the aircraft, where the engines are located under the wing, included the names given in the table 1.4.The example list of the mass objects for the aircraft, where the engines are located in the wing, included the names given in the table 1.5. The mass of designed aircraft is 90759 kg. Coordinates of the center of power for the equipped wing are defined by the formulas:

$$X_w^{/} = \frac{\Sigma m_i^{/} x_i^{/}}{\Sigma m_i^{/}}$$

Table 1.4 - Trim sheet of equipped wing

N	Name	Mass		C.G. coordinates x_i (m)	Moment $m_i x_i$ (kgm)
		Units	total mass m_i (kg)		
1	Wing (structure)	0,0991	8994,2	1,7	15290,16
2	Fuel system, 40%	0,0088	798,6	1,98	1581,38
3	Control system, 30%	0,02	1815,18	2,376	4312,86
4	Electrical equip. 10%	0,009	816,8	0,396	323,46
5	Anti-icing system 70%	0,016	1452,1	-0,396	-575,04
6	Hydraulic system, 70%	0,011	998,3	2,376	2372,07
7	Power units	0,09366	8500,48	0,8	6800,39
8	Equipped wing without fuel and LG	0,25756	23375,8	1,28787	30105,30
9	Nose landing gear	0,00648	588,3	-13,55	-7972,48
10	Main landing gear	0,03299	1994,7	2,178	4344,52
11	Fuel	0,296	26864,6	1,65	44326,69
	Equipped wing	**0,58202**	**52823,6**	**1,34038**	**70804,03**

1.3.2 Trim-sheet of the equipped fuselage

Origin of the coordinates is chosen in the projection of the nose of the fuselage on the horizontal axis. For the axis X the construction part of the fuselage is given. The example list of the objects for the aircraft, which engines are mounted under the wing, is given in table 1.5.

The CG coordinates of the FEF are determined by formulas:

$$X_f = \frac{\Sigma m_i^{/} X_i^{/}}{\Sigma m_i^{/}};$$

After we determined the C.G. of fully equipped wing and fuselage, we construct the moment equilibrium equation relatively to the fuselage nose:

$$m_f x_f + m_w (x_{MAC} + x'_w) = m_0 (x_{MAC} + C)$$

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

$$X_{MAC} = \frac{m_f x_f + m_w \cdot x'_w - m_0 C}{m_0 - m_w}$$

where $\boldsymbol{m_0}$ – aircraft takeoff mass, kg; $\boldsymbol{m_f}$ – mass of fully equipped fuselage, kg; $\boldsymbol{m_w}$ – 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) $\mathbf{B_{MAC}}$ –low wing [2];

For swept wings; at ***X*** = 25°...40° ***C*** = (0,28...0,32) $\mathbf{B_{MAC}}$ **[2]**

Table 1.5 – Trim sheet of equipped fuselage

№	Objects	Mass		Coordinates of C.G.	Moment (kgm)
		Units	Total (kg)		
1	2	3	4	5	6
1	Fuselage	0,0884	8023	19,01	152519,04
2	Horizontal TU	0,0097	880,3	0,85	748,30
3	Vertical tail unit	0,00958	869,4	1,6	1391,15
Equipment					
4	Radar	0,0031	281,3	0,3	84,40
5	Radar equipment	0,0023	208,7	1,1	229,62
6	Instrument panel	0,0053	481	3,4	1635,47
7	Air-navigation system	0,0046	417,4	5,02	2095,80
8	Radio equipment	0,0023	208,7	2,32	484,29
9	Toilet 1	0,00146	133,1	4,09	544,44
10	Toilet 2 and 3	0,00293	266,2	30,99	8250,27
11	Cargo compartment equipment	0,003	272,2	23,592	6423,55
13	Buffet 1	0,00146	133,1	5,25	698,85

Continuing of table 1.5

1	2	3	4	5	6
14	Buffet 2	0,00293	266,2	32,5	8652,27
15	Control system, 70%	0,00857	777,8	19,01	14786,06
16	Electrical equipment, 70%	0,0255	2314,3	19,01	43995,87
17	Hydraulic system, 30%	0,036	3267,3	26,614	86956,56
18	Water 1	0,00065	58,99	4,4652848	263,42
19	Water 2	0,001299	117,9	17,652247	2082,70
20	Oxygen equipment	0,002484	225,5	20,9	4713,01
21	Anti-icing system, 30%	0,004536	411,6	30,464	12541,50
22	Rescue equipment	0,001	90,7	6,058	549,81
23	Seats of pass. economical class	0,01051	954,3	20,9	19946,20
24	Rescue equipment	0,001	90,7	29,431	2671,12
25	Seats of crew	0,000367	33,3	2,67	89,11
26	Seat of attendants 1 and 2	0,00023	20,8	4,26	88,92
27	Seat of attendants 3 and 4 and 5	0,00059	53,5	31,48	1685,68
28	Fuel system, 60%	0,0048	435,6	17,95	7819,79
30	Equiped fuselage without comercial loads	0,239623	21748,010	18,1	390573,991
31	Passangers of economical class	0,06875	10190	20,9	212971
32	Passangers of business class	0,07933	1115	7,39	8239,85
33	Food 1	0,00072	65,5586	4,465284	292,73809
34	Food 2 and 3	0,00144	131,1173	32,6411	4279,8209
35	Baggage of passanger 1	0,017188	1560	11,481828	17911,651

End of the table 1.5

1	2	3	4	5	6
36	Baggage of passanger 2	0,01983	1800	24,9	44820
37	Cargo	0,00832	756	29,86	22574,16
38	Crew	0,00264	240	2,67	640,8
39	Attendants 1 and 2	0,001762	120	4,26	511,2
40	Attendants 3,4 ,5	0,001762	180	17,11042	3079,8764
	Total	**0,41765**	**37905,686**	**18,62240**	**705895,089**
	Checking	0,99967	90729,343		

1.3.3 Calculation of center of gravity positioning variants

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

Table 1.6 – Calculation of C.G. positioning variants

Name	Mass, kg	Coordinates	Moment
Object	m_i	C.G. M	kgm
1	2	3	4
Equiped wing without fuel and L.G.	23375,88	18,2	425441,16
Nose landing gear (retracted)	588,3	26,7	15709,6
Main landing gear (retracted)	1994,73	45,2	90161,7
Fuel	26864,6	2,1	56415,7
Equiped fuselage	21748	18,1	393638,9
Passangers of economical class 1	10190	20,9	212971

End of the table 1.6

1	2	3	4
Passangers of economical class 2	1115	7,39	8239,85
Food 1	65,5	5	327,7
Food 2	131,1	31	4064,6
Baggage of passanger 1	1560	11,5	17940
Baggage of passanger 2	1800	24,9	44820
Cargo	756	27,86	21062,16
Crew	240	2,67	640,8
Attendants 1	120	4,26	511,2
Attendants 2	180	31,46	5662,8
Nose landing gear (opened)	588,3	24,6922826	14528,3
Main landing gear (opened)	1994,7	43,9	87568,6

Table 1.7– Airplanes C.G. position variants

№	Variants of the loading	Mass, kg	Moment of the mass, кg*m	Centre of the mass, m	Centering
1	Take-off mass (L.G. opened)	90729,3	1297607,6	19,3	23,03
2	Take-off mass (L.G. retracted)	90729,3	1293833,1	19,26	21,97
3	Landing variant (L.G. opened)	86932,49	1285654,8	19,7	29,28
4	Transportation variant (without payload)	75111,6	984407,71	18,9	20,09
5	Parking variant (without fuel and payload)	47707	924951,5	19,3	25,20

1.4 Conclusions to the Project Part

During this designing work were obtained next results:

- preliminary design of the middle range aircraft with 189 passengers;

- the cabin layout of the middle range aircraft with 189 passengers;

-the center of gravity of the airplane calculations for five different load schemes of projected aircraft in the range from 20,09 up to 29.28, given in table 1.7;

-the choose of the wheels, which satisfy the theoretic loads during speed 225 MPH: tire size for main wheel H40*14.5-19 and for nose wheel 27*7.75-15 ;

The chosen design of narrow-body aircraft powered by two engines CFM56-7B20 , which are located under wing, makes it possible to increase aerodynamic characteristics of the wing, to reduce the aerodynamic effects from engines jet stream and to decrease the noise level in passenger cabin.

