МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ

Національний авіаційний університет

Кафедра конструкції літальних апаратів

ДОПУСТИТИ ДО ЗАХИСТУ

Завідувач кафедри, к.т.н., доцент

________ Святослав ЮЦКЕВИЧ

«___» ____________ 2024 р.

КВАЛІФІКАЦІЙНА РОБОТА

ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ

«БАКАЛАВР»

Тема: «Резервна система навігації середньомагістрального вантажного літака»

Виконав: __________ **Ілля МИХАЙЛЕНКО**

Керівник: к.т.н., доц. __________ **Юрій ВЛАСЕНКО**

Нормоконтролер: к.т.н., доц. __________ **Володимир КРАСНОПОЛЬСЬКИЙ**

Київ 2024

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

National Aviation University
Department of Aircraft Design

PERMISSION TO DEFEND
Head of the department, Associate Professor, PhD.
_________ Sviatoslav YUTSKEVYCH
"___" ____________ 2024

BACHELOR DEGREE THESIS

Topic: " Backup navigation system of medium-range cargo aircraft"

Fulfilled by: ____________ **Illia MYKHAILENKO**

Supervisor:
PhD, associate professor ____________ **Yuriy VLASENKO**

Standards inspector:
PhD, associate professor ____________ **Volodymyr KRASNOPOLSKYI**

Kyiv 2024

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, к.т.н., доцент
________ Святослав ЮЦКЕВИЧ
«___» ____________ 2024 р

ЗАВДАННЯ на виконання кваліфікаційної роботи здобувача вищої освіти

МИХАЙЛЕНКА ІЛЛІ ОЛЕКСАНДРОВИЧА

1. Тема роботи: «Резервна система навігації середньомагістрального вантажного літака», затверджена наказом ректора від 15 травня 2024 року № 794/ст.
2. Термін виконання роботи: з 20 травня 2024 р. по 16 червня 2024 р.
3. Вихідні дані до роботи: крейсерська швидкість польоту Vкр = 620 км/г, дальність польоту L = 1385 км, крейсерська висота польоту Нкр = 10.6 км, члени екіпажу 2, вантажопідйомність 15 000 кг.
4. Зміст пояснювальної записки: вступ, основна частина, що включає аналіз літаків-прототипів і короткий опис проектованого літака, обґрунтування вихідних даних для розрахунку, розрахунок основних льотно-технічних та геометричних параметрів літака, компонування вантажної кабіни, розрахунок центрування літака, спеціальна частина, яка містить аналіз типів резервних систем навігації та їх проблематики, а також розробку обладнання автоматичної пеленгації (ADF) та розрахунок на міцність вузлів кріплення .
5. Перелік обов’язкового графічного (ілюстративного) матеріалу: загальний вигляд літака (A1×1), компонувальне креслення фюзеляжу (A1×1), Дизайн автоматичного пілінгатора (A1×1), розрахункові графіки і діаграми.

6. Календарний план-графік:

№	Завдання	Термін виконання	Відмітка про виконання
1	Вибір вихідних даних, аналіз льотно-технічних характеристик літаківпрототипів.	20.05.2024 – 21.05.2024	
2	Вибір та розрахунок параметрів проектованого літака.	22.05.2024 – 23.05.2024	
3	Виконання компонування літака та розрахунок його центрування.	24.05.2024 – 25.05.2024	
4	Розробка креслень по основній частині дипломної роботи.	26.05.2024 – 27.05.2024	
5	Огляд літератури за проблематикою роботи. Проблема розробки обладнання автоматичної пеленгації.	28.05.2024 – 29.05.2024	
6	Обробка експериментальних даних. Аналіз типів резервних систем навігації.	30.05.2024 – 31.05.2024	
7	Оформлення пояснювальної записки та графічної частини роботи.	01.06.2024 – 02.06.2024	
8	Подача роботи для перевірки на плагіат.	03.06.2024 – 06.06.2024	
9	Попередній захист кваліфікаційної роботи.	07.06.2024	
10	Виправлення зауважень. Підготовка супровідних документів та презентації доповіді.	08.06.2024 – 10.06.2024	
11	Захист дипломної роботи.	11.06.2024 – 16.06.2024	

7. Дата видачі завдання: 20 травня 2024 року

Керівник кваліфікаційної роботи ____________ Юрій ВЛАСЕНКО

Завдання прийняв до виконання ____________ Ілля МИХАЙЛЕНКО

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty
Department of Aircraft Design
Educational Degree "Bachelor"
Specialty 134 "Aviation and Aerospace Technologies"
Educational Professional Program "Aircraft Equipment"

APPROVED BY
Head of the department, Associate Professor, PhD.
_________ Sviatoslav YUTSKEVYCH
"___" ____________ 2024

TASK

for the bachelor degree thesis

Illia MYKHAILENKO

1. Topic: " Backup navigation system of medium-range cargo aircraft", approved by the Rector's order № 794/ст from 15 May 2024.
2. Period of work: since 20 May 2024 till 16 June 2024.
3. Initial data: cruise speed Vcr= 620 km/h, flight range L = 1385 km, operating altitude Hop = 10.6 km, crew members 2, payload 15 tons.
4. Content (list of topics to be developed): introduction, main part: analysis of prototypes and brief description of designing aircraft, selection of initial data, wing geometry calculation and aircraft layout, landing gear design, engine selection, center of gravity calculation, special part: analysis of the backup navigation systems types and their problems, as well as the development of automatic direction finding equipment (ADF) and calculation of the strength of fastening nodes.
5. Required material: general view of the airplane (A1×1), layout of the airplane (A1×1), Design of Automatic Direction Finder (A1×1), schemes, plots and diagrams.

6. Thesis schedule:

№	Task	Time limits	Done
1	Selection of initial data, analysis of flight technical characteristics of prototypes aircrafts.	20.05.2024 – 21.05.2024	
2	Selection and calculation of the aircraft designed parameters.	22.05.2024 – 23.05.2024	
3	Performing of aircraft layout and centering calculation.	24.05.2024 – 25.05.2024	
4	Development of drawings on the thesis main part.	26.05.2024 – 27.05.2024	
5	Review of the literature on the problems of the work. The problem of developing automatic direction finding equipment.	28.05.2024 – 29.05.2024	
6	Processing of experimental data. Analysis of types of backup navigation systems.	30.05.2024 – 31.05.2024	
7	Explanatory note checking, editing, preparation of the diploma work graphic part.	01.06.2024 – 02.06.2024	
8	Submission of the work to plagiarism check.	03.06.2024 – 06.06.2024	
9	Preliminary defense of the thesis.	07.06.2024	
10	Making corrections, preparation of documentation and presentation.	08.06.2024 – 10.06.2024	
11	Defense of the diploma work.	11.06.2024 – 16.06.2024	

7. Date of the task issue: 20 May 2024

Supervisor: ____________ Yuriy VLASENKO

Student: ____________ Illia MYKHAILENKO

РЕФЕРАТ

Пояснювальна записка кваліфікаційної роботи бакалавра «Резервна система навігації середньомагістрального вантажного літака»:

68 с., 7 рис., 8 табл., 10 джерел

Дана кваліфікаційна робота присвячена розробці вантажного літака для середньомагістральних авіаліній з можливістю транспортування великих/негабаритних вантажів, що відповідає міжнародним стандартам польотів, нормам безпеки, економічності та надійності, а також аналіз типів резервних систем навігації та їх проблематики, а також розробку обладнання автоматичної пеленгації (ADF) та розрахунок на міцність вузлів кріплення.

В роботі було використано методи аналітичного розрахунку, компьютерного проєктування за допомогою CAD/CAM/CAE систем, чисельного моделювання і статистичного аналізу експериментальних даних.

Практичне значення результату кваліфікаційної роботи полягає у розробці обладнання автоматичної пеленгації (ADF) та розрахунок на міцність вузлів кріплення.

Матеріали кваліфікаційної роботи можуть бути використані в навчальному процесі та в практичній діяльності конструкторів спеціалізованих проектних установ.

Дипломна робота, аванпроект літака, компонування, центрування, резервні системи навігації та автоматичний пеленгатор

ABSTRACT

Bachelor degree thesis " Backup navigation system of medium-range cargo aircraft "

68 pages, 7 figures, 8 tables, 10 references

This thesis is dedicated to design of a cargo airplane for medium haul airlines with the possibility of transporting big/heavy cargo, which meets international flight standards, safety, economy and reliability standards, as well as analysis of the backup navigation systems types and their problems, as well as the development of automatic direction finding equipment (ADF) and calculation of the strength of fastening nodes.

The design methodology is based on prototype analysis to select the most advanced technical decisions, engineering calculations to get the technical data of designed aircraft and computer based design using CAD/CAM/CAE systems. In special part the numerical modeling and statistical analysis is used to process experimental data.

The practical significance of the result of the qualification work lies in the development of automatic direction finding equipment (ADF) and the calculation of the strength of fastening nodes.

