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 дальньомагістрального пасажирського літака пасажиромісткістю 380 осіб»

Виконала: ___________ **Руслана МОМОТЕНКО**

Керівник: канд.техн.наук, доцент ___________ **Вадим ЗАКІЄВ**

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Київ 2022

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

PERMISSION TO DEFEND
Head of the department
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«___» _______ 2022

BACHELOR DEGREE THESIS
ON SPECIALTY
"AVIATION AND AEROSPACE TECHNOLOGIES "

Topic: «Preliminary design of a long-range passenger aircraft with 380 passenger capacity»

Prepared by: __________**Ruslana MOMOTENKO**

Supervisor: PhD, associate professor __________**Vadim ZAKIEV**

Standard controller: PhD, associate professor __________**Sergiy KHIZNYAK**

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

RUSLANA MOMOTENKO

1. Topic: «Preliminary design of a long-range aircraft with 380 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}=871 kmph, flight range L=11,750 km, operating altitude H_{op}=12 km, 380 passengers.
4. Content (list of topics to be developed): choice and substantiations of the airplane scheme, choice of initial data; engine selection, aircraft layout, center of gravity position calculation, conversion of passenger aircraft into cargo aircraft.
5. Required material: general view of the airplane (A1×1); layout of the airplane (A2×1); drawing of converted version of aircraft with necessary modifications (A1×1).

Graphical materials are performed in 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 ____________ Vadim ZAKIEV

Student ____________ Ruslana MOMOTENKO

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

РУСЛАНА МОМОТЕНКО

1. Тема роботи: «Аванпроект дальномагістрального літака пасажиромісткістю 380 осіб», затверджена наказом ректора № 489/ст від 10 травня 2022 року.

2. Термін виконання роботи: з 23 травня 2022 р. по 15 червня 2022 р.

3. Вихідні дані до роботи: максимальна кількість пасажирів 380, дальність польоту з максимальним комерційним навантаженням 11,750 км, крейсерська швидкість польоту 871 км/год, висота польоту 12 км.

4. Зміст пояснювальної записки: вибір параметрів та обгрунтування схеми проектованого літака, вибір двигунів, розрахунок геометрії та центрування літака, переобладнання пасажирського літака у вантажну версію.

5. Перелік обов’язкового графічного матеріалу: загальний вигляд літака (A1×1), компонувальне креслення фюзеляжу (A2×1), креслення переобладнаної версії літака з необхідними модифікаціями (A1×1).

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: 31.05.2022 рік

Керівник дипломної роботи __________ Вадим ЗАКІЄВ

Завдання прийняв до виконання __________ Руслана МОМОТЕНКО

РЕФЕРАТ

Дипломна робота **«Аванпроект дальньомагістрального пасажирського літака пасажиромісткістю 380 осіб»**:

67 сторінок, 10 рисунків, 7 таблиць, 11 літературних посилань, 3 креслення

Об'єкт проектування: дальньомагістральний пасажирський літак для 380 пасажирів.

Предмет проектування: конвертація пасажирського літака.

Мета роботи: розробка дальньомагістрального пасажирського літака місткістю 380 пасажирів та його конвертацію у вантажний варіант.

Методи дослідження: аналіз прототипів і вибір найбільш досконалих технічних рішень, оцінка геометричних характеристик, розрахунок центру мас літака, конвертація літака у вантажний, розрахунок розподілу навантаження в місці вирізу для дверей головного вантажного відділу.

Наукова новизна результатів полягає у конвертації літака, як дієвого способу продовження життєвого циклу літака, з необхідними модифікаціями, в тому числі установки дверей головного вантажного відділу.

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

ЛІТАК, АВАНПРОЕКТ ЛІТАКА, КОМПОНУВАННЯ ПАСАЖИРСЬКОЇ КАБІНИ, ЦЕНТРУВАННЯ ЛІТАКА, КОНВЕРТАЦІЯ ПАСАЖИРСЬКОГО ЛІТАКА В ГРУЗОВИЙ, НАВАНТАЖЕННЯ У МІСЦІ ВИРІЗУ

ABSTRACT

Bachelor thesis «**Preliminary design of a long-haul passenger aircraft with a 380 passenger capacity**»

67 pages, 10 figures, 7 tables, 11 references, 3 drawings

Object of study: long-haul passenger plane with 380 passengers capacity.

Subject of study: the passenger aircraft conversion.

Aim of bachelor thesis: preliminary design of long-haul passenger aircraft with 380 passenger capacity and conversion into cargo version.

Research and development methods: analysis of prototypes and selection of the most advanced technical solutions, evaluation of geometric characteristics, calculation of the center of mass of the aircraft, design of converted aircraft, calculation of load distribution at the cutout for cargo doors of main deck cargo compartment.

Novelty of the results is the conversion of the aircraft as an effective way to extend the life cycle of the aircraft, with improving of design, including the installation of the doors of the main cargo compartment.

Practical value: determined by the increase in the line of convertible long-haul aircraft. The results of the work can be used in the aviation industry and in the educational process of aviation specialties.

AIRCRAFT, PRELIMINARY DESIGN, PASSENGER CABIN LAYOUT, AIRCRAFT CENTERING, CONVERSION OF PASSENGER AIRCRAFT TO FREIGHTER, LOADS IN THE PLACE OF CUTOUT

Format	№	Designation	Name	Quantity	Notes
			<u>General documents</u>		
A4	1	NAU 22 M 00 00 00 78 TW	Task for work	1	
	2		Documentation for assembly units	3	
A1		NAU 22 M 00 00 00 22 GV	General view		
A1		NAU 22 M 00 00 00 22 FL	Fuselage layout		
A1		NAU 22 M 00 00 00 22 AC	Conversion of aircraft	2	
A4	3	NAU 21 M 00 00 00 22 EN	Long-range passenger aircraft explanatory note	67	

NAU 22 M 00 00 00 78 EN

Ch	Sheet	Document №	Sign	Date
Performed		Momotenko R.		
Supervisor		Zakiev V.		
Adviser				
Stand.contr.		Khyzhnyak.S		
Head of dep.		Ignatovych.S		

List of diploma work

Letter	Sheet	Sheets
		68

AF 402 134

Content

					NAU 22 M 00 00 00 78 EN
Ch	Sheet	Document №	Sign	Date	

Performed by	Momotenko R.			Content	Letter	Sheet	Sheets
Supervisor	Zakiev V.					10	68
Stand.contr.	Khyzhnyak S.				AF 402 134		
Head of dep.	Ignatovych S.						

INTRODUCTION

Today, both freight and passenger air transport are one of the fastest and most efficient way to get / to deliver something from one point in the world to another, which no longer takes a few days of life, but is literally calculated in hours - just what people need today, comfort and savings in time. There are air connections around the world and unite completely different countries that adhere to the same rules and requirements for the carriage of both passengers and cargo. And it is thanks to such close ties that the aviation industry, like any other important industry, operates and develops, because passenger turnover (even in difficult times) and freight support its activities.

But on the other hand, aircraft construction is a complex, time-consuming and quite expensive process, which ultimately produces a good product that lasts for years and meets the needs of passengers or customers (for cargo aircraft).

The process itself is based on certain stages, one of which is described in this paper, it is a preliminary design of the aircraft. Such stages of work on the project as drawing up and processing of statistical data of prototypes of the plane and formation of the technical task are necessary; calculation of the take-off mass of the aircraft and optimization of the masses of functional systems on a PC, assessment of flight characteristics; calculation of geometric parameters of aircraft units, preparation of preliminary drawings; layout and centering of the aircraft; execution of drawings (general view of the aircraft in three projections, and layout with characteristic cross-sections of the fuselage); and, of course, the design and defense of the project.

1. PROJECT PART

1.1. Analysis of prototypes and short description of designing aircraft

1.1.1. Choice of the projected data

The choice of the optimal design parameters of the aircraft is a task of multidimensional optimization aimed at forming the "look" of a promising aircraft. Its configuration implies the whole complex of flight performance, weight, geometric, aerodynamic and economic characteristics. During the formation of the “Aircraft Design”, at the first stage, statistical methods of transfers, approximate aerodynamic and statistical dependencies are widely used. At the second stage, a full aerodynamic calculation is used; updated formulas for calculating the mass of aircraft units, experimental data.

Powered by two engines [11], the 63.69 m long A330-300 with maximum range of 11,750 km, typically carries 380 passengers. The aircraft is based on a stretched A300 fuselage but with new wings, stabilizers and fly-by-wire systems.

The Boeing 787-9 (as well as the Boeing 777) is a direct competitor to the A330-300. There are also such prototypes as Il-96 (Russian long-haul wide-body airliner, powered by four high-bypass engines) and A340-300. Compared to the A330 twinjet (on ground), the heavier A340 (inflight) has four engines and a center-line wheel bogie. But despite this, the A330 family liners have the greatest flight range among all currently operated twin-engine aircraft.

The operational-technical data of prototypes are presented in table 1.1.

The geometry characteristics (wingspan, fuselage length, diameter, cabin characteristics, tail unit etc.) of prototypes are presented in Table 1.2.

Table 1.1. – Operational-technical data of prototypes

Parameters	A340-300	Boeing 787	Il-96	A330-300
The purpose of airplane	Passenger	Passenger	Passenger	Passenger
Maximum take-off weight, m_{tow}, kg	50900	36150	37050	43320
Crew and flight attend. persons	13	12	10	12
Passenger's seat	440	290	300	380
Wing load, kN/m^2	6	6,3	6	5,354
Average cruising quality	19,8	15	15	19,8
Range $m_{\text{к.max}}$, km	14,816	14,140	6,000	11,750
The height of the flight $V_{\text{w. ек.}}$, m	12,6	11,7	10,7	12,6
$V_{\text{pitch max}}$/N, km/h/km	870	902	870	890
$V_{\text{pitch екон}}$/N, km/h/km	850	860	845	845
Power plant				
Number and type of engines	4 turbofan engines	2 turbofan engines	4 turbofan engines	2 turbofan engines
Takeoff thrust, kN	170	329	160	175
Cruise thrust, kN	100	251	100	110
Specific fuel consumption (takeoff), kg/kN (kW)	35	28,8	40	34,6448
Specific fuel consumption (cruising), kg/kN (кW)	58	52,82	55	57,4278
The degree of increase in pressure	30	55,4	30	31,2
Degree of bypass	6	9,1	4,5	6
Take-off and landing				
Airfield base class	D	D	D	D
Landing speed, km/h	235,1	255	271,7	235,1
Takeoff speed, km/h	281,95	290,74	299,6	281,95
Takeoff length, m	1790	1523	2108	1790
Run length, m	668	767	894	668
Takeoff distance, m	2262	2101	2580	2262
Landing distance, m	1178	2148	2371	1178

Table 1.2. – Geometry characteristics

Main geometric parameters	A340-300	Boeing 787	Il-96	A330-300
Wingspan, m	60,3	60,1	57,6	60,3
Quarter-chord sweep angle, °	31	32,2	32,2	31
Mean chord, m	9,4	5,4	6	9,4
Aspect ratio	6,7	11,13	10,3	6,7
Taper ratio	3,5	2	4,7	3,5
Fuselage length, m	63,65	62,80	55,34	63,62
Fuselage diameter, m	5,64	5,87	6,08	5,64
Fuselage extension	11,28	10,8	9	11,28
The form of the cross-section fuselage	circular	circular	circular	circular
Width of the passenger cabin, m	5,44	5,67	5,8	5,44
Length of the passenger cabin, m	60	40	38	60
Cabin height, m	2,4	2,1	2	2,4
Cabin volume, m	1200	963	900	1200
Cabin volume, m^3	200	174,5	140	200
Seats pitch, mm	870	840	860	870
Passage width, m	0,4	0,37	0,45	0,4
HT span, m	20	10	19	20
Quarter-chord sweep angle of HT, °	33	37	37	33
HT aspect ratio	3,24	5,73	5,31	3,24
HT taper ratio	3	3	3	3
VT height, m	8,3	9	7,8	8,3
Quarter-chord sweep angle of VT,°	56	42	42	56
VT aspect ratio	1,04	1,56	1,68	1,04
Gear nacelles, m	25,1	25,6	25,6	25,1
Wheel track, m	9,1	9,8	9,7	9,1

1.1.2. Brief description of the main parts of the aircraft

Purpose and scope

The designed aircraft is designed for commercial transportation of passengers, baggage, cargo on long-distance routes 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;
- providing 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 conditions of flight behind instruments;
- ensuring the stability of transportation.

During the design process, the required amount of fulfillment of these requirements must comply with the standards defined in the Aviation Rules of Ukraine and ICAO documents.

Technical description of the aircraft

The designed aircraft is a wide-body twin-engine turbojet passenger aircraft, made according to the type of classical aerodynamic layout, low-wing scheme, having an all-metal semi-monocoque design. This aircraft is intended for operation on long-distance routes with adequately equipped air navigation facilities. The cabin capacity of the liner is 380 people. The maximum flight range with a maximum payload is 11,750 km.