Provides the maximum level of passenger comfort by using rational layout and convenient service facilities, ergonomic optimization of common and individual space, modern interior design, insulation blankets, which provide low noise in the passenger cabin;

Installation of turbofan engines type, CFM56-7B20 provides high cruise speed and good thrust-to weight ratio.

2. CARGO FASTENING SYSTEM

2.1 Problem statement

Currently, according to the situation in the world, airlines are looking for opportunities to reduce losses by converting passenger cabins into cargo . Thus, more and more companies are looking for a compact and smart solution for such transportation. And most importantly, that this solution was safe and profitable. To do this, following idea to convert the passenger compartment into a cargo.

2.2 Overview of cargo transportation in the cabon of passenger aircraft

HAECO company propose to carry the baggage on the top of passenger seats. Simply installed frame-mounted strapping, with no reconfiguration. Similarly to the seat stowage, sees boxes stored on the cabin floor in the row of passenger seat. Its solutions can be quickly reversed as changes. All stowage device optimized by frame and tie-down system both above and below the airline existing seat track.

“Fig. 2.1 - Example of cargo solution on the passenger seat and floor”[6]

				NAU 20 12 S 00 00 00 39 EN
Performed by	Savenok V.V.			Special part
Supervisor	Yuskevych S.S			Letter / Sheet / Sheets
Instructor				
N. contr	Khizhnyak S.V.			AF 402 134
Head of Dep	Ignatovich S.R			

“The palletized version can hold 1000lbs, the all-in-one seat frame can hold 500lbs, and the seat and floor storage systems can hold 240lbs. This gives airlines specific load permissions and the ability to carry heavier cargo. Instead of smaller packages, carriers can now carry larger items in the cabin. which they would have loaded in the belly, with the exception of hazardous materials.” [6]

“Fig. 2.2 - Example of cargo on the block of seats.” [6]

The maximum allowed capacity of reconfigured passenger cabin in the Boeing 737-800 is up to 19 000 kg.

Operational aspects of cargo transportation in passenger compartment according EASA.

Procedures of the cargo transportation in the passenger cabin

“a) A risk assessment shall be performed in order to identify hazards related to operating cargo flights using cabin configurations which have been approved for transporting only passengers.

b) Checks shall be made before take-off, before landing and whenever requested by the captain to ensure that cargo is properly stowed and secured.

c) Operators shall establish procedures to manage emergencies in the cabin.

d) Operators shall publish temporary revisions to the OM to include the new type of operations and the related procedures.” [7]

Loading for transport of cargo in passenger compartment including on passenger seats

“a) Exact cargo weight and position in the cabin and in the cargo hold shall be reflected in the mass and balance documentation (load sheet).

b) The pilot-in-command shall be provided with information on the content of all the cargo such as through provision of the cargo manifest or other appropriate documentation.

c) The operator shall load the aircraft considering the different levels of available fire protections of the loading areas (i.e. passenger cabin and lower deck cargo compartments).

d) For the bulkheads that have a placard indicating maximum capacity, the cargo items stowed in aft of these bulkheads shall not exceed the maximum capacity indicated in the placard.

e) The maximum capacity limitations in the required safety placards (on or adjacent to the cargo approved stowage locations) shall not be exceeded. All stowage instructions specified in the placards apply.

f) The mass of the cargo shall not exceed the structural loading limits of the aircraft. Compliance with CS-25.

g) The cargo placed in enclosed stowage areas shall not be of such size that they prevent latched doors from being closed securely.

h) The cargo items shall be stowed only in a location that is capable of restraining it.

i) The cargo stowage location shall be such that, in the event of an emergency evacuation, it will not hinder aisle access and egress.

j) The cargo shall not be placed where it can impede access to emergency equipment.

k) The cargo shall be checked to ensure proper stowage in the following instances (at the minimum):

- Before take-off,
- Before landing,
- Under orders of the Pilot in Command (PIC).

l) The aisle(s) shall remain free of cargo to enable access to the seats and the goods in case of smoke or fire.

m) Any smoke/ fire within the cabin must be easily detected and effectively fought using the existing emergency equipment. Thoroughly briefed crew members (not part of the flight crew) shall be on-board to survey and access all areas of the cabin during all flight phases. There must be an adequate number of trained crew members acting as fire-fighter with sufficient amount of firefighting equipment. This equipment may be stowed in the cabin using existing stowage provisions (overhead bins, stowage's) provided that the location is identifiable for the crew. Specific details must be coordinated with local regulatory authorities.

n) Crew members in the cabin should use existing cabin crew seats and must not share seat rows with cargo. There must be a clear separation of areas occupied by cabin occupants and those fitted with cargo during taxi, take-off and landing. At least one empty seat row between cargo and reserved occupant seats must be established.

o) 'Under seat stowage' is allowed only if the seat is equipped with a restraint bar system and the cargo items can be placed fully underneath the seat. The loading of the cargo under each seat should not exceed 9 kg (20 lbs).

p) The cargo packaging shall be able to equalize the pressure so that it can handle the Delta Pressure (DP) during the flight, as applicable.

q) All smoke and fire detectors shall be maintained as per Maintenance Manual instructions.

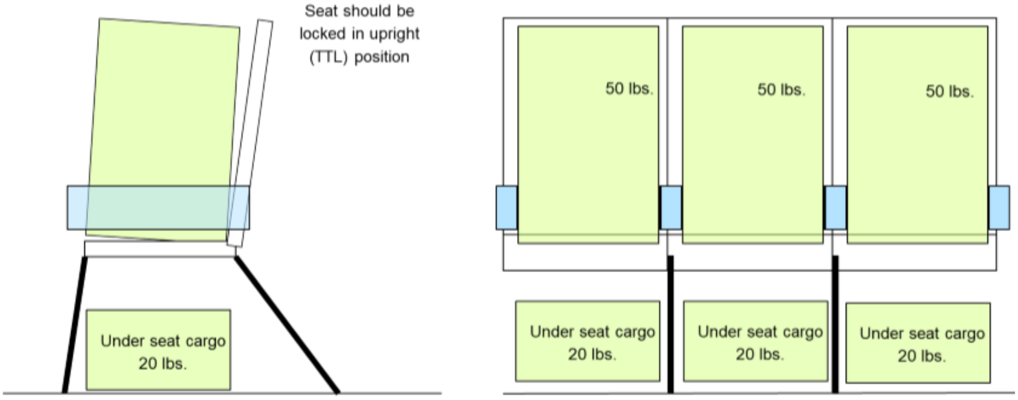
r) The Air Conditioning system shall be set taking into account the nature of the cargo transported in the cabin and the number and distribution of cabin occupants.

v) If nets are used to restrain cargo items, these nets should be (E)TSO approved and any load limitations of these nets including their attachment means should be adhered to. Any deformation of these nets due to the mass of the cargo items restrained under emergency landing, flight or ground loads should be evaluated for contact to other objects in the cabin and be shown not to block emergency evacuation paths nor access to emergency equipment.” [7]

Example for loading cargo on seats :

- Cargo carriage on seat for 3 boxes maximum 22.5kg.