The materials of the qualification work can be used in the aviation industry and educational process of aviation specialties.

Bachelor thesis, preliminary design, cabin layout, center of gravity calculation, backup navigation systems and automatic direction finder

Format	№	Designation	Name	Quantity	Notes
			General documents		
A4	1	NAU 24 18M 00 00 00 94 TW	Task for work	1	
	2	NAU 24 18M 00 00 00 94	Medium-range cargo aircraft	2	
A1		Sheet 1	General view		
A1		Sheet 2	Fuselage layout		
A4	3	NAU 24 18M 00 00 00 94 EN	Medium-range cargo aircraft	56	
			Explanatory note		
			Documentation for assembly units		
A1	4	NAU 24 18M 00 00 00 94	Design of Automatic Direction Finder	1	

	Sh.	№ doc.	Sign	Date
Done by		Mykhailenko I.A.		
Supervisor		Vlasenko Y.V.		
St.control.		Krasnopolskyi V.S.		
Head of dep.		Yutskevych S.		

NAU 24 18M 00 00 00 94 EN

Backup navigation system of medium-range cargo aircraft. (List of diploma work)

list	sheet	sheets
Q	9	56

404 ASF 134

CONTENT

INTRODUCTION 12
1. PRELIMINARY DESIGN OF MID RANGE AIRCRAFT 13
1.1 Analysis of prototypes and short description of designed aircraft 13
1.2 Brief description of the main parts of the aircraft 14
1.2.1 Wing 14
1.2.2 Pylons 15
1.2.3 Fuselage 16
1.2.4 Middle Section of the Fuselage 16
1.2.5 Tail Section of the Fuselage 17
1.2.6 Doors and Hatches 17
1.2.7 Empennage 18
1.2.8 Vertical Stabilizer 18
1.2.9 Horizontal Stabilize 19
1.2.10 Landing Gear 20
1.2.11 Crew Cabin 20
1.2.12 Cargo Cabin 21
1.2.13 Aircraft Powerplant 21
Conclusions to the analytical part 23
2. AIRCRAFT MAIN PARTS CALCULATIONS 24
2.1 Geometry calculations for the main parts of the aircraft 24
2.1.1 Wing geometry calculation 24
2.1.2 Fuselage layout 28
2.1.3 Lavatories 30
2.1.4 Layout and calculation of basic parameters of tail unit 30

2.1.5 Landing gear design 33
2.1.6 Choice and description of power plant 36
2.2 Determination of the aircraft center of gravity position 36
2.2.1 Determination of centering of the equipped wing 36
2.2.2 Determination of the centering of the equipped fuselage 37
2.2.3 Calculation of center of gravity positioning variants 39

Conclusions to the project part 40
3. BACKUP NAVIGATION SYSTEM OF MEDIUM-RANGE CARGO AIRCRAFT 41
3.1 Importance and role of the backup navigation system 41
3.2 Types of aircraft backup navigation systems 42
3.3 Real-world examples of an integration of the backup navigation system 46
3.4 The critical role of backup navigation systems in ensuring flight safety 49
3.5 Development of elements of Automatic Direction Finder 51
3.6 Calculation of the stress-strain state of nodes of Automatic direction finder 56
Conclusions to the special part 61
GENERAL CONCLUSIONS 62
REFERENCES 64
Appendix 65
Appendix A 66

INTRODUCTION

In modern aircraft design, one of the main requirements for aircraft from a commercial point of view is a reduced weight of the aircraft, which leads to a reduction in fuel consumption, and makes it cheaper and more competitive. The next key points are sufficient passenger capacity and ease of maintenance as much as possible.

The production of structural elements from composite materials is gaining more and more popularity. The field of use of these materials is quite extensive, starting with fairings and ending with highly loaded elements of the aircraft structure, such as spars, stringers, ribs, skins, etc. These materials have much less weight and are not inferior in strength to aluminum alloys used in aircraft construction. In addition, they are quite resistant to corrosion and allow reducing the number of parts. Due to such characteristics, fuel consumption is reduced. Therefore, one of the important tasks in aircraft design, such as reducing its cost, is to a certain extent solved by the use of modern composite materials.

1. PRELIMINARY DESIGN OF MID RANGE AIRCRAFT

1.1 Analysis of prototypes and short description of designed aircraft

The selecting of the optimum design parameters of the aircraft is the multidimensional optimization task, aimed at forming a "look" promising aircraft. In its configuration mean the whole complex flight-technical, weight, geometrical, aerodynamic and economic characteristics. In forming the "Appearance of the plane" in the first stage is widely used statistics methods transfers, approximate aerodynamic and statistical dependence. The second stage uses a full aerodynamic calculation; aircraft specified formulas of aggregates weight calculations, experimental data. The application of these data makes it possible to study the requirements for the design, their transformation, and further determination of the aircraft final appearance.

Prototypes of the aircraft, taking for the designing aircraft were in ranges of maximum payloud of 10 to 26 tones of cargo. Such aircraft like An-178, An-74, KC-390 will compete with projected aircraft in this market segment. Statistic data of prototypes are presented in table 1.1.

Table 1.1

Operational-technical data of prototypes

Parameters	Planes		
	An-178	An-74	KC-390
1	2	3	4
Max payload, kg	18000	10000	26000
Crew, [persons]	2-3	3-4	2
Flight range with $G_{payload,max}$, [km]	1350	1450	4850
Range of cruising altitudes, [km]	10	10.1	10.9
Number of engines and their type	2 Turbojet	2 Turbojet	2 Turbojet
Take off thrust, [kN]	2*94	2*65	2*139.4
Pressure ratio	26	20	36
Take off run distance, [m]		600	

Ending of the table 1.1

1	2	3	4
Wing span, [m]	30.32	31.89	35.06
Sweepback angle at ¼ of the chord, [°]	25		
Wing aspect ratio	9.33		
Wing taper ratio	4.61		
Fuselage length, [m]	32.235	28.07	33.91
Fuselage diameter, [m]	3.9	2.5	
Fuselage fineness ratio	7.68		
Cargo cabin width, [m]	2.7	2.1	
Cargo cabin length, [m]	13.21	11.3	
Cabin height, [m]	2.73	1.8	
Horizontal tail span, [m]	9.4		
Horizontal tail sweepback angle, °	32		
Vertical tail sweepback angle, [°]	40		
Landing gear base, [m]	11.37		
Landing run distance, [m]		450	
Take off gross mass, [kg]	51000	32000	81000
Landing mass, [kg]	51000		

The high-profile scheme is determined by the relative position of the aircraft units, their numbers and shape. Aerodynamic and operational characteristics of the aircraft depends on the aircraft layout and aerodynamic scheme of the aircraft. Fortunately chosen scheme allows to increase the safety and economic efficiency of the aircraft.

1.2 Brief description of the main parts of the aircraft

The aircraft is a cantilever high-wing type with two by-pass turbojet engines mounted in nacelles under the wing and tricycle landing gear featuring a single-strut nose gear and two dual-strut main gears.

1.2.1 Wing

The wing is swept, high-mounted, with a high aspect ratio and trapezoidal planform with a rearward sweep. It is designed based on supercritical airfoils. The wing comprises a central section (center wing box) and two outer panels, connected to the center wing box with flange joints. The wing is attached to the fuselage at four points through arcs on the first and second spars of the center wing box and with the help of a fuselage fairing.

The wing's construction is of the box type. The center wing box and the outer wing panels contain spars, ribs, and panels made of aluminum alloys. The box sections house fuel tanks, which can be accessed through service hatches on the top of the center wing box and the bottom of the outer wing panels.

The center wing box consists of a rectangular box in planform, with forward and aft compartments. The forward sections of the center wing box are installed before the first spar, while the aft compartments are located behind the second spar. These compartments include extendable single-slot flaps made of composite materials.

The outer wing panels are trapezoidal in planform, consisting of a structural frame, forward and aft compartments. The wingtips of the outer panels are equipped with aerodynamic surfaces that have a trapezoidal shape.

The forward compartment of the outer wing panels houses a retractable leading edge and three slat sections made of aluminum alloys. The forward part of the outer wing panels consists of panels made of composite materials and a frame made of aluminum alloys.

The aft compartment of the outer wing panels contains two sections of extendable double-slot flaps with fixed deflectors, an aileron, and five sections of deflectable spoilers that operate in braking, descent, and aileron modes. The aft part of the outer wing panels consists of panels made of composite materials and a frame made of aluminum alloys.

1.2.2 Pylons

Two pylons are installed on each outer wing panel, to which the nacelles and by-pass turbojet engines are attached. The pylon consists of a box, forward section, aft section, fairings, and a mounting compartment. Inside the box are pipelines and components for air extraction in the air conditioning system and the anti-icing system.

The box has nodes for connection with the wing and engine mounts. The forward and aft sections, nacelle fairing, fairings, and mounting compartment are attached to the box.