Structurally, the aircraft is divided into the following elements:

– caisson type wing;

– fuselage, including pressurized cabin for crew and passengers and cargo compartment;

– horizontal and vertical tail of the aircraft (HT, VT);

– power plant with turbofan engines;

– aircraft landing gear.

A feature of the liner is efficiency and environmental friendliness through the use of new turbojet engines. Such parameters were obtained due to an increase in the aerodynamic quality of the aircraft. The new aircraft has improved the flow around the fuselage, due to the use of a uniform narrowing of the nose (without protrusions and concavity). Due to the use of composite materials, the pressure in the cabin was reduced to more comfortable conditions, which correspond to those at an altitude of 2400 m.

The design of the fuselage has been significantly changed to increase its reliability, ensure safety in case of damage, reduce the rate of crack growth, ensure a given resource, reduce weight and improve the quality of the outer surface.

Pressurized cabin of ventilation type. Reduced the risk of aileron reversal, which is often subject to highly swept wings. The landing distance has been reduced (from 3.3 km to 2.2 km), which facilitates the landing of the aircraft at A-class airfields.

Selection and justification of the scheme of the aircraft

The scheme of the aircraft is determined by the relative position of the units, their number and shape. Its aerodynamic and technical-operational properties depend on the scheme and aerodynamic layout of the aircraft. Successfully chosen scheme allows to increase the safety and regularity of flights, and the economic efficiency of the aircraft. The choice of the design of the designed aircraft is preceded by the study and analysis of the schemes of aircraft adopted as prototypes. The following are subject to substantiation:

I. location of the wings and plumage relative to the fuselage, as well as the choice of their shape;

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

III. type and location of chassis supports;

The designed aircraft is made according to the low-plane scheme. The aerodynamic scheme is a classic low plane, justified by the following factors:

- increasing the safety of passengers in the event of a fall (part of the impact energy will be absorbed by the wing);

- improving buoyancy when landing on water.
- possible screen effect during emergency landing.
- the underfuselage part of a wing more effectively takes part in creation of aerodynamic lifting force.
- since the chassis supports are connected to the wing, and in flight mode the chassis is removed in the middle of the fuselage, the mass of this structure is less than in the high-altitude scheme.
- since the engines are placed on pylons under the wing, air losses from shading the air intakes are minimal.

Disadvantages:

- with the increase of the degree of double-loop increase the dimensional and mass parameters of the engine, this must be taken into account when calculating the chassis, in order to ensure the normal operation of the engine.
- dust and other elements can get from the runway when placing the engines under the wing, which can lead to engine failure.

The tail of the aircraft is placed according to the normal scheme - HT and VT are behind the wing and attached to the tail.

The main advantages of a normal scheme are:

- possibility of effective use of wing mechanization;
- easy balancing of the aircraft with the flaps released;
- placement of the plumage behind the wing, which allows you to make the nose of the fuselage shorter, which not only improves the pilot's view, but also reduces the area of VT, as the shortened nose of the fuselage causes less destabilizing travel moment;
- possibility to reduce the areas of VT and HT, as the arm of VT and HT is much larger than in other schemes.

Naturally, this scheme is characterized by disadvantages:

- HT creates a negative lift in almost all flight modes, which reduces the lift of the entire aircraft;

- HT operates in perturbed airflow behind the wing, which negatively affects its operation.

When choosing the location of the engines take into account the peculiarities of the general layout of the aircraft, operating conditions and ensure maximum service life of the engines, get the lowest frontal resistance of the power plant, minimize air loss in the air intake. In this scheme the aircraft engines are placed under the wing on the pylons, which provides the above advantages. One of the disadvantages of this scheme of placement of engines on the wing is that increasing the degree of double-loop increases the diameter of the engine. Therefore, when assembling engines under the wing, it is necessary to increase the height of the chassis to ensure a normalized distance from the perimeter of the nacelle to the ground.

The designed aircraft has a three-support chassis scheme with a nose support. This chassis scheme provides the aircraft with high stability on takeoff and mileage, good handling when moving on the ground and effective braking of the wheels due to the lack of hood. Aircraft that implement such a chassis scheme have a horizontal position of the longitudinal axis, both in the parking lot and when moving around the airfield, so for pilots it improves the view from the cockpit and increases comfort for passengers. A three-support chassis scheme with a nose support can greatly simplify the takeoff and landing of the aircraft in crosswinds, if all three chassis supports are made in a way that is self-orienting and equipped with self-oscillating dampers.

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

The airworthiness standards of aircraft require that the aircraft have at least two engines. This is necessary so that in the event of a single engine failure at the end of the runway, the aircraft can take off and set a safe altitude with a certain vertical speed and the angle of the take-off trajectory. If 50% of the engines fail in flight, the aircraft must be able to continue the horizontal flight with less altitude and speed. The optimal number of engines on the aircraft depends on its mass, range, class of aerodrome base, engine parameters and is determined definitively for each type of aircraft by calculating the following steps. At this stage, the number of engines is tentatively set according to statistics, taking into account the degree of increase in engine pressure and the degree of double-loop.

Selection of basic wing parameters

The main parameters of the wing include the profile and relative thickness $\underline{c}$, sweep χ 0.25 chords, elongation λ, narrowing η, the angle of the transverse V wing and the specific load on the wing P, the shape of the wing in plan. The aerodynamic characteristics of the wing are largely determined by the shape of the wing in the plan. The parameters of the profile (X_c, f) and the relative thickness of the wing ($\underline{c}$) depend on the number M of cruising flight - M_{cr}.

If the designed aircraft M_{cr}<0.6, then for its wing is most appropriate to use asymmetric ("bearing") profiles with rounded leading edge and with a relatively forward (20 ... 30% chord) position of the maximum thickness $\underline{c}$, which is in the root part of the wing may be 15 ... 18%, and at the end of the wing - 10 ... 12% of the chord.

These circumstances determine the "economical" use of arrow-like, i.e. the sweep angle of the wing of a subsonic aircraft is usually selected at a minimum determined by the value of the specified speed (number of M_{cr}) of cruising flight.

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

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

Increasing the narrowing η has a positive effect on the distribution of external loads, stiffness characteristics 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 increasing the area of the wing served by mechanization, significantly increases its efficiency.

However, the increase in narrowing has its downsides. The main one is the tendency of the wing with a large narrowing to the final disruption of the flow while reducing the efficiency of the ailerons. Due to these circumstances, the narrowing of the straight wings of subsonic aircraft is usually filled small and is $\eta = 2 ... 2.5$, which provides close to a minimum inductive resistance of the wing and high values of C_{Ymax}.

The angle of the transverse V wing is known to serve as a means of ensuring the degree of transverse stability of the aircraft. Its size and sign depend visually on the scheme of the aircraft, and for aircraft with arrow-shaped wings - also on the angle of sweep. Sweep increases the transverse stability of the wing and therefore the sagittal wings should be given a negative transverse V. Sweep increases the transverse stability. However, layout and other requirements (for example, landing with a roll) can cause a positive V of the swept wing. This will cause the installation in the control system of automatic damping dampers and require some increase in the area of vertical plumage. Choose the following basic parameters of the wing: $\lambda=10$; $\eta=3,5$; $\underline{c}=0,11$; $\chi_{0,25}=31°$.

Selection of the main parameters of the fuselage

The aerodynamic and weight characteristics of the fuselage significantly depend on its shape and size, which are determined by such geometric parameters as the shape of the cross section, elongation λ_f and diameter of the fuselage D_f. It should be noted that the elongation and length of the fuselage are specified in the subsequent layout of the aircraft in terms of providing the necessary volume to accommodate the crew, passengers and cargo, as well as acceptable shoulders L_{VT} and L_{HT} horizontal and vertical plumage. The elongation of the fuselage and its parts (λ_{nose} and λ_{tail}) are chosen for reasons of aerodynamics and weight of the fuselage. Preliminary assessment of the diameter of the fuselage should be performed based on statistics and parameters of the prototypes. We choose the following main parameters of the fuselage: for calculations we take the diameter D_f = 5.6 m, λ_f = 5.8.

1.2. Geometry calculations for the main parts of the aircraft

The geometry calculation process combines the following interconnected processes: aerodynamic, volume-mass and structural-power layout, centering calculation. Fulfillment of each of these conditions is aimed at obtaining high economic efficiency of the aircraft. The aerodynamic layout must ensure compliance with aerodynamic requirements, which is reduced to solving problems to ensure:

- a wide range of speeds V from takeoff and landing to V_{max} maximum with a minimum transition time from one speed to another at the initial and final flight modes of the aircraft;
- the maximum aerodynamic quality of the aircraft in cruising flight at a given speed. This requirement provides for minimum aircraft resistance and, in particular, minimal balancing losses;
- when taking off and landing as much as possible the size of the aircraft;
- on all modes of flight of the aircraft normalized (necessary) reserves of stability and controllability;
- on the aircraft the most favorable conditions for the operation of the power plant, determined by the optimal possible losses at the inlet of the air into the engines and at the outlet of the gasses from the outlet nozzles of the engines;
- safe access of the aircraft to extreme flight modes (for example, high speeds or large angles of attack) that do not lead to flutter, buffing, corkscrew, deep breakdowns and other extremely dangerous phenomena.

1.2.1. Wing geometry calculation

The determination of wing geometrical characteristics is based on the take-off mass m_o and the specific load on the wing P_o:

Firstly, find the area of the wing:

$$S_{wfull} = \frac{m_o \cdot g}{P_o} = \frac{233000 \cdot 9{,}81}{6332} = 361\ m^2$$

The wingspan is calculated by the formula:

$L_w = \sqrt{S_w \cdot \lambda_w} = \sqrt{631\ \cdot\ 10} = 60.3\ m;$

Root chord $b_o = \frac{2\cdot S_w\cdot \eta}{(1+\eta)\cdot l} = \frac{2\cdot 361\cdot 3,5}{(1+3,5)\cdot 60,3} = 9,3\ m;$

Tip chord $b_t = \frac{b_o}{\eta} = \frac{9,3}{3,5} = 2,7\ m;$

When choosing the power scheme of the wing determine the number of spars and their position, as well as the location of the wing.

Modern aircraft use a caisson two- or three-spar wing; The spar wing is characterized by light sports, medical and other aircraft.

The relative position of the spars in the wing on the chord is equal to:

$\underline{X_i} = \frac{X_i}{b}$, where X_i - distance of the i-th spar from the leading edge of the wing, b is the chord.

In a wing with two spars $X_i = 0.2$; $X_i = 0.6$.

X_i = 0,81; X_i = 0,22;

X_i = 2,44; X_i = 0,81;

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

The value of MAC is found geometrically: $b_{MAC} = 5.1\ m$

After determining the geometric characteristics of the wing, we turn to the assessment of the geometry of the ailerons and high-lift devices.

The geometric parameters of the aileron are determined this way:

- aileron span: $l_{ail} = (0,3\ldots0,4)\ l/2\ =\ 10,5\ m;$
- aileron chord: $b_{ail} = (0,22\ldots0,2\text{б})\ b\ =\ 1,2\ m;$
- aileron area: $S_{ail} = (0,05\ldots0,08)\ S_w\ /2\ =\ 9,1\ m^2.$

Increasing l_{ail} and b_{ail} more than the recommended values is irrational. With increasing l_{ail}above the above values, the growth of the aileron moment coefficient slows down, and the scope of mechanization decreases. With increasing b_{ail} decreases the width of the caisson.

On the third generation aircraft there was a tendency to reduce the relative amplitude and area of the ailerons. Due to this, the scope and area of mechanization can be increased, which improves the takeoff and landing characteristics of the aircraft.

1.2.2. Fuselage layout

When choosing the shape and size of the cross section of the fuselage must be based on the requirements of aerodynamics (flow and cross-sectional area).

Applied to subsonic passenger and transport aircraft (V < 800 km/h) impedance is almost unaffected. Therefore, the shape should be chosen from the condition of providing the lowest values of frictional resistance C_{Xfr} and profile resistance C_{Xpr}.

For subsonic aircraft, the nose part of the fuselage should be $l_{nose} = (2\ldots3) \cdot D_f$, where D_f is the diameter of the fuselage.

In addition to taking into account the requirements of aerodynamics when choosing the shape of the section should take into account the conditions of layout and strength requirements.

To ensure the minimum weight of the most appropriate cross-sectional shape of the fuselage should be considered a round section. In this case, the thickness of the fuselage skin is the smallest. As a variant of such a section it is possible to use a combination of two or more circles both vertically, and horizontally.

<u>Determination of geometric and structural-power parameters of the fuselage</u>

The geometric parameters of the fuselage include:

- fuselage diameter D_f;
- fuselage length l_f;
- fuselage extension $\lambda_f = \frac{l_f}{D_f}$
- elongation of the nose part of the fuselage $\lambda_{fnose} = \frac{l_{fnose}}{D_f}$;
- elongation of the tail of the fuselage $\lambda_{ftail} = \frac{l_{ftail}}{D_f}$,

where l_{fnose} and l_{ftail} - respectively, the length of the nose and tail of the fuselage.

The length of the fuselage is determined taking into account the scheme of the aircraft, the layout and centering, as well as providing a landing angle of attack α_{land}.