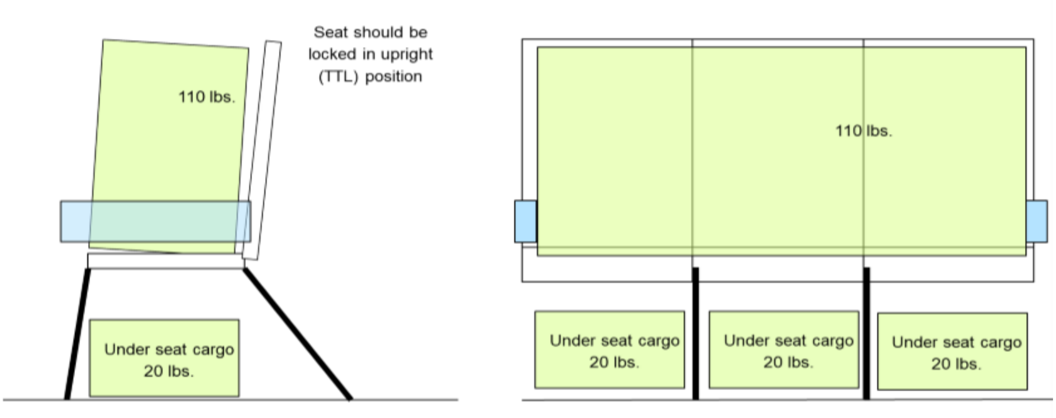
Maximum cargo height is top of seat backrest;



“Fig. 2.3 - Example of cargo on the seats for 3 boxes.” [8]

- Cargo carriage on seat for 1 box maximum 50kg .

Maximum cargo height is top of seat backrest;



“Fig. 2.4 - Example of cargo on the block of seat.” [8]

Procedures for loading and unloading

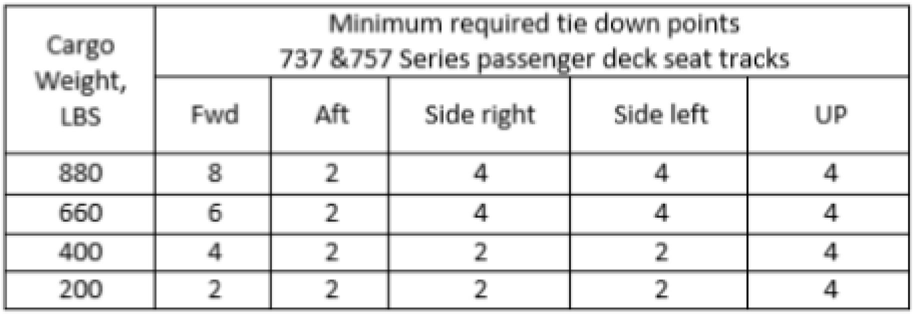
“Sequence for loading*:*

- First, load the lower forward cargo compartment
- Next, load the main deck from the front to the back
- Last, load the lower centre/aft cargo compartments (lower cargo compartment aft of the wing)

Sequence for unloading:

- reverse order from loading sequence.” [9]

Minimum required tie down points.



Cargo Weight, LBS	Minimum required tie down points 737 &757 Series passenger deck seat tracks				
	Fwd	Aft	Side right	Side left	UP
880	8	2	4	4	4
660	6	2	4	4	4
400	4	2	2	2	4
200	2	2	2	2	4

Table. 2.1 – Minimum required tie down points;

Note: One strap has two tie down points engaged in the tracks.

Examples of fittings

Fig. 2.5 - Example of cargo fittings to the seat track

Fig. 2.6 - Example of a double stud fittings

2.3 Re-equipment of passenger cabin:

- Installation of the passenger seats in following order 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30.

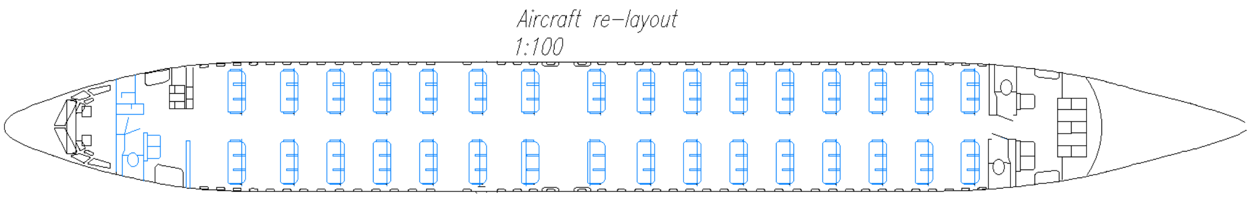


Fig.2.7 Re-layout of passenger cabin

- <u>Loading cargo on seats</u>:

a) Install the cargo carriage on seat for 3 boxes maximum 50 kg.

For it maximum cargo height will be not higher than seat backrest .

b) Other variant, install interim cargo carriage on seat for 1 box maximum 200 kg.

For it maximum cargo height will be not higher than seat backrest .

c) Boxes must be fasten by 4 fittings and 2 ropes. Minimum required tie down points: fwd-2; aft-2; side left-2; side right- 2.

- <u>Element of cargo fastening system:</u>

Fittings - a device with which luggage is attached to the point of attachment, namely the seat track, for safe transportation.

Ropes – a device for secure attachment around luggage.

Lanyards - a device for creating tension or eliminating the relaxation of tension.

Note: Make sure that all fittings, ropes, lanyards, all load securing will withstand any load. The weakest element of the system is the ropes. The belt and fitting determines the holding capacity of the fasteners. We take into account the angle between the actual direction of the force and the belt. If the angle between the actual direction of force and the belt is 0 °, so the maximum holding capacity of the rope or belt will be applied. And larger this angle, the belt's ability to hold is more reduced. At an angle of 45 ° between the actual direction of force and the belt should be done for cargo snapping.

- Maximum holding capacity and minimum required number of ropes and fittings of the load securing system

Table 2.2 - Maximum holding capacity of load securing system;

Restraint equipment	Holding capacity
Braided multilayer rope	Up to 300 kg
Fittings for light loads (with rings)	Up to 900 kg
Fittings for heavy loads (solid)	Up to 2250 kg

Table 2.3 - Minimum required number of ropes and fittings;

Cargo weight kg	Up		Other direction	
	Ropes	Fittings	Ropes	Fittings
Up to 199kg	1	2	1	2
200-399	2	2	1	2
400-599	3	2	2	2
600-799	4	4	2	2
800-999	5	4	3	2

Note: table refers for lightweight cargo fittings and for tying loads around from one fixture to another.

- All fittings and ropes of any type must be approved by the airline;
- Minimum interval for installation fittings, between each other, must be 50 cm;
- Ropes must be attached to the product;

- To one fitting or mounting device we can attached maximum 3 ropes in the same directions.

2.4 Calculations of a cargo mounts

Cargo boxes located on the passenger seat with height not more, than top of seat backrest. Tie-down points located on seat track and for luggage fastening are used double fittings and ropes.