1.2.3 Fuselage

The fuselage is a thin-walled, framed shell with a cylindrical shape in the middle section and a conical, double-curvature shape in the nose and tail sections. The nose section houses the crew cockpit, while the transport cabin extends from the nose, through the middle, to the tail sections, between frames 8 and 43. Both the cockpit and the transport cabin are pressurized. The fuselage frame is made of aluminum semi-finished products, including the skin, stringer set made of extruded and bent profiles, typical frame rims, reinforced frames, beams, and reinforcing plates for cutouts in the shell under the center wing box, nose and main landing gear bays, door, and hatch openings.

In the nose section of the fuselage, there is a radome housing the radar, the cockpit canopy, and the cockpit floor with reinforcements for the commander’s seat, the co-pilot’s seat, the inspector’s seat, and the flight engineer’s seat. This section also includes the nose landing gear bay, which is covered by doors operated by the landing gear strut, technical compartments, and a bulkhead with a door for the crew.

The canopy has a welded steel frame with electrically heated windshields made of laminated glass, side windows in the form of vents, and rear windows made of acrylic glass.

1.2.4 Middle Section of the Fuselage

The middle section of the fuselage features the transport cabin floor, which is 13.21 meters long and 2.728 meters wide. The cargo floor is constructed from a set of lower frames, longitudinal beams and rails, and an anti-slip coating. The floor has seven rows of sockets for tie-down fittings to secure cargo and four rails for installing sections of removable airlift equipment. Removable panels in the floor provide access to the underfloor space.

The sides of the cargo cabin house aircraft system equipment and fittings for installing cargo winches and paratrooper seats.

The central structural compartment in the middle section of the fuselage is made from assembled riveted panels, structural sidewalls, and lower frames made from forgings and stampings. These components attach to the wing center section spars and the main landing gear struts.

1.2.5 Tail Section of the Fuselage

The tail section of the fuselage includes a cargo door, a tail assembly attachment compartment with a fuselage fairing between frames 50-53, on which the vertical stabilizer is mounted, an auxiliary power unit (APU) compartment, and the fuselage end. The APU compartment, located at the fuselage end, contains intake and exhaust devices, doors, and fireproof bulkheads. The cargo door opening, located between frames 36 and 57, is bordered by side beams and reinforced frames and diaphragms. The cargo door has a width of 2.728 meters at the cargo floor threshold at frame 36.

1.2.6 Doors and Hatches

The entry door, with an integrated ladder and hydraulic lift, is located at the front of the cargo cabin on the left side near frames 8-10, with a fuselage opening size of 860x1800 mm.

The forward emergency hatch is located on the right side of the aircraft near frames 8-10, with an opening size of 610x1220 mm.

Side doors for paratrooper deployment, with an opening size of 900x1900 mm, are located on both sides of the aircraft to allow for two-stream paratrooper deployment. They also serve as exits in case of emergency landings on land and water.

All doors can be manually opened from both inside and outside the aircraft. The entry door, forward emergency hatch, and side doors for paratrooper deployment serve as Type 1 emergency exits and are used for emergency evacuation on land and water when transporting personnel in the cargo cabin. Each emergency exit is accessible and optimally positioned for evacuation. The emergency exits for the crew are the cockpit canopy windows on the left and right sides of the cockpit.

The cargo door consists of a ramp with side locks, hinged at the cargo floor threshold and opening outward, two ladders manually attached on the ground to the rear end of the ramp frame, a door with side and upper locks hinged at the fuselage end and supported by the rear end of the ramp and side beams of the opening, as well as a pressure shield supported by the structural frame 50 and the door. The door and pressure shield open inward into the fuselage.

1.2.7 Empennage

The aircraft features a T-tail configuration with a single vertical stabilizer and a fixed horizontal stabilizer mounted on the vertical fin. The empennage consists of vertical and horizontal stabilizers, fairings, and endplates.

1.2.8 Vertical Stabilizer

The vertical stabilizer comprises the fin, rudder, and fore fin. The fin consists of a box-type structure, forward section, and tail section. The fin is joined to the fuselage at the upper surface of the tail assembly, where the horizontal stabilizer is also attached. The box section of the fin is made of metal (aluminum alloys) and consists of front and rear spars, twelve ribs, and right and left panels reinforced with stringers. The forward section of the fin is also metal (aluminum alloys), consisting of a removable leading edge, root, tip, and standard ribs, a structural beam, and skin. The tail section of the fin is made of three-layer composite panels and diaphragms. Some panels are made of aluminum alloys. Brackets for attaching the rudder, made of aluminum alloys, are mounted on the rear spar. The fin attaches to the fuselage at frame 50 at the front spar and frame 53 at the rear spar.

The rudder is primarily made of composite materials and consists of a frame (skin, ribs, and end caps), a spar, a forward section, and brackets for six supports, three of which are connected to the control drives. The brackets are made of aluminum alloys.

The fore fin attaches to the fuselage, fairing, and fin. It consists of a radio compartment made of a metal leading edge with diaphragms and side panels of honeycomb construction from composite materials (PKM), a metal control system compartment with a hatch on the left side and a diaphragm between it and the radio compartment, as well as a rib at the joint of the fore fin with the fuselage fairing.

1.2.9 Horizontal Stabilizer

The horizontal stabilizer includes the stabilizer and elevators separated by a fairing and an endplate. The stabilizer consists of two cantilevers, each with a box-type structure, a forward section, a tail section, and end caps. The box section is metal (aluminum alloys) and consists of front and rear spars, upper and lower panels reinforced with stringers, and fifteen beam-type ribs. The forward section attaches to the front spar and consists of a removable leading edge with an anti-icing system, comprising a pressure chamber shell, wall, and diaphragms made of aluminum alloys.

The tail section attaches to the rear spar and is made of aluminum diaphragms and panels (three-layer composite materials, some panels are aluminum alloys). The tail section includes a booster compartment. Brackets for attaching the elevator, made of aluminum alloys, are mounted on the rear spar. The end cap is a metal structure (aluminum alloys) consisting of a leading edge, ribs, skin, diaphragms, and brackets for attaching static dischargers.

Each stabilizer cantilever has an attached elevator. The elevator is primarily made of composite materials and consists of a frame (skin, ribs, and end caps), a spar, a forward section, and brackets for attaching it to the stabilizer, with three of these connected to the control drives. The brackets are made of aluminum alloys.

The fairing consists of an aluminum alloy frame to which radio-transparent fiberglass shells are attached. The endplate is located at the junction of the stabilizer and the fin, consisting of front and rear sections. The front section is metal (aluminum alloys) and consists of a frame, panels with hatches, beams, and belts. The rear section consists of composite panels, aluminum frames, belts, metallization strips with static dischargers, and an end cap with a tail light. For maintenance and inspection of the structure and systems, hinged and removable panels and hatches with covers are provided. Drain holes are located on the lower surfaces of the stabilizer, elevator, root rib, and rudder mounting brackets for condensation drainage.

1.2.10 Landing Gear

The aircraft's landing gear allows for operation from both paved runways and prepared unpaved airstrips. The aircraft is equipped with tricycle landing gear, consisting of a nose gear and main gears (two struts on each side). Two adjustable-height cargo supports with hydraulic drives are installed on the threshold frame of the fuselage, allowing for threshold height adjustment depending on the height of the loading platform or cargo vehicle.

The main landing gear components are made from high-strength steel and titanium forgings, including large-sized parts.

The nose gear consists of a semi-lever shock strut with a built-in two-chamber shock absorber, two non-braked wheels, a steering mechanism, locks for the extended and retracted positions, and a hydraulic cylinder for retracting and extending the gear.

Each main gear shock strut is a semi-lever type with a built-in shock absorber and one braked wheel. In the extended position, the strut is held by a folding brace. The struts are retracted transversely to the aircraft axis into bays under the fuselage floor and landing gear fairings. The bays are closed by doors mechanically linked to the struts. The main gear's cargo floor height regulation system (PBGP) allows the rear threshold height from the ground to be reduced from 1430 mm (corresponding to the empty equipped aircraft weight) to 1042 mm, with a ramp angle to the ground of 9.5 degrees and ladder angles of 12 degrees.

1.2.11 Crew Cabin

The crew cabin is equipped with four workstations: captain, co-pilot, inspector, and an additional station for either an escort or an aviation and airborne transport equipment technician. The workstations are oriented in the direction of flight.

All labels, indicators, and signals in the crew cabin are in English. The pilots' seats are equipped with sights for positioning them correctly. The seats are adjustable to fit individual anthropometric data. Each workstation is equipped with necessary emergency and rescue equipment. On the left side, at the rear of the cabin, behind the captain's station, there are a toilet and a wardrobe for personal belongings of the crew members. The floor level of the crew cabin is higher than the cargo cabin floor; a step is installed for access.

For emergency evacuation on land or water, sliding and removable windows are provided in the canopy. Safety ropes are installed above the windows. The crew cabin is also equipped with emergency rescue beacons. To meet noise standards, the interior surfaces are covered with vibration-damping and thermal-acoustic insulation, with decorative paneling serving as an additional soundproofing layer.