Define the following parameters of the fuselage:

- $l_f = \lambda_f \cdot D_f = 5{,}8 \cdot 5{,}6 = 32{,}5\ m;$
- $l_{nose} = \lambda_{nose} \cdot D_f = 2 \cdot 5{,}6 = 11{,}2\ m;$
- $l_{tail} = \lambda_{tail} \cdot D_f = 3{,}5 \cdot 5{,}6 = 19{,}6\ m;$

At the stage of sketch design, in the process of preliminary research to determine the length of the fuselage ratio for aircraft can be recommended:

With sweep-back wing $L_f/l_w = 0.8\ldots0.95, where\ l_w = 8\ldots10$

$$L_f/l_w = 0.95\ldots1.25, where\ l_w = 3\ldots5$$

When determining the diameter of the fuselage seek to ensure a minimum midship section Sms on the one hand and to ensure the layout requirements on the other. For transport aircraft, the middle of the fuselage is primarily due to the dimensions of the cargo cabin.

The pitch of normal frames in the construction of the fuselage is in the range of 360 ... 600 mm, depending on the size of the fuselage.

Layout of passenger and household equipment of the fuselage

The size of the passenger cabin of the aircraft is determined by the number of passengers in the standard placement of seats.

According to the level of comfort, passenger planes are divided into three classes:

first class, tourist and economic. The greatest comfort for passengers is provided in the first class, the least in the economy.

To determine the diameter of the fuselage, the prototypes must select the number of seats in one row and determine the desired width of the passenger cabin.

The length of the passenger cabin when performing it in one cabin is determined by: $l_{cab} = 1200 + \left(\frac{n}{m} - 1\right) \cdot t_w + (235 \ldots 250)\ m$, where n is the number of passengers; t - seats pitch; m is the number of passenger seats in one row.

Long cabins look uncomfortable and then they are divided into separate salons. The length of each cabin is determined in the same way as the cabins. In the case of the layout of the cabin with different passenger classes (such as first and tourist) must be divided by a rigid partition into the cabin.

l_{cab1} = 3,400 m – business class;

l_{cab2} = 17,200 m – first salon of economy class

l_{cab3} = 17,200 m – second salon of economy class

The total length of the passenger compartment, not including cupboards, toilets, and wardrobe is 37.8 m.

After determining the length of the cabin, you need to check compliance with the requirements for the amount per passenger

1st class $\nu_{pass} = V_{cab}/n = 1{,}5 \ldots 1{,}8$ m^3

tourist class $\nu_{cab} = 1{,}2 \ldots 1{,}3$ m^3

economy class $\nu_{cab} = 0{,}9 \ldots 1{,}0$ m^3

The greater the flight range, the greater the specific volume. If the ν_{cab} requirements are not met, the cab size must be increased.

When arranging the passenger cabin should take care to create proper comfort and safety of passengers. The airworthiness standards stipulate that when flying with H = 3500 m the cabin must be airtight, the excess pressure in the cabin is not less than 567 mmHg (2400 m), speed of change of pressure in a cabin no more than 0,18 mmHg/s, supply of fresh air not less than 24 kg/h on the passenger, temperature in a cabin of 18...22 °C and humidity of 30...60%.

The height of the passenger cabin in the area of passages must be at least 1900...2000 mm. The passenger cabin is made with one floor level and does not allow protrusions and depressions in it, and there should be no threshold near the front door.

Crew cabin

The cockpit must be as small as possible, but at the same time provide normal conditions for work and rest of the flight crew. The most stringent requirements are set for pilots' jobs. In addition to convenience, they must provide a good overview. The size of the crew cabin depends on the number of crew members. On the middle and near main lines the crew consists of 3...4, on local lines 2...3 people.

The crew includes: ship's commander (captain), co-pilot (first officer), flight engineer, navigator, flight attendant. Depending on the flight route, the composition of the crew may vary. For example, navigators and flight attendants may not be assigned to routes equipped with beacons and air traffic control systems. The pilots are placed in seats next to each other, the flight engineer is often located behind the seat of the co-pilot, so that there was a visual connection between him and the commander of the ship. There are no requirements for the jobs of other flight crew members.

The cockpit is separated from other rooms by a rigid partition with doors that close. Each passenger aircraft must have the following number of flight attendants [1]:

1) For aircraft with a passenger capacity of more than 9 but less than 51 passengers - 1 flight attendant;
2) For aircraft with a passenger capacity of more than 50 but less than 101 passengers - 2 flight attendants;
3) For aircraft with a capacity of more than 100 passengers - 2 flight attendants and one additional flight attendant for each compartment (or part of the compartment), containing 50 seats above the specified 100.

During take-off and landing, flight attendants should be as close as possible (as far as possible) to the required floor level exits and be evenly distributed on the aircraft to ensure the most efficient exit of passengers in an emergency evacuation. This determines the location of the workplaces of flight attendants.

Escorts are located outside the cockpit and must have separate seats (sometimes folding) with seat belts.

The crew cabin is designed like a prototype.

1.2.3. Luggage compartment

Luggage spaces are usually placed in an airtight part of the fuselage under the cockpit floor or on the ground floor. Most often, the trunks are arranged in front and behind the passenger cabin in order that by adjusting the load can be kept within the specified limits of the centering of the aircraft, especially with an incomplete number of passengers.

Sometimes on multi-seat and wide-body aircraft, the size of the luggage space is increased so that in the case of an incomplete number of passengers to be able to load the aircraft to full commercial load at the expense of mail and cargo.

For loading and unloading of luggage and cargo, the outer doors of the trunk must have dimensions not less than those specified. A hatch should be provided for access to the trunk of the aircraft.

To increase the efficiency of transportation, it is necessary to make maximum use of the tailings of the fuselage and tail cock, placing in them trunks, aircraft equipment, etc.

The required amount of luggage space is determined by the formula:

$V_{lreq} = V_b \cdot n_{pass} = 141\ m^3$, where $V_b = 0.36\ldots0.38$ – for fuselage where D_f > 5,5 m;

1.2.4. Galleys and buffets

Depending on the number of passengers, 1...2 kitchens are provided to provide food for passengers on intercontinental and long-distance trunk lines. International standards stipulate that if the aircraft is a mixed layout, then be sure to make two kitchens. If the duration of the flight is less than 3 hours, passengers are currently not provided with food, in which case buffets for water and tea are provided. Buffets and toilets may not be made on airplanes with a flight time of less than one hour.

Kitchens and cupboards must be located at the door, preferably between the cockpit and the passenger, or have a separate cargo door. On wide-body aircraft, the kitchen is located under the floor, and food carts are lifted into the cabin by elevator. Sometimes they are made 2-storey: downstairs kitchen, upstairs sideboard.

Buffets and kitchens can be placed near toilets or combined with wardrobes.

The total volume of the kitchen: $V_k = (0,1...0,12) \cdot n_{pass}$, і її площа $S_k = \frac{V_k}{h_k}$, where $h_k = 2$ m – kitchen height.

$V_k = 0,1 \cdot 380 = 38$ m^3, $S_k = \frac{38}{2} = 19$ m^2

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

Meals are given to passengers every 3.5 ... 4 hours of flight.

1.2.5. Wardrobe

Wardrobes for passengers' outerwear are located near the main doors for entry and exit of passengers. It is desirable to make the wardrobe for the crew's clothes separate. Perform wardrobes of 2 types. Relatively narrow in such a way that it can hang on the shoulders, suspended on fixed pipes of the coat no more than 2 rows. The width of one row is 500 ... 600 mm, the pitch of the shoulders 70 ... 80 mm.

Area of such wardrobe $S_{wardrobe} = (0,035...0,040)n_{pass} = 0,035 \cdot 380 = 13,3$ m^2

Wardrobes should be located as close as possible to the passenger compartment and separated from it by a curtain or removable partition so that in summer, when the wardrobes are not used, install additional seats in their place. Hats, briefcases and small bags are stored on shelves located on board along the passenger cabin. Height of shelves from a floor of a cabin of 1700 ... 1800 mm.

1.2.6. 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 40 passengers, at $t = 2...4$ hours for 50 passengers and $t < 2$ hours for 60 passengers.

Toilet area $S_t = 1.5 \dots 1.6$ m^2 with a width of at least one meter. The norms stipulate that there is a supply of water and chemicals in the toilets per person: at $t > 4$ hours, $q = 2.0$ kg; $t = 2...4$ hours, $q = 1.0$ kg; $t < 2$ hours, $q = 0.7$ kg. Total supply of water and chemical liquid:

$$m_p = q \cdot n_{pass} = 2 \cdot 380 = 760\, kg.$$

1.2.7. Emergency exits and emergency means

Normal doors for entry and exit of passengers are performed on the left side of the aircraft [2]. The height of the door depends on the diameter of the fuselage and is equal to 1400 ... 1830 mm. The width of the door should be at least 860 mm, on wide-body aircraft, to reduce the time of entry and exit, often the door is made so wide that they can enter at the same time for 2 people. Threshold at the door is not allowed, the doorway below is limited by the floor plane.

For emergency departure of the aircraft on both sides of the aircraft make emergency exits, the main door is counted among the emergency. The number of emergency exits depends on the number of passengers.

According to the requirements of airworthiness, the number and size of emergency hatches must be such that during training on the ground (checking the departure of the aircraft), with 50% of all exits open, including the main, or separately all left and all right exits, evacuation carried out for 90 seconds. It is established that in the presence of two normal exits on the port side and two emergency exits on the starboard side 120 ... 160 passengers leave the plane in 30 seconds. On high-altitude aircraft must be the upper emergency exits of the fuselage at the rate of 1 hatch for 35 passengers. Airworthiness standards require having at least one easily accessible door. According to ICAO standards, the size of the emergency hatch must be such that an ellipse of at least 483x660 mm can be inscribed inside it. In the area where the crew is located, there must be either one exit on each side of the fuselage measuring at least 480x510 mm, or one upper hatch not less than 500 ... 700 mm, or a round hatch 0610 mm.

If normal and emergency exits are located high above the ground, then for the exit of passengers it is necessary to have an inflatable emergency ladder, its weight together with the cylinder 40 ... 45 kg. Space for it is taken near the front door or emergency hatch. For aircraft flying over the sea, individual inflatable vests and group life rafts are provided, the weight of one raft for 6 people complete with equipment and food for 3 days is 15 kg. Group rafts can accommodate from 6 to 25 people.

The main door - 890x1800 mm (2 pcs. On the left side in the bow and tail of the fuselage).

Service doors - 690x1600 mm (2 pcs. On the starboard side in the bow and tail of the fuselage).

Emergency door - 510x1100 mm (2 pcs. On the left and right board access to the wing).

All doors can be used as emergency.

The windows of the passenger cabin are located in one light line (for multi-deck by number of decks). The shape of the window is round with a diameter of 300 ... 400 mm or rectangular with rounded corners.

We accept the windows of the passenger cabin rectangular with convex sides and rounded corners 260x350 mm.

1.2.8. Layout and calculation of basic parameters of tail unit

One of the most important tasks of aerodynamic layout is the choice of the location of the horizontal tail unit. To ensure the longitudinal static stability of the aircraft overload, its CM must be in front of the focus of the aircraft and the distance between these points, attributed to the value of the average aerodynamic chord (CAC) of the wing, determines the degree of longitudinal stability, ie $m_x^{Cy} = \underline{x_T} - \underline{x_F} < 0$, where m_x^{Cy} – is the moment coefficient; $x_T,\ x_F$- center of gravity and focus coordinates. If m_x^{Cy} = 0, then the plane has the neutral longitudinal static stability, if m_x^{Cy} > 0, then the plane is statically unstable. In the normal aircraft scheme (tail unit is behind the wing), focus of the combination wing – fuselage during the install of the tail unit is moved back.

The areas of vertical S_{VT} and horizontal S_{HT} tail units are

$S_{HT} = (0,18...0,25)S = 0,19 \cdot 361 = 68,5\ m^2$;

$S_{VT} = (0,12...0,20)S = 0,15 \cdot 361 = 54,2\ m^2$.

The values of L_{HT} and L_{VT} depend on a number of factors. First of all, their size is affected by: the length of the nose and tail of the fuselage, sweep and location of the wing, as well as the conditions for ensuring the stability and controllability of the aircraft.

Determining the area of rudder and elevator. Elevator balance area usually take:

$S_{eb} = (0,3...0,4)S_{HT} = 0,3 \cdot 68,5 = 20,5\ m^2$.

Rudder balance area:

$S_{rb} = (0,35...0,45)\ S_{VT} = 0,35 \cdot 54,2 = 19\ m^2$.

Area of elevator trim tab:

$S_{te} = (0,08…0,12)\ S_e = 0,1 \cdot 20,5 = 2,1\ m^2$

Area of rudder trim tab:

$S_{tr} = (0,04...0,06)\ S_r = 0,05 \cdot 19 = 0,95\ m^2$

Determination of the range of horizontal tail. The wingspan and plumage of the aircraft is associated with static dependence:

$l_{HT} = (0,32...0,5)\ l_w = 0,4 \cdot 60,3 = 24,1$ m

The height of the vertical tail h_{VT} is determined depending on the location of the wing relative to the fuselage and the location of the engines on the aircraft. In view of the above, take: $h_{VT} = (0,13...0,16)\ l_w = 0,14 \cdot 60,3 = 8,4$ m

Narrowing of horizontal and vertical plumage should be chosen for airplanes with M <1, $\eta_{HT} = 2...4$ and $\eta_{VT} = 2...5$.