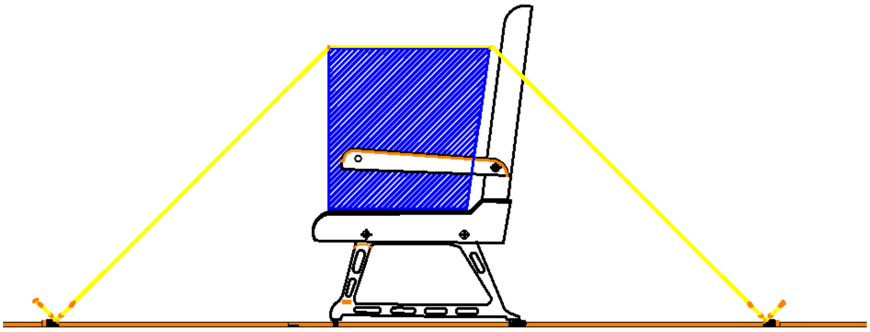


Fig. 2.7 – Luggage fastening

Reliable fastening should provide against displacement during transportation from overloads ((forward, backward, sideways)

In case of cargo less than 1000kg, overloads will be:

- Forward n_x^p= 9
- Backward n_y^p= 2
- Sideways n_z^p= 1.5

If the weight fits up to 17 frames, then n_z^p=3

$x_1 = a_1 = 100$ $y_1 = h_1 = 102$ $z_1 = b_1 - b_2 = 112$
$x_2 = a_2 = 100$ $y_2 = h_1 = 102$ $z_2 = b_1 - b_2 = 112$
$x_3 = f_1 = 100$ $y_3 = h_1 = 102$ $z_3 = b_1 - b_2 = 112$
$x_4 = f_2 = 100$ $y_4 = h_1 = 102$ $z_4 = b_1 - b_2 = 112$

Calculate the direction cosines for the respective directions for each mooring element:

$l = \sqrt{x^2 + y^2 + z^2}$

$l_1 = 181.515$ $\cos x_1$=0.551 $\cos y_1$=0.562 $\cos z_1$=0.617

$l_2 = 181.515$ $\cos x_2$=0.551 $\cos y_2$=0.562 $\cos z_2$=0.617

$l_3 = 181.515$ $\cos x_3$=0.551 $\cos y_3$=0.562 $\cos z_3$=0.617

$l_4 = 181.515$ $\cos x_4$=0.551 $\cos y_4$=0.562 $\cos z_4$=0.617

Determine the stiffness coefficient:

$C_x=\frac{cos^2(x_i)}{l}$ $C_y=\frac{cos^2(y_i)}{l}$ $C_z=\frac{cos^2(z_i)}{l}$

C_{x1}=0.0016 C_{y1}= 0.0017 C_{z1}= 0.0021

C_{x2}=0.0016 C_{y2}=0.0017 C_{z2}=0.0021

C_{x3}=0.0016 C_{y3}=0.0017 C_{z3}=0.0021

C_{x4}=0.0016 C_{y4}=0.0017 C_{z4}=0.0021

Determine the coefficients of effort:

$\alpha_x=\frac{cos_x}{l}$ $\alpha_y=\frac{cos_y}{l}$ $\alpha_z=\frac{cos_z}{l}$

α_{x1}=0.003 α_{y1}=0.0031 α_{z1}=0.0034

α_{x2}=0.003 α_{y2}=0.0031 α_{z2}=0.0034

α_{x3}=0.003 α_{y3}=0.0031 α_{z3}=0.0034

α_{x4}=0.003 α_{y4}=0.0031 α_{z4}=0.0034

Determine inertial forces acting on the load:

$$Q_x= n_x^p \cdot G = 9 \times 200 = 1800$$

$$Q_y= n_y^p \cdot G =2 \times 200 = 400$$

$$Q_z= n_z^p \cdot G =1.5 \times 200 = 300$$

If the weight fits up to 17 frames: $Q_z= n_z^p \cdot G =3 \times 200 = 600$

Determine the forces in any mooring element from the action of external forces:

- From forces Q_x :

$$S_{x1} = S_{x2} = S_{x3} = S_{x4} = \frac{Q_x \cdot \alpha_{x1}}{\sum C_x} = \frac{1800 \cdot 0.003}{0.0064} = 843.75$$

- From forces Q_y :

$$S_{y1} = S_{y2} = S_{y3} = S_{y4} = \frac{Q_y \cdot \alpha_{y1}}{\sum C_y} = \frac{400 \cdot 0.0031}{0.0068} = 182.35$$

- From forces Q_z :

$$S_{z1} = S_{z2} = S_{z3} = S_{z4} = \frac{Q_z \cdot \alpha_{z1}}{\sum C_z} = \frac{300 \cdot 0.0034}{0.0084} = 121.43$$

$$S_{z1} = S_{z2} = S_{z3} = S_{z4} = \frac{Q_z \cdot \alpha_{z1}}{\sum C_z} = \frac{600 \cdot 0.0034}{0.0084} = 242.86$$

Compare the destructive forces of the mooring belt with the strength calculations and determine the safety factor:

$$S_m = S_x + S_y + S_z = 843.75 + 182.35 + 121.43 = 1147.53$$

$$\mu = \frac{4000}{S_m} = 3.487 > 1.5$$

Based on the calculations, the safety factor is more than 1.5, which means that the load is securely fastened and able to withstand overloads that occur during transportation.

2.5 Calculations of eyelet of fittings for static strength

Eyelets are critical structural elements. They usually work on repeated loads, so fatigue life should be checked for the eyes.

1) Design and calculate a eyelet from D16T for a force Pq = 400 kg, acting along the axis of symmetry of the eyelet. The diameter of the bolt is d = 20mm. Manufacturing tolerance equal 0.5mm.

Set the relation $\frac{b}{d} = 2.4$

$$D = 2cm, \qquad b = 2.4 \times 2 = 4.8\ [cm];$$

$$R = \frac{b}{2} = \frac{4.8}{2} = 2.4\ [cm];$$

$$x = \frac{b-d}{2} = \frac{4.8-2}{2} = 1.4\ [cm];$$

Set the relation $z = \frac{y}{x} = 1.4$

$$y = 1.4 \times 0.7 = 1.94 \sim 2\ [cm];$$

Eccentricity:

$$\varepsilon = y - x = 2 - 1.4 = 0.6\ [cm];$$

The thickness of the eyelet is chosen from the conditions of collapse:

$$\delta = \frac{P}{k1 \cdot d \cdot \sigma_в} = \frac{400}{1 \cdot 2 \cdot 727} = 0.3$$

So got the eyelet.

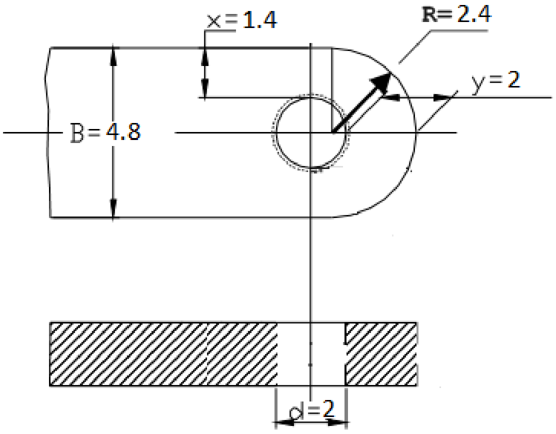


Fig. 2.8 – designed eyelet of fittings

2) Calculation of eyes loaded with force and bending moment.

The strength of such eyes must be checked for normal and tangential stresses.

Verification of strength under normal stresses.