1.2.12 Cargo Cabin

The central fuselage houses the cargo cabin, which has a volume of 122 m^3, a length of 13.21 m (16.7 m with the ramp), and a cross-section of 2.728 x 2.73 m. The cargo cabin floor has an area of 36 m^2 (45.2 m^2 with the ramp) and can carry loads and equipment weighing up to 18 tons (with an overload factor of 2.25).

In the front fuselage between frames 8 and 10 on the left side, a door-trap is used for entry and exit, while the right front emergency hatch serves as an emergency exit. To ensure a comfortable environment, the cargo cabin is lined with interior panels. These panels not only provide decoration and ergonomics but also protect the aircraft system installations and equipment from damage and unauthorized access. The lining panels also serve as an additional soundproofing layer.

The lining allows for the installation of paratrooper seats. Decorative finishes for the cargo cabin panels include lacquer coatings. For ease of maintenance, interior panels are designed to be hinged or easily removable. To meet noise standards, the inner surface of the fuselage in the cargo cabin is covered with thermal and acoustic insulation (T3I). The cargo cabin structure meets the requirements for Class "E" cargo compartments.

1.2.13 Aircraft Powerplant

The powerplant consists of:

- Two main engine installations
- Automatic control and monitoring system for the powerplant (SAUSU)
- Fuel system
- Fire protection system

- Auxiliary power unit

Conclusions to the analytical part

In this section, I have prepared an analysis of aircraft prototypes, selected the main characteristics of the designed aircraft, and provided a brief description of all parts of the aircraft. Additionally, I determined the geometrical and structural parameters of the fuselage layout.

2. AIRCRAFT MAIN PARTS CALCULATIONS

2.1 Geometry calculations for the main parts of the aircraft

The aircraft configuration encompasses the arrangement of its components and structures, as well as the distribution of various loads such as passengers, luggage, cargo, and fuel.

The structural calculations of the aircraft's primary components are conducted based on the information provided in Appendix A.

The selection of the layout scheme and aircraft parameters is driven by their optimal alignment with operational demands.

2.1.1 Wing geometry calculation

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

Full wing area with extensions is calculated according to formula:

$$S_{wfull} = \frac{m_{0*g}}{P_0}$$

$$S_{wfull} = \frac{54665 * 9.81}{2866} = 187.1\ (m^2)$$

$S_w = 187.1\ (m^2)$ this value is not suitable for my aircraft, so I accept the value of the prototype $S_w = 98.58\ (m^2)$

Wing span is calculated according to formula:

$$l = \sqrt{S_w * \lambda}$$

$$l = \sqrt{98.58 * 9.33} = 30.32\ (m)$$

Root chord is calculated according to formula :

$$b_0 = \frac{2S_w * \eta_w}{(1 + \eta_w) * l_w}$$

$$b_0 = \frac{2 * 98.58 * 4.61}{(1 + 4.61) * 30.32} = 4.85\ (m)$$

Tip chord is calculated according to formula:

$$b_t = \frac{b_0}{\eta_w}$$

$$b_t = \frac{4.85}{4.61} = 1.3\ (m)$$

When deciding on the wing's structural design, we assess the number and placement of longerons, as well as the locations for segmenting the wing.

Contemporary aircraft typically employ xenon double or triple longeron wings, a configuration commonly found in light sport, sanitary, and personal aircraft. Our aircraft is equipped with three longerons. I employ the geometric method outlined in Figure 3.1 to determine the mean aerodynamic chord.

Mean aerodynamic chord is equal:

$$b_{MAC} = 3.4165$$

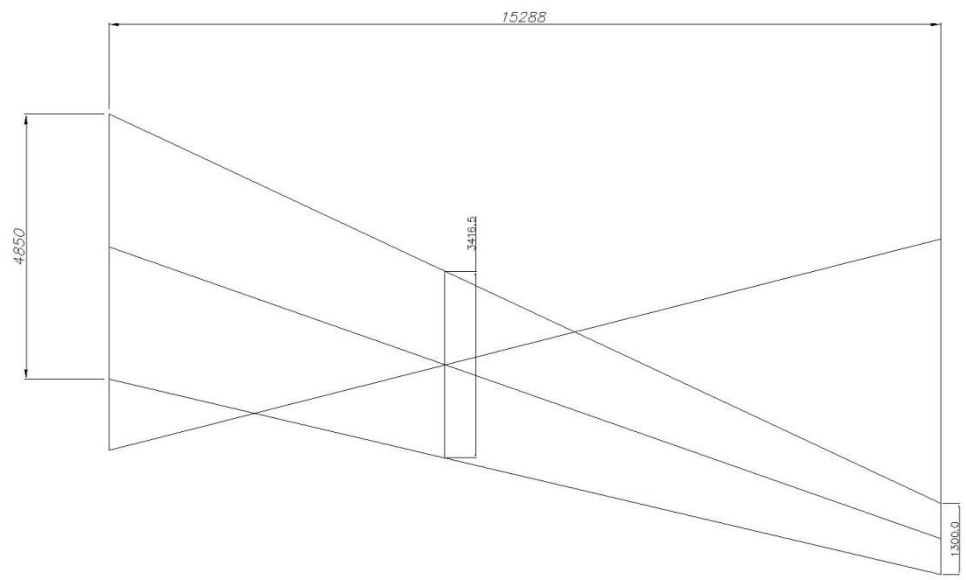


Figure 3.1. – Determination of mean aerodynamic chord

After determination of the geometrical characteristics of the wing we come to the estimation of the ailerons geometrics and high-lift devices.

Ailerons geometrical parameters are determined in next consequence:

Ailerons span is calculated according to formula:

$$l_{ail} = (0.3 \dots 0.4)\frac{l_w}{2}$$

$$l_{ail} = 0.375 * \frac{30.32}{2} = 5.685\ (m)$$

Aileron area is calculated according to formula:

$$S_{ail} = (0.05 \dots 0.08)\frac{S_w}{2}$$

$$S_{ail} = 0.065 * \frac{98.58}{2} = 3.204\ (m^2)$$

Chord of aileron is calculated according to formula:

$$C_{ail} = (0.22 \dots 0.26) b_i$$

$$C_{ail} = 0.24 * 1.709 = 0.41\ (m)$$

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

In the airplanes of the third generation there is a tendency to decrease relative wing span and ailerons area. So,l_{ail} = 0.122. In this case for the transversal control of the airplane we use spoilers together with the ailerons. Due to this the span and the area of high-lift devices may be increased, which improves take off and landing characteristics of the aircraft.

Aerodynamic compensation of the aileron.

Axial $S_{axinail} \leq (0.25 \dots 0.28)\ S_{ail} = 0.26 * 3.204 = 0.83\ (m^2)$

Inner axial compensation $S_{inaxinail} = (0.3..0.31)\ S_{ail}$;

Area of ailerons trim tab.

For two engine airplane:

$$S_{trtab} = (0.04\dots0.06)S_{ail}$$

$$S_{trtab} = 0.05 * 3.204 = 0.16\ (m^2)$$

Range of aileron deflection

Upward $\delta'_{ail} \geq 25^\circ$;

Downward $\delta''_{ail} \geq 15^\circ$.

The objective of determining the geometrical parameters of wing high-lift devices is to ensure that the coefficients of wing lift force during takeoff and landing align with those assumed in the preceding calculations, taking into account the selected configuration of high-lift devices and the characteristics of the airfoil profile.

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

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

In the modern design the rate of the relative chords of wing high-lift devices is:

b_{sf} = 0.25..0.3 – for the split edge flaps;

b_f = 0.28..0.3 – one slotted and two slotted flaps;

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

b_s = 0.1..0.15 – slats.

Effectiveness of high-lift devices (C^*_{ymaxl}) rises proportionally to the wing span increase, serviced by high-lift devices, so we need to obtain the biggest span of high lift devices ($l_{hld} = l_w - D_f - 2l_{ail} - l_n$) due to use of flight spoiler and maximum diminishing of the are of engine and landing gear nacelles.

During the choice of structurally-power schemes, hinge-fitting schemes and kinematics of the high-lift devices we need to come from the statistics and experience of domestic and foreign aircraft construction. We need to mention that in the majority of existing constructions elements of high-lift devices are done by longeron structurally-power schemes.

2.1.2 Fuselage layout

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

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

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

For high subsonic airplanes fuselage nose part has to be:

$$l_{fnp} = (2 \dots 3)D_f$$

$$l_{fnp} = (2 \dots 3)D_f = 2 * 3.9 = 7.8\ (m)$$

In addition to aerodynamic considerations when selecting the cross-sectional shape, it's essential to take into account strength and layout requirements.

To achieve minimal weight, the most favorable fuselage cross-section shape is a circular one, which allows for minimal fuselage skin width. Alternatively, a combination of two or more vertical or horizontal series of circles can also be utilized as a partial solution.