We accept: $\eta_{HT} = 3$ and $\eta_{VT} = 2.5$

Elongation of tail can be recommended - $\lambda_{HT} = 4$ and $\lambda_{VT} = 1,2$;

Determination of tail b_{tip}, b_{cac}, b_{root} perform according to the formulas:

For HT:

$$b_{tip} = \frac{2 \cdot S_{HT}}{(\eta_{HT}+1) \cdot l_{HT}} = 3,08\ m;$$

$$b_{CAC} = 0,66\ \frac{\eta_{HT}^2+\eta_{HT}+1}{\eta_{HT}+1}\ b_{HTtip} = 6,61\ m;$$

$$b_{root} = b_{tip} \cdot \eta_{HT} = 9,24\ m$$

For VT:

$$b_{tip} = \frac{2 \cdot S_{VT}}{(\eta_{VT}+1) \cdot l_{VT}} = 4\ m;$$

$b_{CAC} = 0{,}66\,\frac{\eta_{VT}^2+\eta_{VT}+1}{\eta_{VT}+1}\,b_{VTtip}$ = 8,58 *m;*

$b_{root} = b_{tip} \cdot \eta_{VT} = 12\ m$

The swept tail is taken 3 ... 5° more than the swept wing. This is done to ensure the controllability of the aircraft with the appearance of a wave crisis on the wing.

We take swept tail $\chi_{HT} = 33^\circ$; $\chi_{VT} = 35^\circ$

1.2.9. Landing gear design

During the diploma design, the landing gear scheme is selected, the number of wheels on the supports, the main parameters of the gear (base, removal of the main and nose supports, track), characteristic angles, and chassis tires are selected.

A feature of this landing gear scheme is the location of the main struts within the range of alignments so that all flight positions of the centers of mass are in front of the axes of the main struts, and the center of mass of the empty and equipped aircraft - behind.

At the initial design stage, when the centering has not yet been performed and there are no drawings of the general appearance of the aircraft, only part of the landing gear parameters are determined.

The main wheels axel offset is: $e = 0{,}2 \times b_{MAC} = 0{,}2 \times 5{,}1 = 1\ m$.

If the removal is too large, it is difficult to separate the front leg during takeoff, and if it is very small, it is possible to overturn the aircraft on the tail, when the rear saloons and luggage compartment are loaded first. In addition, the load on the nose support will be too small and the aircraft will be unstable when moving on slippery runways and crosswinds.

The landing gear wheel base is from the expression:

$B = (0{,}3 - 0{,}4)L_f = (6 - 10)e = 24\ m$

Front wheel axial offset will be equal:

$d = B - e = 24 - 1 = 23\ m$

Wheel track is calculated by formula:

$К = (0{,}7...1{,}2)\ B \leq 12\ m$

$К = 0{,}7 \cdot 24 = 16{,}8 < 12\ m$

We accept a landing gear track of 9*m* according to the prototype.

In order to prevent side nose-over - $K > 2H$. 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 in height.

In low planes CM is below the construction horizontal of the fuselage at a distance:

$Y_{cm} = (0{,}18...0{,}20)\ d_f$;

$Y_{cm} = 0{,}2 \cdot 5{,}6 = 1{,}12$

Gear wheels are selected according to the magnitude of the parking load on them from the takeoff mass of the aircraft; dynamic loads are taken into account when selecting the wheels of the nose support. The type of tires (balloon, semi-beam, arch) and the pressure in them is determined by the runway coating 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:

$$\mathrm{P}_{main} = \frac{(\mathrm{B}-\mathrm{e})\cdot m_0\cdot 9{,}81}{B\cdot n\cdot z} = \frac{24{,}1\cdot 233000\cdot 9{,}81}{25{,}1\cdot 2\cdot 2} = 549\ kN$$

$$\mathrm{P}_{nose} = \frac{\mathrm{e}\cdot m_0\cdot 9{,}81\cdot k_g}{B\cdot z} = \frac{233000\cdot 9{,}81\cdot 2}{25{,}1\cdot 2} = 91\ kN,$$

where n and z are the number of supports and wheels on one support, respectively; $k_g = 1{,}5...2{,}0$ – dynamics coefficient.

According to the calculated value of the load on the wheels P_{main} and P_{nose} and the magnitude of the take-off $V_{takeoff}$ and landing $V_{landing}$ speeds are selected from the catalog of pneumatics fulfilling the conditions:

$\mathrm{P}^{к} > \mathrm{P}_{\mathrm{main}}$; $\mathrm{P}^{к} > \mathrm{P}_{\mathrm{nose}}$; $\mathrm{V}^{к}_{landing} > \mathrm{V}_{landing}$; $\mathrm{V}^{к}_{takeoff} > \mathrm{V}_{takeoff}$

Choose the following wheels:

The main gear - 1700x550B mm (brake);

Nose gear - 1140x350V mm (non-braking).

1.2.10. Choice and description of power plant

The A330 was Airbus's first airliner to offer a choice of three engines: the General Electric CF6, Pratt & Whitney PW4000, or the Rolls-Royce Trent 700.

Under the power scheme is understood the articulation of structural elements that provide the perception of loads and their transfer to the balance in the form of transverse bending force and torque. The main elements of the power scheme are spars, wing and plumage panels, reinforced ribs, reinforced frames. In the process of layout it is necessary to link the power circuits, which is as follows:

- wall elements of the wing (spars and beams) and tail should be tied with reinforced frames of the fuselage.
- a space must be provided for the passage of the centerplane caisson through the fuselage.
- landing gear nacelles should not cross the wing power set.
- landing gear struts should be supported by reinforced elements (ribs, frames, chassis niche walls).
- the power elements of the tail feathers must rest on the reinforced frames of the fuselage.
- the handlebar mounting brackets are made as a continuation of the reinforced ribs.

The connection of the power scheme is shown in the drawing of the General view, where the dashed lines with two points are applied to the axes of the spars, reinforced ribs and frames. Reinforcement under landing gear components, engine mounts, etc. depicted in the layout drawing.

On aircraft with a spar circuit, it is often more advantageous not to pass the centerplane of the spars through the fuselage, and close the bending moments on the power frame. With fuselage diameters of more than 2 m, in order not to make slits for strings in the frames, stringers are usually mounted either on handkerchiefs or on slit pads. The bending moment transmitted by the swept spar of the tail to the fuselage frame necessarily gives a component that is transmitted to the longitudinal beam or side rib. These elements must be provided when composing the power scheme of the swept tail unit. It is necessary to show the fin spar mounting unit and explain the setting of the stiffeners. To prevent the development of fatigue cracks in the rivet holes in the skin, for example, the fuselage between the skin and reinforced frames, it is recommended to lay titanium tapes.

1.3. Center of gravity calculation

When performing volume-mass layout, calculations of aircraft centering are performed, ie finding such a position of the center of mass (CM) of the aircraft relative to the geometric mean wing chord (MAC), at which:

- in the case of the version with the rearmost position of the CM provides the minimum allowable margin of static stability of the aircraft;
- in the case of the variant with the most forward position of the CM, the conditions of sufficiency of the deviation of the rudder or stabilizer for longitudinal balancing of the aircraft in all flight modes are provided.

The more efficient the aircraft's longitudinal control and balancing, the more acceptable the frontal alignment may be and, consequently, the wider the operational range of the alignments.

During the operation of the aircraft, the position of its CM changes both as the fuel is produced in flight and as a result of different loading options and flight masses.

Therefore in CP it is necessary to calculate ranges of centers of the plane for the most characteristic cases of its operation:

- take-off mass when the chassis is released;
- takeoff weight with the chassis removed;
- landing weight with the chassis released;
- distillation option (without commercial load at maximum fuel) with the chassis removed;
- parking option (without commercial load, fuel, crew) with the chassis released.

1.3.1 Trim-sheet of the equipped wing

The mass of the equipped wing includes the mass of its structure, part of the mass of the equipment (located in the wing), landing gear and fuel mass. Regardless of where the main gear supports are located (on the wing or on the fuselage), they are included in the centering mass of the equipped wing together with the front support. The origin of these coordinates of the centers of gravity of the masses is chosen in the projection of the starting point of the MAC on the XOY plane. The names of the object, their relative and absolute masses and the coordinates of the centers of mass are entered into the centering statement.

Coordinates of the center of power for the equipped wing are defined by the formulas:

$$X_w^i = \frac{\sum m_i x_i}{\sum m_i} = 627337.02/182506.7 = 3.44m$$

Table 1.3. - Trim sheet of equipped wing

№	Name	Mass		Units	total mass m_i (kg)
		Units	total mass m_i (kg)		
1	Wing (structure)	0,1	26162,2	4,25	111103
2	Fuel system, 40%	0,01	2335,81	5,66	1859,87
3	Control system, 30%	0,002	328,47	5,66	1859,87
4	Electrical equip. 10%	0,002	651,17	0,94	614,52
5	Anti-icing system 70%	0,01	2569,54	0,94	2424,91
6	Hydraulic system, 70%	0,01	2420,29	6,61	15988,39
7	Power units	0,042	12231,12	-3	-36693,36
8	Fire protection system	0,015	4158,58	0,02	88,83

№	Name	Mass		Units	total mass mm_i (kg)
		Units	total mass m_i (kg)		
9	Main landing gear	0,03	8498,68	3,05	25920,98
10	Fuel	0,41	116790,6	4,25	495974,54
Equipped wing without fuel and LG			57217,37	1,84	105441,5
Total			182506.7	3.44	627337.02

1.3.2 Trim-sheet of the equipped fuselage

I assume that the projected plane is symmetrical on the Y axis, so we determine only the coordinate of the center of gravity X. The coordinates of the center of mass of the equipped fuselage is determined by the formula:

$$X_f = \frac{\sum m_i x_i}{\sum m_i} = 3277657{,}03/104439{,}19 = 31.38m$$

Having determined the centers of gravity of the equipped wing and fuselage, we make the equation of equilibrium of moments relative to the nose of the fuselage:

$$m_f x_f + m_w(x_{MAC} + x_w^i) = m_o(x_{MAC} + C)$$

From this equation we determine the position of the wing MAC leading edge relative to the nose of the fuselage, i.e the value of $x_{MAC}$by the formula:

$$X_{MAC} = \frac{m_f x_f + m_w \cdot x_w^i - m_o C}{m_o - m_w} =$$

$$= \frac{104439{,}19 \cdot 31{,}38 + 182506{,}67 \cdot 3{,}44 - 233000 \cdot 1{,}4}{233000 - 182506{,}67} = 27{,}3$$

$$\underline{c} = (0{,}28 - 0{,}32) \cdot b_{MAC} = 1{,}4$$

$$x_T = x_A + \underline{c} = 27{,}3 + 1{,}4 = 28{,}7$$

$$\underline{x_T} = \frac{x_T - x_A}{b_A} 100\% = \frac{1{,}4}{5{,}1} 100\% = 27\%(20 - 42)$$

Table 1.4. – Trim sheet of equipped fuselage

№	Objects	Mass		Coordinates of C.G.	Moment (kgm)
		Units	Total (kg)		
1	Fuselage	0.08	24479,52	30.54	747536,54
2	Horizontal TU	0,009	2714,18	56,96	154603,55
3	Vertical tail unit	0,011	3186,72	56,96	181519,67
Equipment					
4	Anti-icing system, 15%	0,004	1101,23	30,54	33628,59
5	Air-conditioning 15%	0,005	1573,19	29,26	46039,14
6	Heat and sound isolation	0,01	3054,18	31,17	95209,14
7	Control syst 70%	0,003	766,43	30,28	24379,7
8	Hydraulic system 30%	0,004	1037,27	31,61	32995,08
9	Electrical eq, 90%	0,02	5860,56	25,45	149137,76
10	Radar	0,002	547,45	0,64	348,28
11	Air-navig. system	0,003	835,58	3,18	2657,94
12	Radio equipment	0,0015	432,2	3,18	1374,8
13	Instrument panel	0,0034	979,64	2,54	2492,96
14	PTU	0,006	1712,36	62,35	106759,98
Empty fuselage			53899,04	32,59	1756489,93
Equipment					
15	Additional eq.	0,005	1527,09	25,45	38860,87
16	Service equipment		760	30,54	23210,4
17	Mail/Cargo	0,005	1527,09	25,45	38860,87
18	Crew		190	3,18	604,38
19	Flight Attendants		750	31,81	23857,2
	Equipped fuselage without payload		57582,32	32,05	1845678,27
20	Front landing gear	0,007	2124,67	8,2	17422,3
Total			59707	31,2	1863100,57
Commercial loading					
21	Baggage		14820	29,9	443133,18
22	Meals		1412,2	33,08	46718,21
23	Passengers		28500	32,45	924705,07
Total			104439,19	31,38	3277657,03

1.3.3 Calculation of center of gravity positioning variants

Table 1.4. – Calculation of C.G. positioning variants

Name	Mass, kg	Coordinates	Moment
Object	m_i	C.G. M	kgm
Equipped wing without fuel and L.G.	57217,37	1,84	105441,5
Nose landing gear (opened)	2124,67	8,2	17422,3
Main landing gear (opened)	8498,68	32,2	273 657,47
Fuel	116790,61	4,25	495974,54
Equipped fuselage	57582,32	32,05	1845678,27
Passengers	28500	32,45	924705,07
Food	1412,2	33,08	46718,21
Baggage	14820	29,9	443133,18
Nose landing gear (retracted)	2124,67	7,7	16359,96
Main landing gear (retracted)	8498,68	32,2	273 657,47

Table 1.5. – Airplanes C.G. position variants

№	Variants of the loading	Mass, kg	Moment of the mass, kg*m	Centre of the mass, m	Centering
1	Take-off mass (L.G. opened)	286945,8	3904994,05	31,7	32,32
2	Take-off mass (L.G. retracted)	286945,8	3903931,71	31,7	32,28
3	Landing variant (L.G. opened)	179352,3	3443047,86	30,97	24,63
4	Transportation variant (without payload)	242213,7	2489375,25	31,87	34,07
5	Parking variant (without fuel and payload)	121739,8	1905274,7	31,12	26,13

Conclusion to the project part

Aircraft construction is identified as an important component in the global transport of passengers and cargo. It is a high-speed transport that is not currently congested compared to land transport, because in a sense it is a public means of transportation. However, with the advantage that it can transport passengers over long distances and inaccessible, for example, for land or surface transport.