Maximum normal stresses:

$$\sigma = \frac{P}{Fp} + \frac{M}{W}\ [\text{kg}/cm^2]$$

Where σ - maximum tensile stress in the eyelet;

$$\text{Fp} = 2 \cdot\cdot x \cdot \delta = 2 \cdot 1.4 \cdot 0.3 = 0.84$$

Where Fp - weakened cross-sectional area;

$$W = \frac{x \cdot \delta^2}{3} = \frac{1.4 \cdot 0.3^2}{3} = 0.02$$

Where W - moment of resistance over a weakened section;

$$\text{P} = k_1 \cdot d \cdot \delta \cdot \sigma_{\text{в}} = 1 \cdot 2 \cdot 0.3 \cdot 730 = 438\ [\text{N}]$$

Where P – external force; M - external bending moment.

$$\sigma = \frac{438}{0.84} + \frac{2}{0.02} = 621\ [\text{kg}/cm^2]$$

Safety margin for normal stresses:

$$\mu_p = \frac{\sigma_{\text{в}}}{\sigma}$$

Where $\sigma_{\text{в}}$ - tensile strength of the material [kg / cm^2].

$$\mu_p = \frac{730}{621} = 1.175 > 1$$

Maximum tangential stresses:

$$\tau_m = \frac{P}{F_m} + \frac{M}{W_m}\text{, [kg }/cm^2\text{]}$$

Where τ_m - maximum shear stress [kg / cm^2];

$$c = \frac{y}{x} = 1.43$$

$$\tau_m = \frac{438}{0.84} + \frac{2}{0.2} = 531\text{ [kg }/cm^2\text{]}$$

F_m - the area over which the slice of the eyelet occurs;

$$W_m = \frac{\delta \cdot c^2}{3} = \frac{0.3 \cdot 1.43^2}{3} = 0.2$$

. Where Wm - moment of resistance along the cut planes; P is the external force; M - external bending moment.

Shear safety factor:

$$\mu_m = \frac{0.9 \cdot \sigma_{\text{В}}}{\tau_m} = \frac{0.9 \cdot 730}{531} = 1.24 > 1$$

The strength of the eye is provided if the minimum of safety factors is greater than or equal to 1.

Based on the calculations minimum coefficient is greater than 1 and therefore the strength of the eye is provided.

2.8 Conclusion to the Special Part

In this part were obtained next results:

- the variant of re-layout of the passenger cabin for cargo transportation are considered;
- the requirements for luggage fastening and cargo transportation conditions in the passenger cabin are considered;

- the strength of the luggage fastening is calculated and the safety factor is determined $\eta = 3.487 > 1{,}5$, its allows to withstand the load during the flight;
- developed an earlet of a fitting from D16T on fastening of a weight of up to 400 kg;
- the tensile strength of the earlet of fitting material is calculated $\eta_p = 1.175 > 1$, the earlet will not break during tensile stresses;
- the shear safety factor is calculated $\eta_m = 1.24 > 1$, the earlet will not break during shear stresses;
- proves that the earlet of fitting can provide safe and reliable fastening of a load weighting 220kg.

GENERAL CONCLUSION

During this designing work were analyzed the flight characteristics data of middle-range narrow-body prototypes B737-800, A320, A319 and were selected the most effective data for the design aircraft. Was analyzed and selected the comfortable layout of passenger cabin for 189 seats. There were performed calculation of the center of gravity of the airplane for five different load schemes of projected aircraft in the range from 20,09 up to 29,28, that are satisfies the range for narrow-body aircraft. Selected turbofan engines CFM56-7B20 type for low-wing aircraft according to the calculated thrust, which provides high cruise speed and good thrust-to weight ratio. Provides the maximum level of passenger comfort by using rational layout and convenient service facilities, ergonomic optimization of common and individual space, modern interior design, insulation blankets, which provide low noise in the passenger cabin. Were analyzed the possibility of re-equipment the passenger compartment for cargo transportation, considered all requirements for the cargo carriage on the passenger seats and according to this selected an effective layout of passenger seats. There were calculated and developed reliable and safe system for fastening cargo on a passenger seat.

REFERENCES

1) “Aircraft Maintenance Manual” Boeing 737-800. – Boeing company, REV.70 - 1657p.

2) Karuskevich M.V. Design of aviation machines. Modern regional turboprop / Karuskevich, M.V.; Maslak, T.P. – *NAU, 2007. – 61 p.*

3) Karuskevich, M.V. Aircraft design / Karuskevich, M.V.; Maslak, T.P. – *NAU, 2013. - 193 p.*

4) Донець О.Д. Наукові основи створення сучасних реактивних регіональних пасажирських літаків / О.Д. Донець – Київ: НАУ, 2019. – 265 с.

5) CS-25 Large Aeroplanes [Electronic source] – Access mode: URL: https://www.easa.europa.eu/certification-specifications/cs-25-large-aeroplanes (viewed on May 10, 2020)

6) HAECO company [Electronic source] – Access mode: URL: https://www.flightglobal.com/aerospace/haeco-rolls-out-passenger-cabin-freight-stowage-solution/137968.article?fbclid=IwAR2J48UsKMdeejhOY5ieMq6yOLaWX5Cx_NFG2oHIQWmLn1sqOAt-TX5w9ac (viewed on May 25, 2020)

7) Guidelines “Transport of cargo in passenger compartment - exemptions under article 71(1) of regulation 2018/1139 (the basic regulation)” [Electronic source] – Access mode: URL: https://www.easa.europa.eu/sites/default/files/dfu/Guidelines%20for%20the%20tra

NAU 20 12 S 00 00 00 39 EN

Performed by	*Savenok V.V.*			*References*	*Letter*	*Sheet*	*Sheets*
Supervisor	*Yuskevych S.S*						
Instructor					*AF 402 134*		
N. contr	*Khizhnyak S.V.*						
Head of Dep	*Ignatovich S.R*						

nsport%20of%20cargo%20in%20passenger%20aircraft_EASA_issue3_final.pdf (viewed on May 7, 2020)

8) Appendix to Annex 1 “Further guidance for transport of cargo in the passenger cabin under the provisioning of Article 71.1 of the Basic Regulation 2018/1139.” [Electronic source] – Access mode: URL: https://www.easa.europa.eu/sites/default/files/dfu/Guidelines%20for%20the%20transport%20of%20cargo%20in%20passenger%20aircraft_EASA_issue3_final.pdf (viewed on May 7, 2020)

9) Appendix 2 Annex 1 “Further guidance for transport of cargo in the passenger cabin under the provisioning of Article 71.1 of the Basic Regulation 2018/1139.” [Electronic source] – Access mode: URL: https://www.easa.europa.eu/sites/default/files/dfu/Guidelines%20for%20the%20transport%20of%20cargo%20in%20passenger%20aircraft_EASA_issue3_final.pdf (viewed on May 7, 2020)

10) Aviation Tires Specification [Electronic source] – Access mode: URL: https://www.dunlopaircrafttyres.co.uk/tyres (viewed on May 29, 2020)

					NAU 20 12 S 00 00 00 39 EN	Sheet
						40
Ch.	Sheet	Document No	Signed	Date		

APPENDIX 1

NAU 20 12 S 00 00 00 39 EN

Performed by	Savenok V.V.
Supervisor	Yuskevych S.S
Instructor	
N. contr	Khizhnyak S.V.
Head of Dep	Ignatovich S.R