For cargo aircraft, where aerodynamics play a lesser role in fuselage shape selection, a cross-sectional shape closer to rectangular may be more suitable.

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

Fuselage length is calculated according to formula:

$$l_f = \lambda_f * D_f$$

$$l_f = 7.68 * 3.9 = 29.95\ (m)$$

Fuselage nose part aspect ratio is calculated according to formula:

$$\lambda_{fnp} = \frac{l_{fnp}}{D_f}$$

$$\lambda_{fnp} = \frac{7.8}{3.9} = 2$$

Length of the fuselage rear part is calculated according to formula:

$$l_{frp} = \lambda_{frp} * D_f$$

$$l_{frp} = 2.2 * 3.9 = 8.58\ (m)$$

During the determination of fuselage length we seek for approaching minimum mid-section S_{ms} from one side and layout demands from the other.

The mid-section of the fuselage for passenger and cargo airplanes primarily depends on the size of the passenger cabin or cargo hold.

From a design perspective, a round cross-section is favorable as it offers the optimal combination of strength and lightness. However, this shape may not always be the most practical for passenger and cargo accommodation. In many cases, a combination of intersecting circles or an oval fuselage shape proves to be more suitable. It's important to note that while the oval shape may seem ideal, it poses challenges during production as the upper and lower panels may bend under additional pressure, requiring additional reinforcement such as bilge beams.

The spacing between bulkheads in the fuselage typically ranges from 350 to 550mm, depending on the type of fuselage and the class of the passenger cabin.

For diameters less than 2800mm, shapes other than round are preferred, and intersecting circles cross-sections are typically utilized. This ensures that the floor of the passenger cabin remains flat and uncompromised.

2.1.3 Lavatories

The number of lavatories I choose according to the original airplane and it is equal:

$$n_{lav} = 1$$

Area of lavatoryis:

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

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

2.1.4 Layout and calculation of basic parameters of tail unit

One crucial aspect of aerodynamic design is determining the placement of the tail unit. To maintain longitudinal stability, especially during overloading, the center of gravity must be positioned ahead of the aircraft's center of lift. The distance between these points, relative to the mean value of the wing's aerodynamic chord, defines the degree of longitudinal stability.

$$m_x^{Cy} = \bar{x}_T - \bar{x}_F < 0$$

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

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

$$A_{VTU} = (0.05 \ldots 0.08) \rightarrow A_{VTU} = 0.06$$

$$A_{HTU} = (0.8 \ldots 1.1) \rightarrow A_{HTU} = 0.9$$

Determination of the tail unit geometrical parameters.

Area of vertical tail unit is calculated according to formula:

$$S_{VTU} = (0.18 \ldots 0.25) S_w$$

$$S_{VTU} = 0.21 * 98.58 = 21.054\ (m^2)$$

or

$$S_{VTU} = \frac{A_{VTU} * S_w * l_w}{L_{VTU}}$$

$$S_{VTU} = \frac{0.06 * 98.58 * 30.32}{7.5} = 23.9\ (m^2)$$

Area o horizontal tail unit is calculated according to formula:

$$S_{HTU} = (0.12 \ldots 0.2) S_w$$

$$S_{HTU} = 0.19 * 98.58 = 18.87\ (m^2)$$

or

$$S_{HTU} = \frac{A_{HTU} * S_w * b_{MAC}}{L_{HTU}}$$

$$S_{HTU} = \frac{0.9 * 98.58 * 3.4165}{16.2} = 20.27\ (m^2)$$

Values L_{htu} and L_{vtu} depend on some factors. First of all their value are influenced by: the length of henose part and tail part of the fuselage, sweptback and wing location, and also from the conditions of stability and control of the airplane.

Determination of the elevator area and direction:

Altitude elevator area is calculated according to formula:

$$S_{el} = 0.27 * S_{HTU}$$

$$S_{el} = 5.22\ (m^2)$$

Rudder area is calculated according to formula:

$$S_{rud} = 0.24 * S_{vtu}$$

$$S_{rud} = 5.05\ (m^2)$$

Choose the area of aerodynamic balance.

$$0.3 \le M \le 0.6$$

$$S_{eb} = (0.22..0.25) S_{ea}$$

$$S_{rb}=(0.2..0.22)S_{rd}$$

Elevator balance area is:

$$S_{eb} = 0.27 * S_{HTU}$$
$$S_{eb} = 5.09\ (m^2)$$

Rudder balance area is calculated according to formula:

$$S_{rud} = 0.24 * S_{vtu}$$
$$S_{rud} = 5.05\ (m^2)$$

The area of altitude elevator trim tab is calculated according to formula:

$$S_{te} = 0.08 S_{el}$$
$$S_{te} = 0.42\ (m^2)$$

Area of rudder trim tab is equal:

$$S_{tr} = 0.06 * S_{rud}$$
$$S_{tr} = 0.303\ (m^2)$$

Tip chord of horizontal stabilizer is calculated according to formula:

$$b_{tip}^{HTU} = \frac{2 * S_{HTU}}{(\eta_{HTU} + 1) * l_{HTU}}$$
$$b_{tip}^{HTU} = \frac{2 * 18.87}{(2.1 + 1) * 9.4} = 1.29(m)$$

Root chord of horizontal stabilizer is calculated according to formula:

$$b_{root}^{HTU} = \eta_{HTU} * b_{tip}^{HTU}$$
$$b_{root}^{HTU} = 2.1 * 1.29 = 2.709\ (m)$$

Tip chord of vertical stabilizer is calculated according to formula:

$$b_{tip}^{VTU} = \frac{2 * S_{VTU}}{(\eta_{VTU} + 1) * l_{VTU}}$$

$$b_{tip}^{VTU} = \frac{2 * 21.054}{(0.99 + 1) * 4.76} = 4.44\ (m)$$

Root chord of vertical stabilizer is calculated according to formula:

$$b_{root}^{VTU} = \eta_{VTU} * b_{tip}^{VTU}$$

$$b_{root}^{VTU} = 0.99 * 4.44 = 4.39\ (m)$$

2.1.5 Landing gear design

During the initial design phase, when the aircraft's center of gravity position is established and a comprehensive general view of the airplane is not yet available, only certain landing gear parameters can be determined.

Main wheel axel offset is calculated according to formula:

$$B_m = (0.15 \dots 0.2) b_{MAC}$$

$$B_m = 0.17 * 3.4165 = 0.581\ (m)$$

With the large wheel axial offset the lift-of of the front gear during take of is complicated, and with small, the drop of the airplane on the tail is possible, when the loading of the back of the airplane comes first. Landing gear wheel base comes from the expression:

$$B = (0.3 \dots 0.45) L_f$$

$$B = 0.38 * 29.95 = 11.37\ (m)$$

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

Front wheel axial offset will be calculated according to formula:

$$B_n = B - B_m$$
$$B_n = 11.37 - 0.581 = 10.789\ (m)$$

Wheel track is calculated according to formula:

$$T = (0.3 \ldots 1.4)B$$
$$T = 0.37 * 11.37 = 4.37\ (m)$$

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

$$H_{cg} = (0.08 \ldots 0.1)D_f = 0.09 * 3.9 = 0.351 m$$

The selection of landing gear wheels is based on considerations such as size and the load they will bear during takeoff. For the front support, dynamic loading is also taken into account.

The type of pneumatic tires (balloon, half balloon, arched) and their pressure are determined by the type of runway surface that will be utilized. Brake systems are typically installed on the main wheels, and sometimes on the front wheel as well.The load on the wheel is determined:

K_g = 1.5...2.0 – dynamics coefficient.

Nose wheel load is calculated according to formula:

$$P_n = \frac{B_m * M_0 * 9.81 * K_g}{B * z}$$
$$P_n = \frac{0.581 * 54665 * 9.81 * 1.7}{11.37 * 2} = 23292.3\ (N)$$

Main wheel load is calculated according to formula:

$$P_m = \frac{(B - B_m) * M_0 * 9.81}{B * n * z}$$

$$P_m = \frac{(11.37 - 0.581) * 54665 * 9.81}{11.37 * 4 * 2} = 63607.6\ (N)$$

It was chosen aviation tires for designing aircraft for main and nose landing gear. Size parameters is performed in table 2.1.

Table 2.1

Aviation tires for designing aircraft

Main gear		Nose gear	
Tire size	Ply rating	Tire size	Ply rating
1140*458 mm	16	700*270 mm	8

2.1.6 Choice and description of power plant

TA18-100 is an aviation auxiliary gas turbine engine developed in 2000 at PJSC NPP Aerosila. Designed for use on airplanes and helicopters.

AGTE TA18-100 meets the requirements for use on narrow-body aircraft with a capacity of up to 100 seats and heavy helicopters. The engine provides an air start of sustainer engines of aircraft. It also provides 115/200 volt AC power and serves to supply air to the air conditioning system.