Working on one of the important and integral stages in aircraft construction, the preliminary design of the aircraft, the main characteristics of the aircraft were studied, and the main structural elements of the aircraft are described, making it a product that fully and correctly fulfills its intended purpose.

Therefore, during the work on the project, such stages of work on it were passed as compilation and processing of statistical data of the experimental sample of a passenger plane with a capacity of 380 passengers and formation of the technical task; calculation of the take-off mass of the aircraft and optimization of the masses of functional systems on the PC, assessment of flight characteristics; calculation of geometric parameters of aircraft units, preparation of preliminary drawings; layout and centering of the aircraft; execution of drawings (general view of the aircraft in three projections, and layout with characteristic cross-sections of the fuselage); and, of course, project development and defense.

2. SPECAIL PART

The delivery by air, for individual industries, is becoming much more popular than before, because it guarantees speed, reliability and safety of the transported cargo. In the cargo compartments of ordinary passenger aircraft, as a rule, carry almost half of all cargo. However, in times of crisis, companies are trying to ensure a stable profit, without the threat of bankruptcy and looking for effective solutions to such problems.

Only in 2019, the passenger turnover of global airlines increased by 4.2%, according to IATA [4]. Airlines have worked hard to sustain sustainable growth amid a number of challenges, as global trade activity has weakened and political and geopolitical tensions have affected demand.

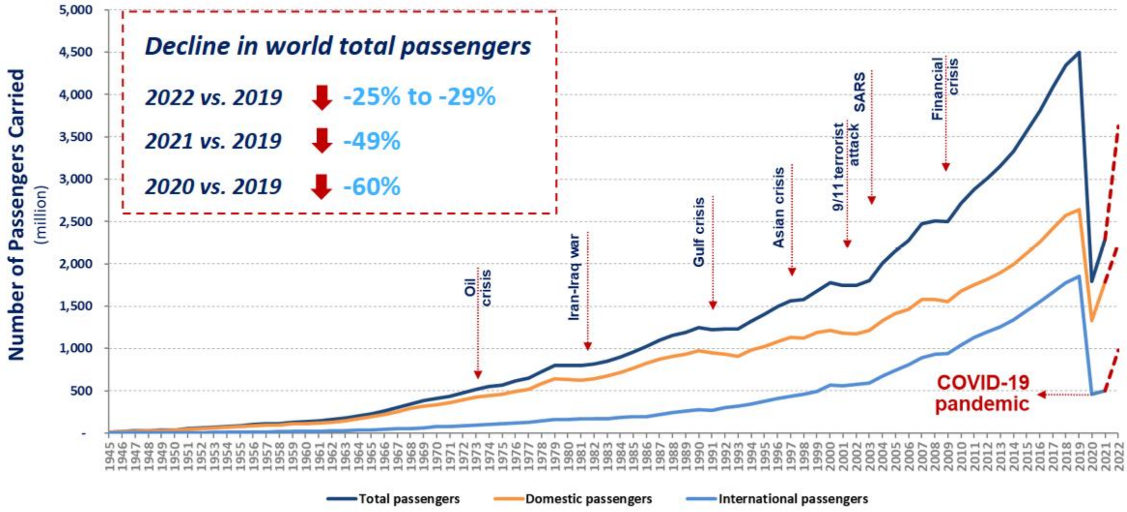


Figure 2.1. World passenger traffic evolution 1945-2022

It was a great ascent for aviation, but soon we had to watch the disaster that came in the form of a pandemic due to the well-known Covid-19. This was a severe blow to absolutely all airlines, in early 2020 they significantly reduced the number of flights or completely stopped flights. The crisis caused by the pandemic was the deepest for aviation, as governments in many countries decided to quarantine, close flights and ban or restrict entry. Figure 2.1 shows the sharp decline in passenger traffic in the world compared to previous years.

However, "trouble does not come alone" and another problem arose - the war in Ukraine. According to IATA data [5] in the pre-war period, Ukraine accounted for 4.1% of total passenger traffic in Europe and total traffic in the world; Russian domestic traffic accounted for 4.5% of global RPK (revenue from passenger-kilometers), and international air passengers accounted for 5.7% of total European traffic. Thus, despite the relatively small share of global traffic directly related to Ukraine and the aggressor country, it seems that the war and the sanctions associated with it have global implications for airlines and IATA in general.

Therefore, due to the situation caused by Covid-19 and the war, the number of passengers decreased. So many airlines have used every opportunity to make money, especially on freight, so it's time to re-equip or another word — convert aircraft.

With such ups and downs, it may seem that all is lost, but the prospect of aviation development is always there, no matter what, and one of these areas is the conversion of passenger aircraft into cargo aircraft.

2.1. An overview of aircraft conversion

As known, a transport (cargo) aircraft is an aircraft (freighter), which is designed to transport a variety of cargo. They differ from passenger ones by simplified household equipment, increased cargo space, large cargo door, stronger floor, installation on board of mechanization of loading and unloading operations. In general, there are three types of transport aircraft development [6]:

1) Derivatives of non-cargo aircraft.

Leading aircraft manufacturers produce such aircraft, as a rule, on the basis of already operated passenger aircraft, which no longer meet the regulatory or commercial requirements for passenger traffic. Prominent examples of such transformations of P2F are Airbus A321P2F, Boeing 737-800F, McDonnell Douglas MD [7]. A convertible aircraft is a passenger aircraft that has served 15-20 years and can be disposed of or re-equipped, and usually the cost of a convertible aircraft consists of the residual value of a passenger liner that has served a certain number of years - about 10-15 million dollars; the cost of conversion - about 4 million dollars; overhaul with maintenance - about 1 million dollars. Conversion process example is shown on the Figure 2.2 below.

Figure 2.2 Converting a Boeing 767-300ER to a cargo plane

2) Dedicated civilian cargo aircraft.

An aircraft originally designed to carry cargo and designed without regard to passenger or military functions, cheaper to manufacture and more economical to operate than compromise passenger and transport counterparts. The aircraft may have certain design features, designed primarily to facilitate the loading and unloading of aircraft. This is primarily a layout "high plan" (allows the location of the cargo as close to the ground), reinforced landing gear with many wheels, cargo hatches at the bottom and top of the fuselage, hatches at the front of the fuselage (folding nose) as shown on Figure 2.3 and rear (swings or folding tail).

Figure 2.3. An-124 on the runway, the nose of the plane rises to open the cargo hold

3) Joint civil-military cargo aircraft.

Those which designed for the transportation of troops, their landing (by parachute or landing), cargo, military equipment and weapons. These are aircraft, the development of which meets the requirements of both civil and military freight, profitable for production and operation:

- because the project is initially designed for freight;
- development costs are shared between the civil sector and the defense industry;
- the number of aircraft required for the army is reduced, because if necessary, the army can requisition civil aircraft.

Many airlines did not carry the required number of passengers due to quarantine, which added to the risk of their financial stability, but it was and it is still necessary to make money in order to continue to exist in demand in the market. However, there is another side that should not let the aviation industry fall — the need for cargo aircraft. Currently, the demand for such services is also very high, as the number of online purchases and various shipments during and after quarantine seems normal. The main advantage of air transportation is speed, so cargo aviation delivers, first of all, the most expensive cargo and goods that require urgent delivery (perishable goods, valuable and expensive goods, clothing, electronics, pharmaceuticals, industrial equipment, components for automotive industry, etc.). But there are not enough cargo planes.

Therefore, one of the reasons for the conversion is that in some cases aircraft manufacturers prefer to upgrade obsolete passenger aircraft that no longer meet the regulatory or commercial requirements for passenger transport. The time saved on the re-equipment of an already operational passenger aircraft is significant, because it takes many times longer to start production for a new aircraft.

In the Special part it is offered to make conversion of the passenger long-haul aircraft Airbus A330-300 with 380 passenger places. The A330-300P2F is an ideal replacement for the older generation of medium-sized narrow-body cargo ships, as it can be converted to carry a large volume of cargo. The A330-300P2F is the ideal replacement for the older generation of narrow-body cargo ships. With main deck cargo compartment for 26 large containers / pallets and 9 containers LD3 on the lower deck (in the forward and aft part), this is one of the most economical trucks in its category. It is also cleaner due to significantly lower fuel combustion and reduced emissions.

The conversion of this aircraft involves the following steps:

- removing of passenger equipment and furnishing (seats, lavatories, entertainments, communications etc.)
- installation of large cargo doors of the main deck and reinforcement of the fuselage around it;
- passenger windows plugging and deactivation of passenger doors;
- cargo loading system installation;
- modification and installation of other systems (ECS, floor drain, fire/smoke detection, etc.)
- floor reinforcement;
- cargo barrier net installation and repair of a cabin.

2.2. Conversion of aircraft

Air delivery for individual industries over time is becoming much more popular than before, because it guarantees speed, reliability and safety of the transported cargo.

In the cargo compartments of ordinary passenger aircraft, as a rule, carry almost half of all cargo. However, in times of crisis, such planes are idle, as happened in a pandemic, and can happen again at any time, so companies that care about making a steady profit, without the threat of bankruptcy, are looking for effective solutions to such problems. One such solution is the conversion of aircraft.

It is also known that each aircraft has its own characteristics, which are given to it by engineers and designers who design and build it for specific purposes. If you look at its original version, it is a passenger plane that can hold a large number of passengers, plus luggage in the luggage compartment of the front and rear lower deck. Such a bird already has the potential to be re-equipped, if necessary, without stopping its life cycle.

However, as we know, transport aircraft are those that have to carry goods and goods of different categories, and since it was determined that this is a normal passenger aircraft that converts to transport, we exclude its military transport purpose.

Therefore, it is possible to reduce the range of goals that it captures and determine what design changes are needed to achieve the goals of freight. It is known that different requirements apply to the carriage of passengers and goods. For example, if there must be an oxygen mask in the passenger compartment next to each passenger, in the case of cargo transportation, their proper attachment and the presence of a fire extinguishing system play an important role. The main modifications that need to be made when convert an aircraft will be listed below.

Cargo door installation

The integration of large cargo doors on the main deck is an important step in the process of converting a passenger plane into freighter, because for proper loading and unloading of various cargoes it is necessary to have a full-size passage that easily allows cargo to enter the aircraft [8].