Appendix 1

Letter	Sheet	Sheets

AF 402 134

```
        ИСХОДНЫЕ ДАННЫЕ И ВЫБРАННЫЕ ПАРАМЕТРЫ
Количество пассажиров                                          189.
Количество членов экипажа                                        2.
Количество бортпроводников или сопровождающих                    5.
Масса снаряжения и служебного груза                         1940.95 кг.
Масса коммерческой нагрузки                                18711.00 кг.

Крейсерская скорость полета                                    820.  км/ч
Число "М" полета при крейсерской скорости                        0.7660
Расчетная высота начала реализации полетов с крейсерской
экономической скоростью                                         10.67  км
Дальность полета с максимальной коммерческой нагрузкой      5600.  км.
Длина летной полосы аэродрома базирования                        2.55 км.

Количество двигателей                                            2.
Оценка по статистике тяговооруженности в н/кг                    2.7000
Степень повышения давления                                      28.00
Принятая степень двухконтурности двигателя                       5.50
Оптимальная степень двухконтурности двигателя                    5.50
Относительная масса топлива по статистике                        0.2200

Удлинение крыла                                                  8.21
Сужение крыла                                                    3.60
Средняя относительная толщина крыла                              0.120
Стреловидность крыла по 0.25 хорд                               25.0  град.
Степень механизированности крыла                                 1.050
Относительная площадь прикорневых наплывов                       0.090
             Профиль крыла - Суперкритический
             Шайбы УИТКОМБА - установлены
             Спойлеры - установлены

Диаметр фюзеляжа                                                 3.91 м.
Удлинение фюзеляжа                                              10.50
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
                   Н А У,  А К И,      КАФЕДРА    "К Л А"

 Значение  оптимального  коэффициента  подъемной силы в расчетной точке
 крейсерского режима полета      Су         0.45315

 Значение коэффициента           Сх.инд.    0.00919

     ОПРЕДЕЛЕНИЕ КОЭФФИЦИЕНТА  Dм = Мкрит - Мкрейс

 Число Маха крейсерское                Мкрейс  0.76597
 Число Маха волнового кризиса          Мкрит   0.77517
 Вычисленное значение                  Dм      0.00920

   Значения удельных нагрузок на крыло в кПА(по полной площади):
             при взлете                           5.274
             в середине крейсерского участка      4.458
             в начале крейсерского участка        5.082
```

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  Значение коэффициента сопротивления фюзеляжа и гондол       0.00870
  Значение коэфф. профиль. сопротивления крыла и оперения     0.00922

  Значение коэффициента сопротивления самолета:
          в начале крейсерского режима                      0.02951
          в середине крейсерского режима                    0.02822
  Среднее значение Су при условном полете по потолкам       0.45315

  Среднее крейсерское качество самолета                    16.05745

Значение коэффициента Су.пос.                                    1.665
Значение коэффициента ( при скорости сваливания ) Су.пос.макс.  2.497
Значение коэффициента ( при скорости сваливания ) Су.взл.макс.  2.060
Значение коэффициента  Су.отр.                                   1.504
Тяговооруженность в начале крейсерского режима                   0.572
Стартовая тяговооруженность по условиям крейс. режима Ro.кр.    2.318
Стартовая тяговооруж. по условиям безопасного взлета Ro.взл.    2.915

Расчетная тяговооруженность самолета   Ro   3.032

Отношение   Dr = Ro.кр / Ro.взл        Dr   0.795

                    УДЕЛЬНЫЕ РАСХОДЫ ТОПЛИВА ( в кг/кН*ч ):
       взлетный                                            36.2511
       крейсерский (характеристика двигателя)              57.8091
       средний крейсерский при заданной дальности полета   61.8878

                     ОТНОСИТЕЛЬНЫЕ МАССЫ ТОПЛИВА:
           аэронавигационный запас        0.03469
           расходуемая масса топлива      0.26135


              ЗНАЧЕНИЯ ОТНОСИТЕЛЬНЫХ МАСС ОСНОВНЫХ ГРУПП:
           крыла                          0.09911
           горизонтального оперения       0.00970
           вертикального оперения         0.00958
           шасси                          0.03842
           силовой установки              0.09366
           фюзеляжа                       0.08848
           оборудования и управления      0.13238
           дополнительного оснащения      0.00509
           служебной нагрузки             0.02139
           топлива при  Lрасч.            0.29603
           коммерческой нагрузки          0.20616

         Взлетная масса самолета "M.o" =  90759. кГ.
     Потребная взлетная тяга одного двигателя 137.58 kH

Относительная масса высотного оборудования и
противообледенительной системы самолета                        0.0229
Относительная масса пассажирского оборудования
(или оборудования кабин грузового самолета)                    0.0168
Относительная масса декоративной обшивки и ТЗИ                 0.0071
Относительная масса бытового (или грузового) оборудования      0.0140
Относительная масса управления                                 0.0060
Относительная масса гидросистем                                0.0168
```

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Относительная масса электрооборудования                          0.0319
Относительная масса локационного оборудования                    0.0031
Относительная масса навигационного оборудования                  0.0046
Относительная масса радиосвязного оборудования                   0.0023
Относительная масса приборного оборудования                      0.0053
Относительная масса топливной системы (входит в массу "СУ")      0.0088
    Дополнительное оснащение:
Относительная масса контейнерного оборудования                   0.0000
Относительная масса нетипичного оборудования                     0.0051
[встроенные системы диагностики и контроля параметров,
  дополнительное оснащение салонов и др.]

             ХАРАКТЕРИСТИКИ ВЗЛЕТНОЙ ДИСТАНЦИИ
Скорость отрыва самолета                                 269.56 км/ч
Ускорение при разбеге                                      2.34 м/с*с
Длина разбега самолета                                  1194. м.
Дистанция набора безопасной высоты                       578. м.
Взлетная дистанция                                      1772. м.

             ХАРАКТЕРИСТИКИ ВЗЛЕТНОЙ ДИСТАНЦИИ
                  ПРОДОЛЖЕННОГО ВЗЛЕТА
Скорость принятия решения                                256.08 км/ч
Среднее ускорение при продолженном взлете на мокрой ВПП   0.28 м/с*с
Длина разбега при продолженном взлете на мокрой ВПП    2044.65 м.
Взлетная дистанция продолженного взлета                2623.03 м.
Потребная длина летной полосы по условиям
прерванного взлета                                     2717.31 м.

             ХАРАКТЕРИСТИКИ ПОСАДОЧНОЙ ДИСТАНЦИИ
Максимальная посадочная масса самолета                   71176.   кг.
Время снижения с высоты эшелона до высоты полета по кругу   21.5  мин.
Дистанция снижения                                          48.87 км.
Скорость захода на посадку                                 243.97 км/ч.
Средняя вертикальная скорость снижения                       1.98 м/с
Дистанция воздушного участка                               515.   м.
Посадочная скорость                                        228.97 км/ч.
Длина пробега                                              715.   м.
Посадочная дистанция                                      1229.   м.
Потребная длина летной полосы (ВПП + КПБ) для
основного аэродрома                                       2053.   м.
Потребная длина летной полосы для запасного аэродрома     1745.   м.

             ПОКАЗАТЕЛИ ЭФФЕКТИВНОСТИ САМОЛЕТА
Отношение массы снаряженного самолета к
массе коммерческой нагрузки                              2.3900
Масса пустого снаряженного с-та приход. на 1 пассажира 236.61 кг/пас.
Относительная производительность по полной нагрузке    411.80 км/ч
Производительность с-та при макс. коммерч. нагрузке  14697.4 кг*км/ч
Средний часовой расход топлива                        3327.069 кг/ч
Средний километровый расход топлива                      4.24 кг/км
Средний расход топлива на тоннокилометр               226.372 г/(т*км)
Средний расход топлива на пассажирокилометр            19.7742 г/(пас.*км)
Ориентировочная оценка приведен. затрат на тоннокилометр 0.3803 $/(т*км)
```
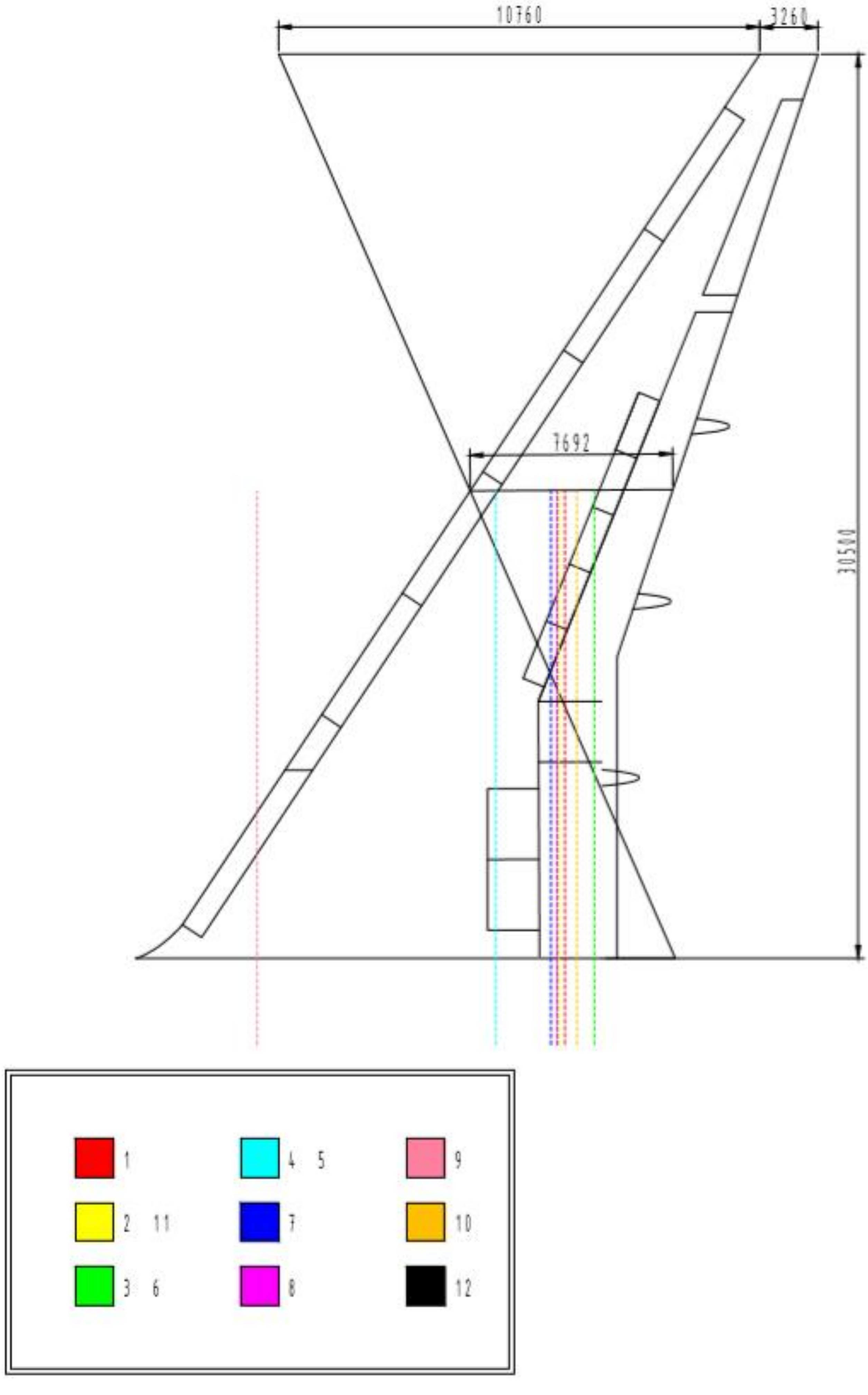