Characteristics of AGTE TA18-100:

- Equivalent air power - 256 kW.
- Selectable AC power - 60 kVA.
- Bleed air consumption - 1.27 kg / s.
- Bleed air pressure - 4.52 kgf / cm^2.
- Bleed air temperature - 210 ° C.
- Fuel consumption - 132 kg / h
- Altitude of launch and operating mode - 9000 m.

- Working temperature range - ± 60 ° C.
- Initial assigned resource - 2000/4000 hours / starts.
- Assigned resource - 12000/15000 hours / starts.
- Weight (without generator) - 150 kg.
- Overall dimensions - 1076 × 684 × 675 mm.

2.2 Determination of the aircraft center of gravity position

2.2.1 Determination of centering of the equipped wing

The equipped wing's mass comprises the structural mass, the mass of equipment housed within the wing, and the mass of fuel. Whether mounted on the wing or fuselage, both the main landing gear and the front gear are accounted for in the equipped wing's mass register. This register details the names of objects, their masses, and their center of gravity coordinates. The coordinates of the mass centers are referenced from the projection of the nose point of the mean aerodynamic chord (MAC) onto the surface XOY. Positive coordinate values are assigned to the rearward part of the aircraft.

The example list of the mass objects for the aircraft, where the engines are located under the wing, included the names given in the table 2.2.

The example list of the mass objects for the aircraft, where the engines are located in the wing, included the names given in the table 2.2. The mass of AC is 54665 kg.

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

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

Table 2.2

Trim sheet of equipped wing masses

№	Name	Mass		C.G. coordinates	Moment (kgm)
		Units	total (kg)		
1	Wing (structure)	0,14604	7983,28	1,47	11728,19
2	Fuel system, 40%	0,00144	78,72	1,50	118,33
3	Control system, 30%	0,00213	116,44	2,05	238,68
4	Electrical equip. 30%	0,00621	339,47	0,34	115,98
5	Anti-icing system 50%	0,0083	453,72	0,34	155,01
6	Hydraulic system, 70%	0,01323	723,22	2,05	1482,52
7	Engine	0,08047	4398,89	-2,1	-9237,67
8	Equiped wing	0,17735	14093,73	0,33	4601,05
10	Nose landing gear	0,004944	270,26	-10,26	-2771,83
11	Main landing gear	0,044838	2451,07	1,11	2713,33
12	Fuel	0,12604	6889,98	1,47	10122,03
	Equiped wing	0,433642	23705,04	0,62	14664,59

2.2.2 Determination of the centering of the equipped fuselage

Origin of the coordinates is chosen in the projection of the nose of the fuselage on the horizontal axis. For the axis X the construction part of the fuselage is given. The example list of the objects for the AC, which engines are mounted under the wing, is given in table 2.3.

The CG coordinates of the FEF are determined by formulas:

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

We can find fuselage center of gravity coordinate X_f by divided sum of mass moment of the fuselage ($m_i^'$, X_i) on sum of total mass of fuselage ($m_i^'$):

$$X_f = \sum m_i \bullet X_i / \sum m_i = 16.22\ (m)$$

After we determined the center of gravity (CG of FEW) and fuselage, we construct the moment equilibrium equation relatively fuselage nose:

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

From here we determined the wing MAC leading edge position relative to fuselage, means X_{MAC} is calculated according to formula:

$$X_{MAC} = \frac{m_f * x_f + m_w * x_w - m_0 * c_n}{m_0 - m_w}$$

$$X_{MAC} = 12.061\ (m)$$

Where m_0 – AC takeoff mass, kg; m_f – mass of FEF, kg; m_w – mass of FEW, kg; C – distance from MAC leading edge to the CG point, determined by the designer.

Table 2.3

Trim sheet of equipped fuselage masses

№	Objects	Mass		Coordinates of C.G.	Moment (kgm)
		Units	Total (kg)		
1	Fuselage	0,13782	7533,93	14,975	112820,61
2	Horizontal tail unit	0,01865	1019,50	0,8512	867,80
3	Vertical tail unit	0,02186	1194,97	1,8632	2226,48
4	Radar equipment	0,0059	322,52	1,08	348,33
5	Instrument panel	0,0103	563,05	1,93	1086,69
6	Air-navigation system	0,0088	481,05	2,216	1066,01
7	Radio equipment	0,0044	240,53	2,16	519,54
8	Toilet 1	0,0002	10,93	3,7	40,45
9	Cargo compartment equipment	0,0002	10,93	11,45	125,18
10	Control system, 70%	0,00497	271,69	13,975	3796,79
11	Electrical equipment, 70%	0,01449	792,09	14,975	11861,64
12	Hydraulic system, 30%	0,00567	309,95	17,97	5569,81
13	Air conditioning system equipment	0,00332	181,49	14,975	2717,78
14	Decorative paneling	0,0208	1137,03	14,975	17027,05
15	Heat and sound isolation	0,0078	426,39	14,975	6385,15
16	Anti-icing system, 30%	0,00498	272,23	8,985	2446,01
17	Additional equipment	0,0082	448,25	13,975	6264,34
18	Fuel system, 60%	0,00216	118,08	13,975	1650,12
19	Auxiliary power unit	0,00821	448,79	15,5	6956,39
20	Equiped fuselage without comercial loads	0,28873	15783,43	16,22	183776,16
21	Cargo	0,2444	13360,13	14,975	200067,89
22	Non-typical equipment	0,033228	1816,41	14,975	27200,72
	Total	0,566358	30959,97	13,28	411044,76

2.2.3 Calculation of center of gravity positioning variants

The list of mass objects for centre of gravity variant calculation given in Table 2.5 and Center of gravity calculation options given in table 3.6, completes on the base of both previous tables.

Table 2.4

Calculation of C.G. positioning variants

Name	Mass, kg	Coordinates	Moment
Object	m_i	C.G., m	kgm
Equiped wing without fuel and L.G.	14093,73	8,995	126815,38
Nose landing gear (retracted)	270,26	1,9	513,51
Main landing gear (retracted)	2451,07	13,3	32599,22
Fuel	7008,05	11,5	80592,61
Equiped fuselage	15783,43	16,22	256007,16
Cargo	13360,17	14,975	200067,89
Nose landing gear (opened)	270,26	2,9	783,76
Main landing gear (opened)	2451,07	14,3	35050,29

Table 2.5

Airplanes C.G. position variants

№	Name of objects	Mass, kg	Momen, kgm	C.G., m	Centering
1	Take-off mass (L.G. opened)	54665	696595,76	12,72	19,15
2	Take-off mass (L.G. retracted)	54665	699317,09	12,76	20,61
3	Landing variant (L.G. opened)	51182,91	655193,81	12,80	21,65
4	Transportation variant (without payload)	39606,54	499249,21	12,61	15,92
5	Parking variant (without fuel and payload)	32598,49	415935,27	12,76	20,43

Conclusions to the project part

In this section, we have determined the center of mass position characteristics and presented the main calculations for the aircraft. We checked the mass position of the primary parts, equipment, and furnishings relative to the mean aerodynamic chord (MAC). Following the design of the wing and fuselage, we calculated the center of gravity for the fully equipped aircraft.

We found that the aircraft's center of gravity position ranges from 12.61 m to 12.80 m, which aligns with the desired values for this type of aircraft. Key dimensions were also calculated, including the wingspan at 30.32 m, wing area at 98.58 m^2, fuselage length at 29.95 m, landing gear base at 11.37 m, and track at 4.37 m. The leading edge of the wing's MAC is positioned 12.061 m from the fuselage, meeting the design specifications.

Additionally, we selected engines that fulfill the requirements for the designed aircraft and determined the geometric parameters of the fuselage layout.

3. Backup navigation system of medium-range cargo aircraft

3.1 Importance and role of the backup navigation system

Navigation systems play a key role in aviation, providing pilots with critical information to accurately determine the position of their aircraft, navigate designated flight paths, and reach their destination safely. These systems are critical to maintaining situational awareness, avoiding interference, and complying with designated airways and airspace regulations. In addition to improving flight safety, navigation systems also contribute to operational efficiency by optimizing routes, minimizing fuel consumption and reducing flight time. In general, navigation systems are essential tools that enable pilots to navigate diverse and often complex environments, ensuring the safe and successful completion of flights.

Medium-range cargo aircraft, typically designed to cover distances of several hundred to several thousand miles, form the backbone of commercial air travel, carrying cargo between regional and international destinations. The importance of navigation systems in this context is emphasized by the need to navigate smoothly over different terrains, weather conditions and airspace while adhering to strict operating time limits and safety protocols.

Drawing on the wide range of available navigation systems, this study delves into the complex landscape of backup navigation systems tailored to the unique requirements of medium-range cargo aircraft. As explained in the previous review, these backup systems serve as vital safeguards, offering redundancy and resilience in the face of primary system failures or navigation problems. By exploring the nuances of backup navigation systems and their integration into medium-range cargo aircraft, this study aims to highlight their indispensable role in aviation safety and operational reliability.