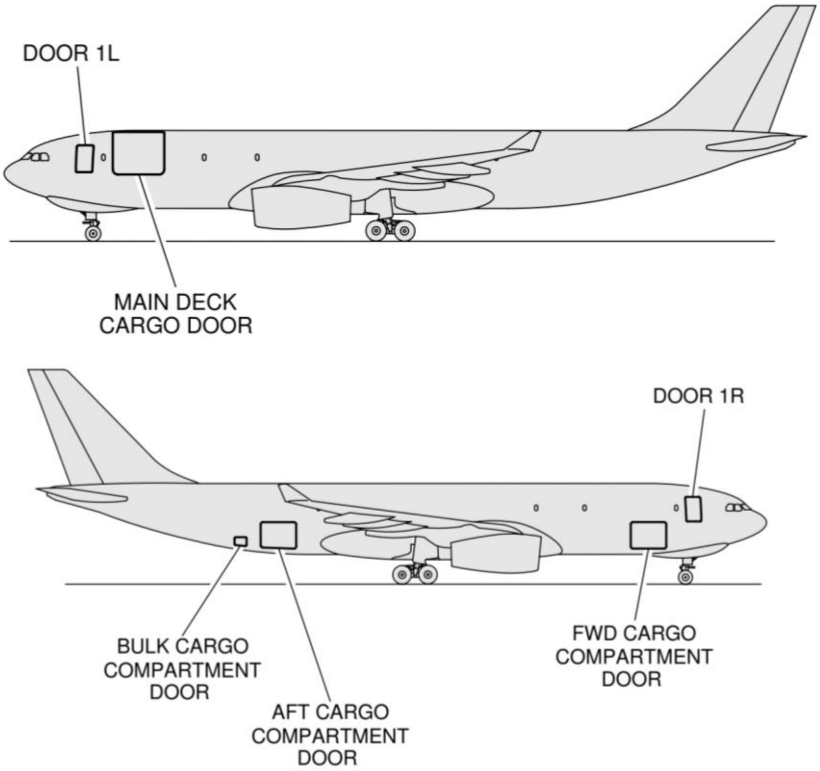


Figure 2.4. Location of the door on the right and left side in Airbus A330-300P2F

Therefore, for the convenience of operating the cargo version of the aircraft, as shown on the Figure 4, the windows which are located in this area will be removed in the front left part of the fuselage and skin in this area will be cut too, then plugged and the Main Deck Cargo door with hydraulic drive will be installed in this place, with dimensions: 3.58 m x 2.56 m.

It is also necessary to reinforce the structure of the fuselage around the cargo door, to prevent various loads, including due to the size of the door and the hydraulic system through which they open, close and lock.

Modifications of fuselage

Conversion is carried out to give the passenger plane a new life as a cargo plane, so the re-equipment from the inside begins with the removal of any items that are no longer necessary for the aircraft carrying the cargo, and it is important to carry out certain procedures. The removal of passenger seats and all passenger equipment and furnishing, including communications, lavatories, galley, entertainment system, etc.

However, there is still a courier zone, which should have no more than 8 people, including 2 pilots. Therefore, there should be 5 non-flight crew seats, galley equipment, stowage compartment and lavatory in this area.

Plugging of windows and deactivation of doors

Rounded sealed windows on the upper deck of the passenger fuselage are usually required for passengers to have access to the light inside the cabin. Historically, the most common is the rounded shape of the window and it is caused by the fact that such a hole less weakens the structure of the fuselage. But for the same transport aircraft, the number of such windows plays a big role.

Therefore, one of the points in the conversion is the mandatory plugging of all windows of the main deck, removing of windows which are located on the place where the main deck cargo compartment door should be and deactivation of passenger doors in the aft part of fuselage, such a modification acquires structural load resistance and must withstand loads, including decompression, also less maintenance efforts required. The work is performed by installing plugs in the form of metal plates that are attached surface to the installation site of windows. However, there are exceptions: the 1L and 1R front passenger doors, as shown in Figure 4, which are used for service and staff entry, and the cockpit windows themselves.

Cargo loading system installation

To handle a certain number of pallets with cargo loading, unloading and placing cargo on board the cargo aircraft, it is also necessary to have a loading system. Such a system should be economical in time and other significant costs, so that staff of several people can easily load and unload cargo from / to the aircraft.

The entire length of the cargo deck's main deck shall include a control system for moving cargo pallets or containers in and out of the compartment, guide elements, multi-directional ball transfer panels and a conveyor system for roller trays, and a power drive system.

Containers or pallets, moved by the power drive system, first pass through the area of the main cargo door, then enter the compartment through the rollers on the threshold of the bullet transfer panels located in the door area of the compartment. Further movement inside the compartment is carried out by means of a drive wheel system and on roller trays.

The maximum load of the Airbus A330-300P2F is 62 tons of cargo, with a maximum range of 6,780 km. There are many variations of cargo placement in the cargo compartment of the upper and lower decks. For example, the following configuration will be taken: 26 pallets with cargo on the main compartment of the aircraft (22 - side by side, 4 - single row); 6 pallets - lower front deck, 5 pallets - lower aft deck of the aircraft.

Figure 2.5. Main deck cargo compartment of the A330 after conversion

Other system installation

There is also a need to modify some aircraft systems, such as the environmental control system, in other words ECS, for the special configuration of the cargo ship, certain elements are removed that are necessary for the passenger version of this aircraft, but not relevant to the transport version; also adding parts that are already required for this cargo version of the aircraft unique to the entry configuration of the cargo ship. An already edited system must maintain the same (or better) airflow rate, temperature control, duct pressure, and noise levels that meet FAR 25.831 requirements for airflow and temperature control.

In turn, it is necessary to modify the air conditioning system, because if, for example, in the passenger version of the aircraft detection and elimination of fire is a fairly simple task, then access to the cabin of the main luggage compartment of the convertible version is missing. Therefore, in case of fire, to extinguish it in the cargo compartment of class E according to the headlights, it is necessary to completely block the air flow to the main cargo compartment, but also to supply fresh air to the areas of the flight crew and couriers.

It is also advisable to install fire detection and extinguishing systems for the freighter, such as fire sensors due to overheating (front edge of the wing, landing gear, engines, etc.), smoke detectors in all cargo compartments (main, lower front, lower rear), smoke detectors in the bathroom and so on; and a fire extinguishing system for the main elements of the aircraft (for engines, auxiliary power plant, for the main, lower front and rear cargo compartments).

In order to provide oxygen to the crew and couriers, the oxygen system is modified, and as mentioned in the previous paragraph - this should be done so that the aircraft is no longer focused on transporting large numbers of people, only the flight crew. Oxygen cylinders will be located both in the cockpit and in the toilet area, in case of sudden decompression.

The conversion also includes a water supply system, as the cargo version of the aircraft requires less water than the one required by the previous version. The drain system, which is kept for couriers and flight crew, should also be modified, and special dams should be installed on the main deck of the cargo compartment along the edge of the side to prevent water leakage.

Cargo barrier

It is also necessary to install a 9g cargo barrier between the main cargo compartment and the cab together with the courier area for conversion. It must be installed to prevent the movement of cargo and to distribute the load evenly in the event of cargo being moved inside the cabin, to separate and protect the flight crew from cargo in the event of an emergency landing or fire in the main deck cargo hold. Such a cargo barrier (smoke curtain with 9g net) should be installed right after the cockpit, before MDCD and according to FAR 25.561, this barrier should withstand a 9g acceleration of all ULDs in order to avoid crew's serious injury.

According to all the above modifications, we have a full cabin of a cargo aircraft complying with class E and in accordance with FAR CS § 25.857 (Cargo compartment classification (e)) [3] - a cargo compartment of class E on board an aircraft is a compartment intended only for the carriage of cargo, in which:

a) there is a smoke detector or fire detection system to warn the pilot or flight engineer;

b) there are means of stopping the supply of air for ventilation, which are controlled by crew members from the cabin;

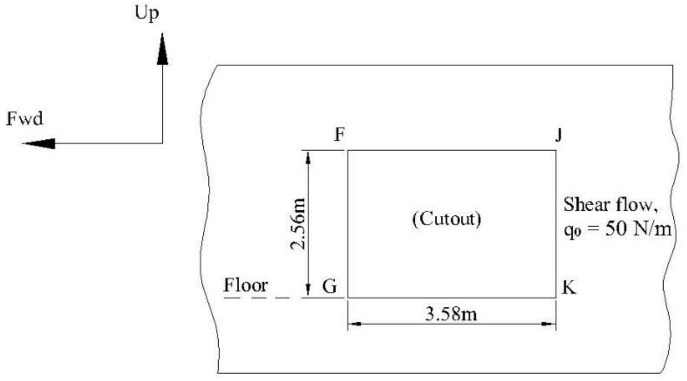
c) there are precautions against dangerous amounts of smoke, flames or harmful gases entering the crew cabin;

d) emergency exits for crew members are available under any load conditions.

2.3. Calculation of cargo door cutout

For the main cargo compartment of the front left part of the fuselage, take the cutout for the cargo door with dimensions 3.58 m x 2.56 m, and the radius of the fuselage - 2.82 m (diameter 5.64 m), the external structures of this cut are subject to internal loads, so there is a need determining the distribution of these loads, we take two of them - shear and bending moment.

1) The figure below shows the cutout with dimensions and how the load are redistributed around it, constant shear flow q_0 = 50 N/m



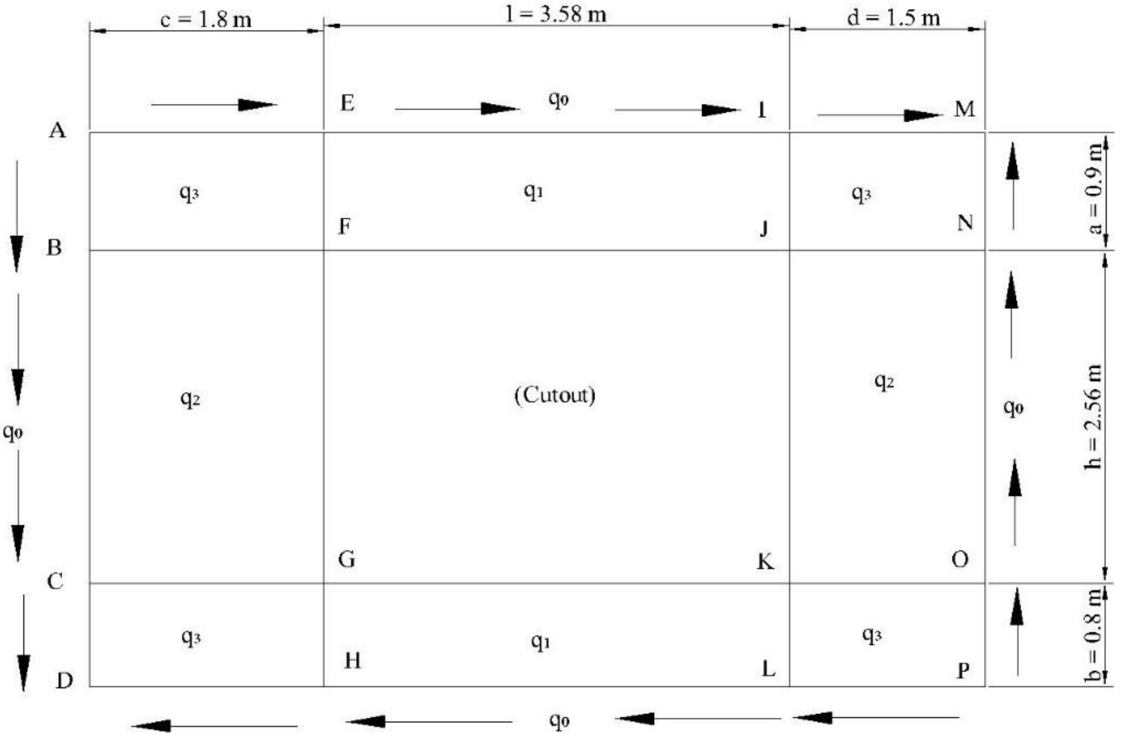


Figure 2.6. Shear flow distribution

2) Axial loads acting on stringers because of fuselage bending moment shown on figure below:

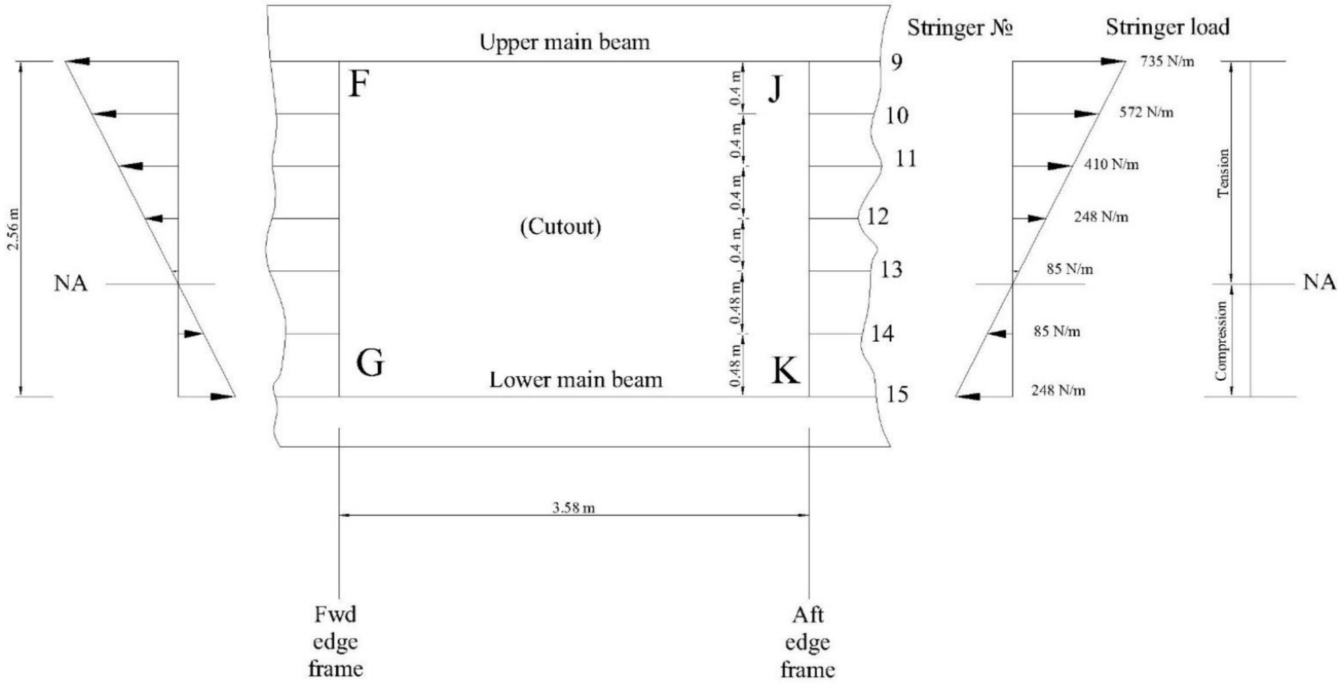


Figure 2.7. Bending moment

Suppose that between main and auxiliary beams there are two stringer bays and on both sides of the cutout (between edge and adjacent frame) one bay for the frame.