List of diploma work

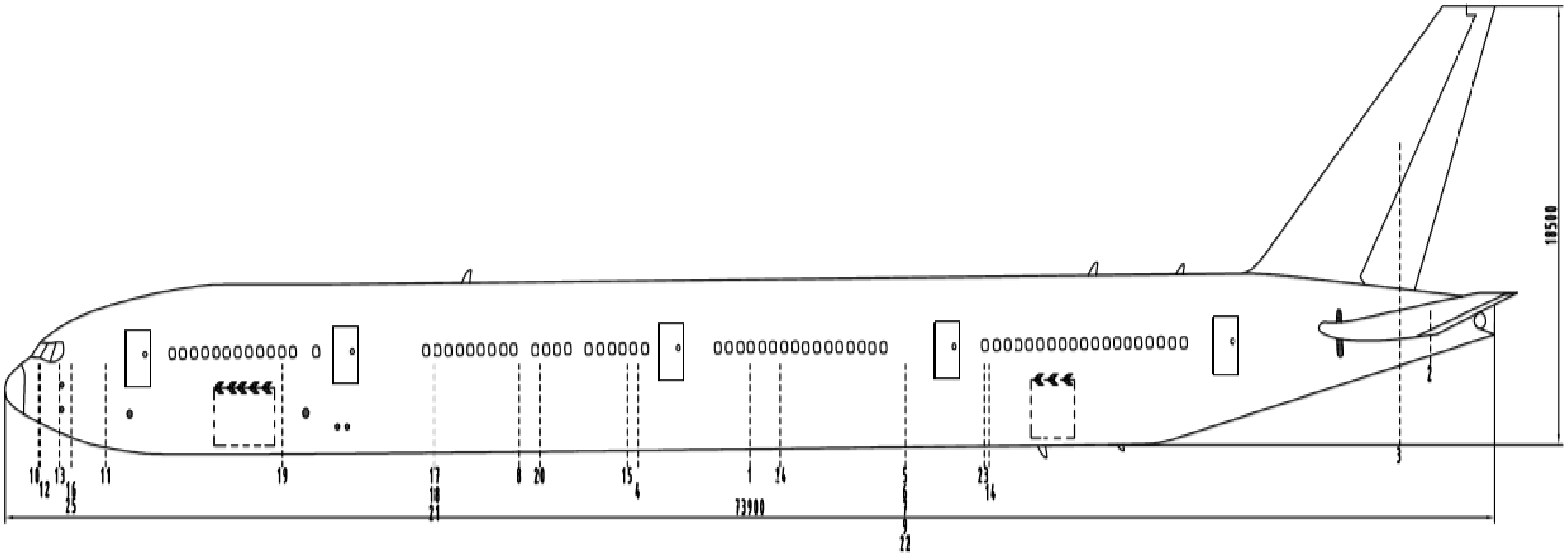
Format	№	Designation	Name	Quantity	Notes
			General documents		
A4	1	NAU 20 12 S TP	Task of work	1	
			Middle-range passenger aircraft	2	
A1	2	NAU 20 12 S 00 00 00 39 GV	General View		
A1	3	NAU 20 12 S 00 00 00 39 AL	Aircraft layout		
A4	3	NAU 20 12 S 00 00 00 81 EN	Explanatory note	37	
			Special part documentation		
A1	4	NAU 20 12 S 25 22 00 81 CF	Cargo Fastening System Construction	1	

Aircraft design department				NAU 20 12 S 00 00 00 39 EN			
Done by	Savenok V.V.			List of diploma work	list	sheet	sheets
Supervisor	Yutskevich						
Instructor					402 AF 134		
N. contr.	Khizhnyak						
Head. of d.	Ignatovich						

Appendix A



Appendix B


10
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18500

Appendix C

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                            П Р О Е К Т
                    С А М О Л Е Т А   С   Т Р Д Д
                   Н А У,   кафедра  К Л А
 ПРОЕКТ    дипломный          Расчет выполнен    04.03.2020
 Исполнитель Довбня Анастасия Викторовна  Руководитель  Маслак Т.П.

        ИСХОДНЫЕ ДАННЫЕ И ВЫБРАННЫЕ ПАРАМЕТРЫ
Количество пассажиров                                        460.
Количество членов экипажа                                      2.
Количество бортпроводников или сопровождающих                 12.
Масса снаряжения и служебного груза                         6335.65 кг.
Масса коммерческой нагрузки                                48617.80 кг.