Through a comprehensive examination of primary navigation systems, the importance of backup systems, and design and implementation challenges, this study attempts to provide valuable information on the critical relationship between navigation technologies and the aviation industry. Additionally, by anticipating future trends and innovations, it aims to contribute to the current discourse on improving navigation capabilities and safety standards for medium-range cargo aircraft in an ever-evolving aviation landscape.

3.2 Types of aircraft backup navigation systems

Aircraft backup navigation systems are essential for ensuring safe navigation when primary systems fail. These systems provide redundancy and help pilots maintain situational awareness and control. Here are the main types of backup navigation systems used in aircraft, along with examples:

- Inertial Navigation System (INS)

Inertial navigation is a method of navigation (determining the coordinates and parameters of the movement of various objects — ships, planes, missiles, etc.) and controlling their movement, which is based on the properties of inertia of bodies, which is autonomous, that is, it does not require the presence of external landmarks or signals coming from the outside. Non-autonomous methods of solving navigation tasks are based on the use of external landmarks or signals (for example, stars, beacons, radio signals, etc.). These methods are quite simple in principle, but in several cases they cannot be carried out due to lack of visibility or interference with radio signals, etc. The need to create autonomous navigation systems was the reason for the emergence of inertial navigations.

Purpose: INS provides position, orientation, and velocity information without relying on external signals. It uses accelerometers and gyroscopes to calculate the aircraft's position based on its last known location.

Example: Honeywell's Laseref VI INS, which provides continuous navigation capabilities even when GPS signals are unavailable.

- DME (Distance Measuring Equipment)

Distance Measuring Equipment (DME) is a transponder-based radio navigation system that measures slant range distance by synchronizing the propagation delay of radio signals. The DME system consists of a transmitter/receiver (interrogator) in the aircraft and a receiver/transmitter (transponder) on the ground. The aircraft is interrogated and the DME ground station responds.

Aircraft use DME to determine their distance from a ground transponder (ground station) by sending and receiving pulse pulses of fixed duration and spacing. Ground stations are usually co-located with VORs. The low power DME can also be co-located with the ILS glide slope antenna installation where it provides accurate landing distance. Simultaneous synchronization of two DME ground stations by the aircraft allows us to locate the aircraft in two dimensions: latitude and longitude. With the help of an altimeter, the plane is in 3D space. When co-located with a VOR, it also provides flight direction.

It is important to understand that the DME provides the physical distance from the aircraft to the DME transponder. This distance is often called the tilt range and trigonometrically depends on both the height above the transponder and the distance from the ground to it. In the figure 3.1 we can see comparison of GPS, GLONASS, Galileo and COMPASS orbits with International space station, Hubble Space Telescope and geostationary orbits and the nominal size of the earth.

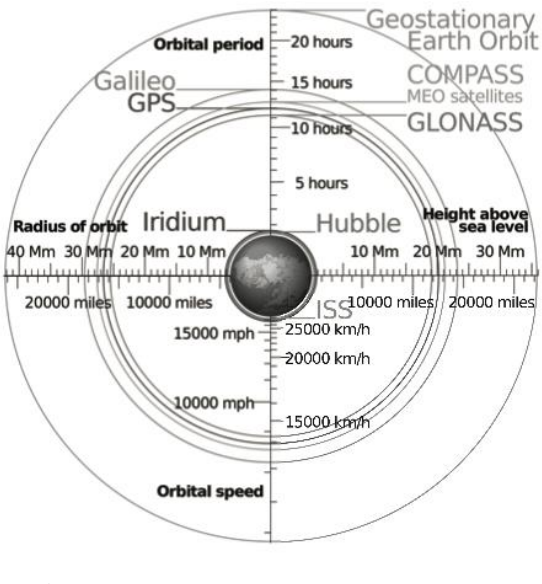


Fig. 3.1 – Comparison of GPS, GLONASS, Galileo and COMPASS orbits

Purpose: DME measures the distance between the aircraft and ground-based DME stations. By using multiple DME stations, an aircraft can triangulate its position.

Example: Collins Aerospace DME-900, which supports precise navigation by providing distance information from multiple ground stations.

- VOR (VHF Omnidirectional Range)

VOR is a system of omnidirectional transmitters of the ultra-short-wave radio range for aircraft navigation. Allows aircraft with the appropriate receiver to determine location and maintain a flight course by receiving radio signals transmitted via a network of ground-based radio beacons.

Fig. 3.2 – Ground station DVOR (Doppler VOR), combined with a DME transmitter

Purpose: VOR provides azimuth information to the aircraft, allowing it to determine its position relative to a VOR station.

Example: BendixKing KX 155A, a widely used VOR receiver in general aviation.

- Automatic Direction Finder (ADF)

An automatic direction finder (ADF) is a marine or aircraft radio-navigation instrument that automatically and continuously displays the relative bearing from the ship or aircraft to a suitable radio station. ADF receivers are normally tuned to aviation or marine NDBs (Non-Directional Beacon) operating in the LW band between 190 – 535 kHz. Like RDF (Radio Direction Finder) units, most ADF receivers can also receive medium wave (AM) broadcast stations, though these are less reliable for navigational purposes.

Purpose: ADF uses low and medium frequency radio signals from non-directional beacons (NDBs) to determine the aircraft's bearing to the station.

Example: BendixKing KR 87, which provides reliable ADF navigation information.

- Satellite-Based Augmentation Systems (SBAS)

SBAS maintain greater signal accuracy through the use of satellite broadcasting of messages. Such systems usually consist of several ground systems, the location coordinates of which are known with high accuracy.

Purpose: SBAS enhances the accuracy and reliability of GPS signals by providing corrections and integrity information.

Example: WAAS (Wide Area Augmentation System) in the United States, which improves GPS accuracy for en-route and precision approaches.

- Radio Magnetic Indicator (RMI)

RMI usually associated with an Automatic Direction Finder (ADF) that provides a bearing for the adjusted NDB. While simple ADF displays may have only one needle, a typical RMI has two connecting two different ADF receivers, allowing the pilot to determine position by intercepting a bearing.

Purpose: RMI integrates information from ADF and VOR systems, displaying the aircraft's bearing to NDBs and VOR stations on a single instrument.

Example: Collins Aerospace RMI-36, which provides combined ADF and VOR information for better situational awareness.

- Ground-Based Augmentation Systems (GBAS)

GBAS is an augmentation system in which the user receives additional information to improve GNSS navigation accuracy from a ground-based transmitter when maneuvering around the airfield, approaching and landing.

Purpose: GBAS enhances GNSS (Global Navigation Satellite System) signals for precision approach and landing, providing corrections and integrity monitoring.

Example: The Honeywell SmartPath GBAS, which supports Category I precision approaches.

- Inertial Reference System (IRS)

IRS refers to a solid-state unit of three Ring Laser Gyros detecting accelerations in 3 dimensions; they may also contain quartz accelerometers. Inertial Reference Unit (IRU) refers to a computer that integrates IRS outputs and provides inertial reference outputs for use by other navigation and flight control systems, including the Flight Management System (FMS)

Purpose: IRS is similar to INS but typically includes additional sensors and systems for more accurate navigation.

Example: Honeywell's IRU (Inertial Reference Unit), part of the Enhanced Ground Proximity Warning System (EGPWS).

3.3 Real-world examples of an integration of the backup navigation system

In medium-range passenger aircraft, such as the Boeing 737 and Airbus A320 families, backup navigation systems are integrated into the avionics suite to provide redundancy and enhance safety. Here’s how these systems are typically integrated:

1. Boeing 737

- Inertial Navigation System (INS)

Integration: The Boeing 737 often uses the Honeywell Laseref IV INS. This system is integrated into the aircraft's Flight Management System (FMS) and provides critical navigation data in the event of GPS signal loss.

Function: The INS continuously updates the aircraft's position, velocity, and attitude, using internal accelerometers and gyroscopes.

- DME

Integration: DME equipment in the 737 works with the aircraft's navigation radios and the FMS. By using multiple DME stations, the FMS can triangulate the aircraft's position.

Function: This system ensures accurate position updates, especially during en-route and approach phases where precision is crucial.

- VOR

Integration: The Boeing 737's VOR receivers are part of its navigation radios. The FMS uses VOR data to calculate the aircraft's position and to navigate along airways defined by VOR radials.

Function: Pilots can tune to VOR frequencies manually or automatically via the FMS for en-route navigation and approaches.

- Automatic Direction Finder (ADF)

Integration: ADF receivers in the 737 are connected to the aircraft's navigation system. The ADF system provides bearing information to NDBs, which is displayed on the navigation display.

Function: ADF is used primarily for non-precision approaches and en-route navigation in areas with NDB coverage.

- Satellite-Based Augmentation Systems (SBAS)

Integration: The Boeing 737 uses SBAS like WAAS (Wide Area Augmentation System) to enhance GPS accuracy. The SBAS corrections are fed into the GPS receivers integrated with the FMS.

Function: This provides more accurate position data, especially useful for precision approaches such as RNAV (GPS) approaches.