2.3.1. Load distribution due to fuselage skin shear

Suppose that there is a constant shear flow q_0 which is equal to 50 N/m.

$$q_{0.1} = \left(1 + \frac{h}{a+b}\right) q_0 = \left(1 + \frac{2.56}{0.9+0.8}\right) \times 50 = 125.3\ (N/m)$$

$$q_{0.2} = \left(1 + \frac{l}{c+d}\right) q_0 = \left(1 + \frac{3.58}{1.5+1.8}\right) \times 50 = 104.24\ (N/m)$$

$$q_{0.3} = \left[\left(\frac{l}{c+d}\right)\left(\frac{h}{a+b}\right) - 1\right] q_0 = \left[\left(\frac{3.58}{1.5+1.8}\right)\left(\frac{2.56}{0.8+0.9}\right) - 1\right] \times 50 =$$
$$= 31.7\ (N/m)$$

Axial loads of frame and beam (which is carried by its outer chord) determination by shear flow summarization

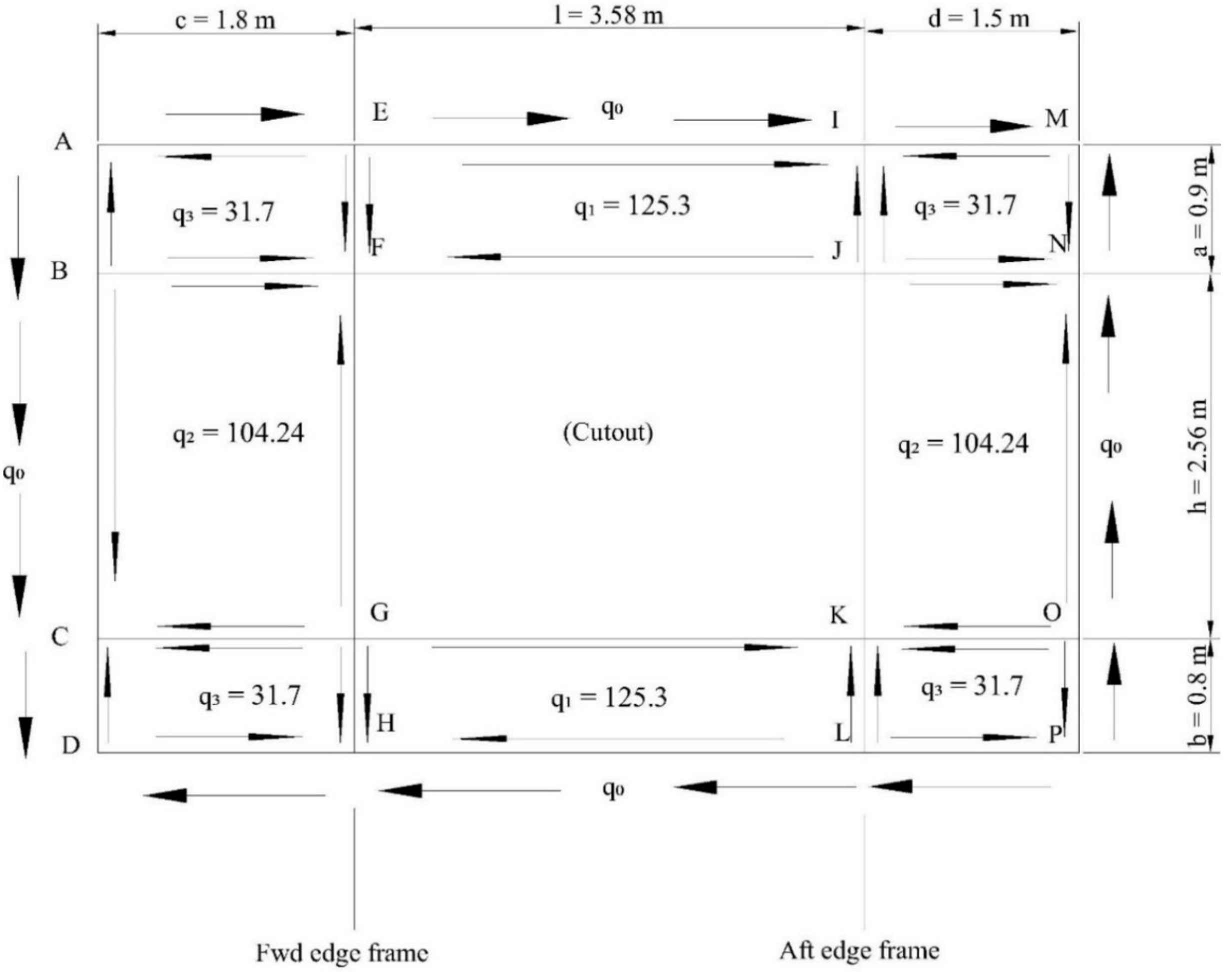


Figure 2.8. Calculated shear stresses

2.3.2. Load distribution due to bending of the fuselage

Under given fuselage loads on stringer (fuselage bending moment)

From point K (upper main beam reaction load S_9):

$$3.58 \times S_9 = -85 \times 0.48 + 85 \times 0.96 + 248 \times 1.36 + 410 \times 1.76 + 572 \times \times 2.16 + 735 \times 2.56;$$

$$S_9 = \frac{4216.8}{3.58} = 1177.87(N) - tension.$$

From point K (lower main beam reaction load S_{15}):

$$3.58 \times S_{15} = -248 \times 2.56 - 85 \times 2.08 + 85 \times 1.6 + 248 \times 1.2 + 410 \times \times 0.8 + 572 \times 0.4;$$

$$S_{15} = 49.92(N) - compression.$$

Shear flow under 9th stringer (at axial loads diffusion):

$$\text{Aft edge frame } \rightarrow q_{9,10} = \frac{1177.87 - 735}{1.5} = 295(N/m)$$

$$\text{Forward edge frame } \rightarrow q_{9,10} = \frac{1177.87 - 735}{1.8} = 246(N/m)$$

Shear flow over the 15th stringer (at axial loads diffusion):

$$\text{Aft edge frame } \rightarrow q_{14,15} = \frac{49.92 - (-248)}{1.5} = 198(N/m)$$

$$\text{Forward edge frame } \rightarrow q_{BF14,15} = \frac{49.92 - (-248)}{1.8} = 165(N/m)$$

Shear flow under and over 9th and 15th stringers are shown on Figure 9.

Shear flows of fwd edge frame (between upper and auxiliary beams):

$$0.5a \times q_{EF} + 0.5A \times 3q_{EF} = a \times (q_1 + q_2)$$

$$q_{EF} = \frac{q_1 + q_3}{2} = \frac{125.3 + 31.7}{2} = 78.5\left(\frac{N}{m}\right)$$

$$3q_{EF} = 3 \times 78.5 = 235.5\left(\frac{N}{m}\right)$$

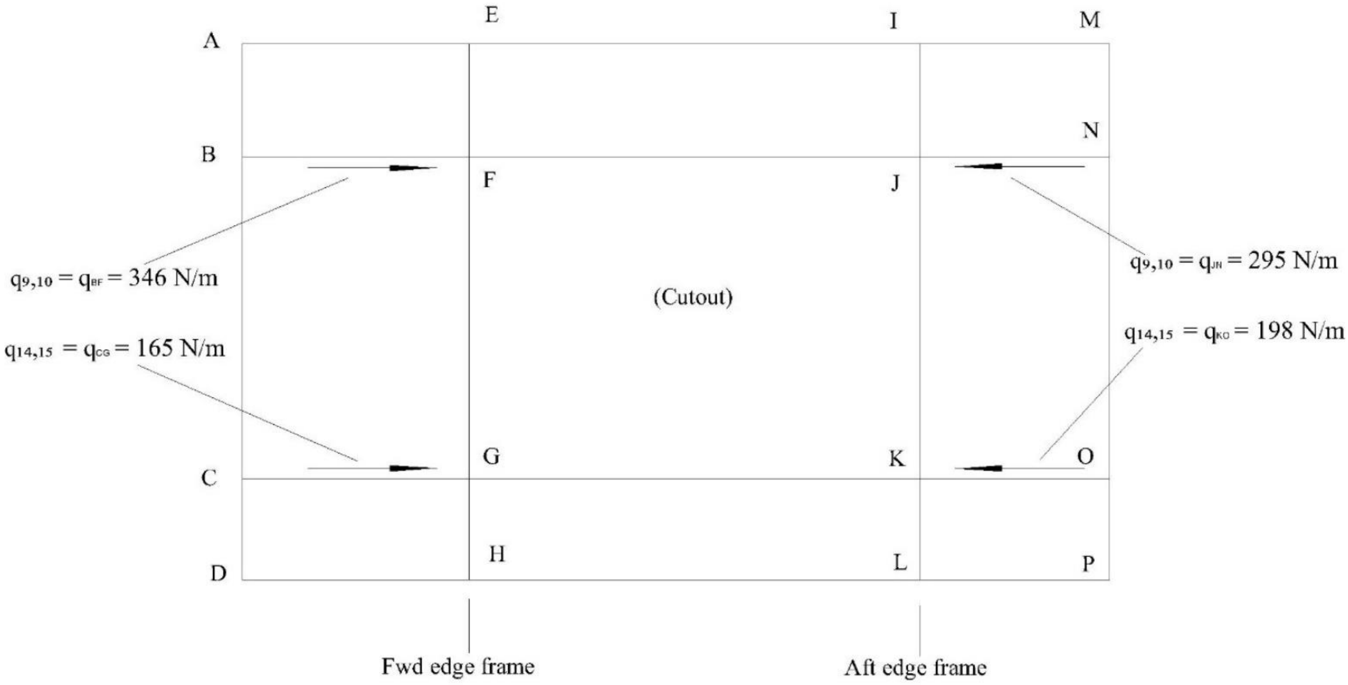


Figure 2.9. Shear flow

Same for fwd edge frame (between lower and auxiliary beam):

$$\frac{h}{4}(3q_{FG} + q_{FG} + q_{FG} + 3q_{FG}) = q_2 \times h$$

$$q_{FG} = \frac{q_2}{2} = \frac{104.24}{2} = 52.12\left(\frac{N}{m}\right)$$

$$3q_{FG} = 3 \times 52.12 = 156.36\left(\frac{N}{m}\right)$$

Shear flows for the fwd edge frame are shown on Figure 10, drawing made in AutoCAD and measurements of parameters as those in the table 2.1 were calculated there too.

Located on $\frac{1}{3}$ distance between main and auxiliary beams R_{EF} and R_{GH} (beam reactions) are calculated from the main beam. Based on the calculations of these reactions, the reactions of all other beams can be calculated in the same way.