Крейсерская скорость полета                                  905.  км/ч
Число "M" полета при крейсерской скорости                      0.8510
Расчетная высота начала реализации полетов с крейсерской
экономической скоростью                                       13.10  км
Дальность полета с максимальной коммерческой нагрузкой     11000.  км.
Длина летной полосы аэродрома базирования                      3.30 км.

Количество двигателей                                          2.
Оценка по статистике тяговооруженности в н/кг                  2.3400
Степень повышения давления                                    34.00
Принятая степень двухконтурности двигателя                     3.50
Оптимальная степень двухконтурности двигателя                  3.50
Относительная масса топлива по статистике                      0.4500

Удлинение крыла                                                8.70
Сужение крыла                                                  3.30
Средняя относительная толщина крыла                            0.110
Стреловидность крыла по 0.25 хорд                           35.0  град.
Степень механизированности крыла                               0.800
Относительная площадь прикорневых наплывов                     0.000
Профиль крыла - Суперкритический
Шайбы УИТКОМБА - не применяются
Спойлеры - установлены

Диаметр фюзеляжа                                               6.20 м.
Удлинение фюзеляжа                                            11.90
Стреловидность горизонтального оперения                      35.0 град.
Стреловидность вертикального оперения                       40.0  град.
```

```
                   Р Е З У Л Ь Т А Т Ы   Р А С Ч Е Т А
                 Н А У,     КАФЕДРА   "К Л А"
Значение  оптимального  коэффициента  подъемной силы в расчетной точке
крейсерского режима полета     Су        0.50390

Значение коэффициента          Сх.инд.   0.00886

    ОПРЕДЕЛЕНИЕ КОЭФФИЦИЕНТА  Dм = Мкрит - Мкрейс

Число Маха крейсерское               Мкрейс  0.85104
Число Маха волнового кризиса         Мкрит   0.85693
Вычисленное значение                 Dм      0.00589

  Значения удельных нагрузок на крыло в кПА(по полной площади):
            при взлете                          5.298
            в середине крейсерского участка     4.179
            в начале крейсерского участка       5.078



  Значение коэффициента сопротивления фюзеляжа и гондол      0.00680
  Значение коэфф. профиль. сопротивления крыла и оперения    0.00888

  Значение коэффициента сопротивления самолета:
            в начале крейсерского режима                   0.02701
            в середине крейсерского режима                 0.02511
  Среднее значение Су при условном полете по потолкам      0.50390

  Среднее крейсерское качество самолета                   20.07011

Значение коэффициента Су.пос.                                   1.259
Значение коэффициента ( при скорости сваливания ) Су.пос.макс.  1.889
Значение коэффициента ( при скорости сваливания ) Су.взл.макс.  1.612
Значение коэффициента  Су.отр.                                  1.177
Тяговооруженность в начале крейсерского режима                  0.441
Стартовая тяговооруженность по условиям крейс. режима Ro.кр.    2.352
Стартовая тяговооруж. по условиям безопасного взлета Ro.взл.    2.953

Расчетная тяговооруженность самолета   Ro   3.100

Отношение   Dr = Ro.кр / Ro.взл        Dr   0.797
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                     УДЕЛЬНЫЕ РАСХОДЫ ТОПЛИВА ( в кг/кН*ч ):
        взлетный                                            40.0184
        крейсерский (характеристика двигателя)              60.9254
        средний крейсерский при заданной дальности полета   66.1026

                       ОТНОСИТЕЛЬНЫЕ МАССЫ ТОПЛИВА:
               аэронавигационный запас        0.02964
               расходуемая масса топлива      0.36506



             ЗНАЧЕНИЯ ОТНОСИТЕЛЬНЫХ МАСС ОСНОВНЫХ ГРУПП:
               крыла                        0.11261
               горизонтального оперения     0.01053
               вертикального оперения       0.01043
               шасси                        0.03305
               силовой установки            0.09259
               фюзеляжа                     0.07888
               оборудования и управления    0.09598
               дополнительного оснащения    0.00749
               служебной нагрузки           0.01887
               топлива при  Lрасч.          0.39470
               коммерческой нагрузки        0.14483

            Взлетная масса самолета "М.о" =  335686. кГ.
     Потребная взлетная тяга одного двигателя 520.34 kH

Относительная масса высотного оборудования и
противообледенительной системы самолета                        0.0184
Относительная масса пассажирского оборудования
(или оборудования кабин грузового самолета)                    0.0108
Относительная масса декоративной обшивки и ТЗИ                 0.0055
Относительная масса бытового (или грузового) оборудования      0.0154
Относительная масса управления                                 0.0037
Относительная масса гидросистем                                0.0119





Относительная масса электрооборудования                        0.0203
Относительная масса локационного оборудования                  0.0017
Относительная масса навигационного оборудования                0.0026
Относительная масса радиосвязного оборудования                 0.0013
Относительная масса приборного оборудования                    0.0030
Относительная масса топливной системы (входит в массу "СУ")    0.0135
    Дополнительное оснащение:
Относительная масса контейнерного оборудования                 0.0054
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Относительная масса нетипичного оборудования                   0.0021
[встроенные системы диагностики и контроля параметров,
  дополнительное оснащение салонов и др.]


                      ХАРАКТЕРИСТИКИ ВЗЛЕТНОЙ ДИСТАНЦИИ
Скорость отрыва самолета                                305.43 км/ч
Ускорение при разбеге                                     2.52 м/с*с
Длина разбега самолета                                 1422. м.
Дистанция набора безопасной высоты                      578. м.
Взлетная дистанция                                     2001. м.

             ХАРАКТЕРИСТИКИ ВЗЛЕТНОЙ ДИСТАНЦИИ
                ПРОДОЛЖЕННОГО ВЗЛЕТА
Скорость принятия решения                               290.16 км/ч
Среднее ускорение при продолженном взлете на мокрой ВПП   0.45 м/с*с
Длина разбега при продолженном взлете на мокрой ВПП    2053.28 м.
Взлетная дистанция продолженного взлета                2631.66 м.
Потребная длина летной полосы по условиям
прерванного взлета                                     2725.77 м.

             ХАРАКТЕРИСТИКИ ПОСАДОЧНОЙ ДИСТАНЦИИ
Максимальная посадочная масса самолета                   230007.   кг.
Время снижения с высоты эшелона до высоты полета по кругу  24.3  мин.
Дистанция снижения                                           60.99 км.
Скорость захода на посадку                                 262.82 км/ч.
Средняя вертикальная скорость снижения                        2.10 м/с
Дистанция воздушного участка                                522.   м.
Посадочная скорость                                        247.82 км/ч.
Длина пробега                                               857.   м.
Посадочная дистанция                                       1379.   м.
Потребная длина летной полосы (ВПП + КПБ) для
основного аэродрома                                        2303.   м.
Потребная длина летной полосы для запасного аэродрома      1958.   м.

              ПОКАЗАТЕЛИ ЭФФЕКТИВНОСТИ САМОЛЕТА
Отношение массы снаряженного самолета к
массе коммерческой нагрузки                              3.1274
Масса пустого снаряженного с-та приход. на 1 пассажира 337.14 кг/пас.
Относительная производительность по полной нагрузке    488.28 км/ч
Производительность с-та при макс. коммерч. нагрузке  42939.3 кг*км/ч
Средний часовой расход топлива                        9839.361 кг/ч
Средний километровый расход топлива                     11.14 кг/км
Средний расход топлива на тоннокилометр                229.146 г/(т*км)
Средний расход топлива на пассажирокилометр         21.7958 г/(пас.*км)
Ориентировочная оценка приведен. затрат на тоннокилометр0.4368 $/(т*км)
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