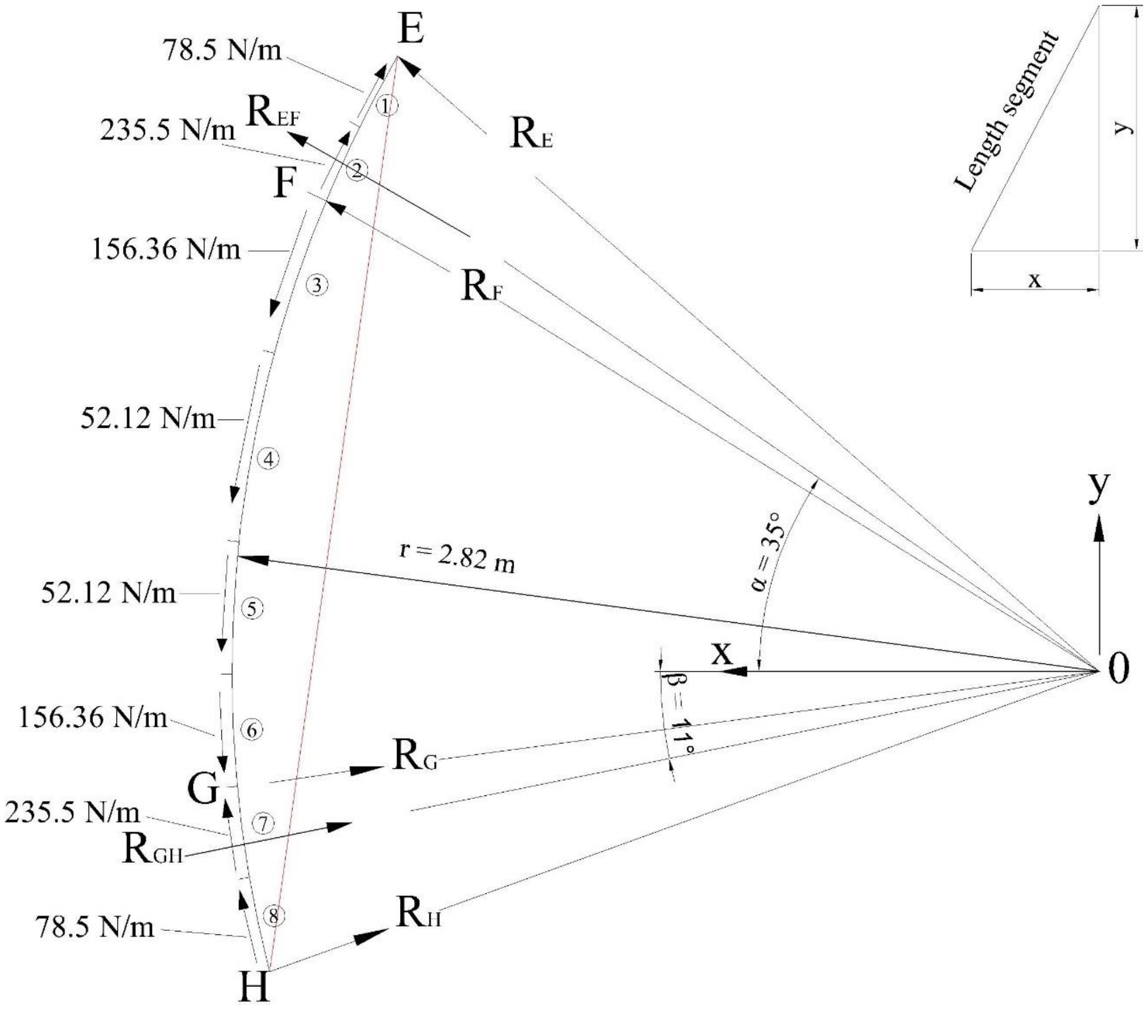


Figure 2.10. Beam reactions R_{EF} and R_{GH}

Table 2.1. Segment length in x and y direction:

Segment №	Shear, N/m	x, m	y, m
1	78.5	0.18	0.33
2	235.5	0.15	0.34
3	156.36	0.24	0.7
4	52.12	0.16	0.87
5	52.12	0.03	0.61
6	156.36	0.02	0.52
7	235.5	0.06	0.42
8	78.5	0.09	0.44

Equilibrium equation for vertical frame:

$$R_{EF}sin\alpha + R_{GH}sin\beta + 78.5y_1 + 235.5y_2 - 156.36y_3 - 52.12y_4 - 52.12y_5 - 156.36y_6 + 235.5y_7 + 78.5y_8 = 0;$$

$$R_{EF}sin\alpha + R_{GH}sin\beta + 78.5(y_1 + y_8) + 235.5(y_2 + y_7) - 156.36(y_3 + y_6) - 52.12(y_4 + y_5) = 0;$$

$$R_{EF}sin35° + R_{GH}sin11° + 78.5(0.33 + 0.44) + 235.5(0.34 + 0.42) - 156.36(0.7 + 0.52) - 52.12(0.87 + 0.61) = 0.$$

$$R_{EF} + 0.33R_{GH} = 41.46$$

Equilibrium equation for horizontal frame:

$$-R_{EF}cos35° + R_{GH}cos11° + 78.5x_1 + 235.5x_2 - 156.36x_3 - 52.12x_4 - 52.12x_5 - 156.36x_6 + 235.5x_7 + 78.5x_8 = 0;$$

$$-R_{EF}cos35° + R_{GH}cos11° + 78.5(x_1 - x_8) + 235.5(x_2 - x_7) - 156.36(x_3 - x_6) - 52.12(x_4 - x_5) = 0;$$

$$-R_{EF}cos35° + R_{GH}cos11° + 78.5(x_1 - x_8) + 235.5(x_2 - x_7) - 156.36(x_3 - x_6) - 52.12(x_4 - x_5) = 0;$$

$$-R_{EF} + 1.2R_{GH} = 15.75.$$

The R_{EF} and R_{GH} beam reactions may be defined this way:

$$\begin{cases} R_{EF} + 0.33R_{GH} = 41.46 \\ -R_{EF} + 1.2R_{GH} = 15.75 \end{cases}$$

$$R_{EF} = 30(N)$$

$$R_{GH} = 37.4(N)$$

Therefore

$$R_E = \frac{R_{EF}}{3} = \frac{30}{3} = 10(N/m)$$

$$R_F = \frac{2R_{EF}}{3} = 20(N/m)$$

$$R_G = \frac{2R_{GH}}{3} = 24.93(N/m)$$

$$R_H = \frac{R_{GH}}{3} = 12.46(N/m)$$

Conclusion to the special part

Air delivery guarantees speed, reliability and safety of the transported cargo. In times of crisis, conventional passenger planes are idle, as they were during the pandemic, and can happen again at any time, so companies are looking for effective solutions to such problems, and one of them is the conversion of aircraft.

Such a long-haul and wide-body bird as the Airbus 330-300 has the potential to re-equip, if necessary, without stopping the life cycle.

As different requirements are applied to transportation of passengers and cargoes it is necessary to make certain modifications at re-equipment of the plane. Research on the topic has shown that the main changes are subject to such systems and components as:

- passenger equipment and furniture (seats, toilets, entertainment, communications, etc.)
- there is a need to install large cargo doors of the main deck and strengthen the fuselage around it;
- passenger windows and passenger doors must be deactivated and clogged;
- cargo loading systems must be installed;
- modification and installation of other systems (ECS, floor drain, fire / smoke detection, etc.)
- floor reinforcement;
- installation of a cargo barrier grid and repair of a cabin.

GENERAL CONCLUSION

Summarizing all the above, we can confirm that aircraft construction is both a complex, time-consuming and quite expensive process, but also an important area at the moment for passenger transport and cargo transportation. Flying on an airplane allows you to cover long distances in short periods of time, now it is considered an advantage for humanity. However, the process of developing and designing such an aircraft, on the contrary, is more time-consuming. So, for an example of successful use of time and a product that has already passed a certain life path, we have an aircraft that is a potential candidate for conversion.

The main necessary changes during conversion were studied in Special part: deactivation and plugging of windows and doors for passengers; removing of passenger equipment and furnishing; installation of cargo loading system; installation of the door of the main cargo compartment in the front left part of the fuselage; installation of an environmental control system, floor drain, oxygen system, water system, fire detection and extinguishing system, and installation of a 9g barrier. Also, drawings of the convertible aircraft with modifications were made and the loads on the fuselage skin around the main cargo door were calculated.

The conversion of aircraft is proposed in order to increase the number of freighters and give aircraft that have been used for 10-15 years a chance to extend the life cycle without using new raw materials. As there may be a growing need to transport large amounts of aid to countries with shortages of certain products, cargo planes are needed to transport all of them, and convertible options may be the ones to re-equip rather than build a new one. This is primarily due to the fact that nowadays there is a certain tension between the countries on the planet, not excluding the difficult situation in Ukraine, which affects almost everyone, and this, among other things, may pose a threat to the aviation industry as well. However, as Confucius said, "Our greatest strength is not to never fall, but to rise every time we fall".

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Appendix A

INITIAL DATA AND SELECTED PARAMETERS

Passenger Number	380
Flight Crew Number	2
Flight Attendant or Load Master Number	10
Mass of Operational Items	1651.22 kg
Payload Mass	45900.00 kg

Cruising Speed	871.00 km/h
Cruising Mach Number	0.8186
Design Altitude	12.00 km
Flight Range with Maximum Payload	7400.00 km
Runway Length for the Base Aerodrome	3.30 km

Engine Number	2
Thrust-to-weight Ratio in N/kg	2.7100
Pressure Ratio	40.00
Accepted Bypass Ratio	4.50
Optimal Bypass Ratio	4.50
Fuel-to-weight Ratio	0.2900

Aspect Ratio	9.26
Taper Ratio	4.00
Mean Thickness Ratio	0.110
Wing Sweepback at Quarter of Chord	31.0°
High-lift Device Coefficient	1.050
Relative Area of Wing Extensions	0.010
Wing Airfoil Type	supercritical
Winglets	yes
Spoilers	yes

Fuselage Diameter	5.64m
Fineness Ratio of the fuselage	10.50
Horizontal Tail Sweep Angle	35.0°
Vertical Tail Sweep Angle	40.0°

CALCULATION RESULTS

Optimal Lift Coefficient in the Design Cruising Flight Point	$C_y=0.48274$
Induce Drag Coefficient	$C_x = 0.00895$

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

Cruising Mach Number	0.81861
Wave Drag Mach Number	0.82389
Calculated Parameter D_m	0.00529

Wing Loading in kPa (for Gross Wing Area):

At Takeoff	5.223
At Middle of Cruising Flight	4.401
At the Beginning of Cruising Flight	5.025

Drag Coefficient of the Fuselage and Nacelles	0.00617
Drag Coefficient of the Wing and Tail Unit	0.00896

Drag Coefficient of the Airplane:

At the Beginning of Cruising Flight	0.02606
At Middle of Cruising Flight	0.02479
Mean Lift Coefficient for the Ceiling Flight	0.48274
Mean Lift-to-drag Ratio	19.47307
Landing Lift Coefficient	1.557
Landing Lift Coefficient (at Stall Speed)	2.335
Takeoff Lift Coefficient (at Stall Speed)	1.926
Lift-off Lift Coefficient	1.406
Thrust-to-weight Ratio at the Beginning of Cruising Flight	0.473
Start Thrust-to-weight Ratio for Cruising Flight	2.223
Start Thrust-to-weight Ratio for Safe Takeoff	2.555
Design Thrust-to-weight Ratio Ro	2.683
Ratio $D_r = R_{cruise} / R_{takeoff}$ Dr	0.870

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

Takeoff	36.1475
Cruising Flight	58.4044
Mean cruising for Given Range	63.3152

FUEL WEIGHT FRACTIONS:

Fuel Reserve	0.02834
Block Fuel	0.26963

WEIGHT FRACTIONS FOR PRINCIPAL ITEMS:

Wing	0.12185
Horizontal Tail	0.01168
Vertical Tail	0.01206
Landing Gear	0.03788
Power Plant	0.08286
Fuselage	0.08645
Equipment and Flight Control	0.10097
Additional Equipment	0.00107
Operational Items	0.00581
Fuel	0.29797
Payload	0.24128

Airplane Takeoff Weight	M = 284317.0 kg
Takeoff Thrust Required of the Engine	381.45 kN

Air Conditioning and Anti-icing Equipment Weight Fraction	0.0106
Passenger Equipment Weight Fraction (or Cargo Cabin Equipment)	0.0002
Interior Panels and Thermal/Acoustic Blanketing Weight Fraction	0.0043
Furnishing Equipment Weight Fraction	0.0398
Flight Control Weight Fraction	0.0032
Hydraulic System Weight Fraction	0.0100
Electrical Equipment Weight Fraction	0.0124
Radar Weight Fraction	0.0040
Navigation Equipment Weight Fraction	0.0061
Radio Communication Equipment Weight Fraction	0.0030
Instrument Equipment Weight Fraction	0.0071
Fuel System Weight Fraction	0.0096

Additional Equipment:

Equipment for Container Loading	0.0000
No typical Equipment Weight Fraction (Build-in Test Equipment for Fault Diagnosis, Additional Equipment of Passenger Cabin)	0.0011

TAKEOFF DISTANCE PARAMETERS

Airplane Lift-off Speed	277.41 km/h
Acceleration during Takeoff Run	$1.99\ m/s^2$
Airplane Takeoff Run Distance	1491.00 m
Airborne Takeoff Distance	578.00 m
Takeoff Distance	2069.00 m

CONTINUED TAKEOFF DISTANCE PARAMETERS

Decision Speed	263.54 km/h
Mean Acceleration for Continued Takeoff on Wet Runway	0.14 m/s^2
Takeoff Run Distance for Continued Takeoff on Wet Runway	3323.12 m
Continued Takeoff Distance	3901.50 m
Runway Length Required for Rejected Takeoff	4045.40 m

LANDING DISTANCE PARAMETERS

Airplane Maximum Landing Weight	222170.00 kg
Time for Descent from Flight Level till Aerodrome Traffic Circuit Flight	22.2 min
Descent Distance	53.77 km
Approach Speed	250.63 km
Mean Vertical Speed	2.02 m/s
Airborne Landing Distance	517.00 m
Landing Speed	235.63 km/h
Landing run distance	763.00 m
Landing Distance	1280.00 m
Runway Length Required for Regular Aerodrome	2138.00 m
Runway Length Required for Alternate Aerodrome	1818.00 m

Appendix B

Mean aerodynamic chord of the wing