- Ground-Based Augmentation Systems (GBAS)

Integration: Some Boeing 737 aircraft are equipped with GBAS receivers, allowing them to use systems like Honeywell SmartPath for precision approaches.

Function: GBAS provides highly accurate and reliable landing guidance, often used for Category I precision approaches.

2. Airbus A320

- Inertial Reference System (IRS)

Integration: The A320 typically uses the Honeywell or Thales IRU (Inertial Reference Unit) as part of its Air Data Inertial Reference System (ADIRS). This is fully integrated into the aircraft's FMS.

Function: The IRS provides critical navigation data, including position, velocity, and attitude, which is used throughout the flight.

- DME

Integration: DME systems in the A320 are connected to the aircraft's Multi-Mode Receiver (MMR). The FMS uses distance data from multiple DME stations to triangulate the aircraft’s position.

Function: This ensures accurate positioning, which is particularly important for area navigation (RNAV) and approach procedures.

- VOR

Integration: VOR receivers in the A320 are part of its navigation suite, and the information is processed by the FMS. Pilots can manually tune VOR frequencies or rely on the FMS for automated tuning.

Function: VOR is used for en-route navigation and approaches, providing azimuth information to the aircraft.

- Automatic Direction Finder (ADF)

Integration: ADF equipment is integrated into the A320’s avionics, providing bearing information to NDBs displayed on the navigation displays.

Function: ADF is used for non-precision approaches and en-route navigation.

- Satellite-Based Augmentation Systems (SBAS)

Integration: The A320 uses SBAS such as EGNOS (European Geostationary Navigation Overlay Service) and WAAS. The corrections are integrated into the FMS for improved GPS accuracy.

Function: Enhanced GPS accuracy supports precision approaches and other critical navigation tasks.

- Ground-Based Augmentation Systems (GBAS)

Integration: The A320 can be equipped with GBAS, such as the Honeywell SmartPath system, allowing it to use enhanced precision approaches.

Function: GBAS provides corrections for GNSS signals, ensuring high accuracy and integrity for landing operations.

In both the Boeing 737 and Airbus A320, these backup navigation systems are seamlessly integrated into the avionics and flight management systems. This integration allows pilots to maintain situational awareness and navigate safely even if primary navigation systems fail, providing multiple layers of redundancy. These systems collectively ensure that the aircraft can safely and accurately navigate from departure to arrival, including precision approaches and landings.

3.4 The critical role of backup navigation systems in ensuring flight safety

Backup navigation systems play an indispensable role in ensuring flight safety by providing alternative sources of navigation data. These systems include Inertial Navigation Systems (INS), Distance Measuring Equipment (DME), VHF Omnidirectional Range (VOR), Automatic Direction Finder (ADF), Functional Augmentation Satellite Systems (SBAS) and Ground Functional Augmentation Systems (GBAS). Each of these systems works on different principles and technologies, which ensures that the failure of one system does not lead to the failure of the aircraft's navigation capabilities.

For example, ANN works independently of external signals, which makes it immune to interference and interference. DME and VOR provide ground navigation data, providing accurate distance and azimuth information. SBAS and GBAS increase the accuracy and reliability of Global Positioning System (GPS) data, providing high-precision navigation and approach capabilities. Integrating these various systems into the aircraft's avionics suite ensures that pilots always have access to reliable navigation data, greatly reducing the risk of navigation errors.

In the course of my research, I found various real-life incidents where backup systems played a crucial role in preventing disasters, in the following paragraphs I will briefly write about these cases:

1. United Airlines flight 232.

One of the most notable cases where backup navigation systems played a critical role in preventing a disaster was United Airlines Flight 232. On July 19, 1989, a McDonnell Douglas DC-10 experienced catastrophic tail engine failure, resulting in a crash. failure of all hydraulic control systems of the aircraft. Despite the loss of normal flight control, the crew managed to maintain some degree of control by using the differential thrust of the other engines.

Although navigation was not the primary concern in this incident, the role of back-up systems, including navigation, was critical in helping the crew understand their position relative to the nearest airport. The crew's ability to use available navigational aids to locate and navigate to Sioux City Airport was instrumental in their successful emergency landing, albeit with significant casualties. This incident highlights the importance of having multiple reliable systems in place to provide critical information in emergency situations.

2. Air Transat flight 236.

Another important case is Air Transat flight 236, which took place on August 24, 2001. This Airbus A330 experienced a total loss of engine power over the Atlantic Ocean due to fuel exhaustion. The aircraft's back-up navigation systems, including INS and GPS, played a critical role in enabling the crew to reach Lajes Air Base in the Azores using the remaining numbering and electronic systems.

Despite the loss of main engine power, backup systems provided the necessary location information, allowing the pilots to safely return the aircraft to the air base where they made an emergency landing. This incident highlights the importance that back-up navigation systems play in ensuring that accurate navigation information is available even in the most difficult circumstances.

3. Flight 006 of Singapore Airlines.

Singapore Airlines Flight 006, which crashed on October 31, 2000 while attempting to take off from Chiang Kai-shek International Airport in Taiwan during a typhoon, demonstrates the potential consequences of navigation errors. Although the crash was primarily due to pilot error in attempting to take off from a closed runway, the investigation emphasized the importance of reliable navigation aids. Having accurate back-up navigation systems could have provided additional situational awareness and potentially prevented the confusion that led to the disaster.

Backup navigation systems are indispensable in modern aviation, providing the necessary redundancy to ensure continuous and accurate navigation. They play a critical role in ensuring flight safety by offering alternative sources of navigation data, thereby reducing the risk of total navigation failure. Real-life incidents such as United Airlines Flight 232, Air Transat Flight 236, and Singapore Airlines Flight 006 illustrate the vital role these systems play in disaster prevention. The integration and reliability of these systems remain a cornerstone of aviation security, underscoring their importance in ongoing efforts to improve the safety and reliability of air travel.

3.5 Development of elements of Automatic Direction Finder

3.5.1 Automatic Direction Finder description and work

The Automatic Direction Finder (ADF) is a digitally tuned, solid-state receiver that provides directional information for stations operating within the 200 KHz to 1799 KHz frequency range. Additionally, it offers audio reception, allowing pilots to identify stations and listen to transcribed weather updates or AM broadcast radio stations. The device features a gas-discharge display that indicates the active ADF frequency in the left window, while the right window can show either the standby frequency, a flight timer, or a programmable elapsed timer. The flight timer logs the total flight duration, and the programmable elapsed timer can be reset to count upwards from zero or preset to count down to zero, which is particularly useful for non-precision timed approaches, fuel management, and dead reckoning navigation.

The ADF includes an automatic dimming circuit that adjusts the display brightness based on ambient light levels. A single-chip microprocessor controls the display, manages the timer functions, tunes the device, and provides timing reference signals. The unit uses a non-volatile electrically alterable memory (EAROM) to retain active and standby frequencies even when powered off. The tuning circuitry features a single reference frequency crystal and a large-scale integrated circuit (LSI). This ADF is exceptionally compact, requiring only 1.3 inches of panel height, and its power consumption is only 12 watts at any input voltage, thereby negating the need for forced air cooling.

Indicator 1 is a single-needle Automatic Direction Finder (ADF) display, which is the standard model used with the ADF system. It is available with either a manually rotatable compass card or a slaved compass card, the latter of which can be connected to the stepper motor output of the KCS 55/55A

Pictorial Navigation System. Indicator 2, a dual-needle ADF display, also offers options for manual or slaved compass cards.

The single needle indicator is one of the measuring instruments that are used in modern industries, for example, engine building and other industries that require high measurement accuracy. The sample is usually used to measure clearances, pitch and straightness of the crankshaft, pullout and other quantities that include the distance between two surfaces or small displacements (oscillation) of components. Most often, an hour-type mikometer is used, which shows values to the nearest 0.01 mm.

A single needle indicator head produces a calibrated rod that transmits a linear pulse to an easy-to-read dial. Most of the dials have graduations with marks of 0.01 m, so that one full turn of the indicator lamp corresponds to one tenth of a millimeter of line. It has marks for every tenth of a mm, so the operator does not need to visually adjust the number of full revolutions if the measurement exceeds the full revolution.

The indicator of the arrow type is firmly mounted on a stable surface: if the installation is not sufficiently stable, the device will collapse, and the result will be inaccurate.

Antenna 1 is a blade-type ADF antenna, whereas Antenna 2 is a low-profile ADF antenna that incorporates both loop and sense antennas. Additionally, it contains preamplifiers and modulators that merge the antenna signals into a single RF signal, which is then transmitted to the ADF via a triaxial cable of various lengths.

The Automatic Direction Finder has two operational modes. In ANT (Antenna) mode (with the ADF button disengaged), the loop antenna is deactivated, allowing the unit to function solely as a receiver. This permits audio reception through the speaker or headphones. The indicator needle remains fixed at the 90° relative position, and the ANT message on the left side of the display is illuminated. This mode, which provides slightly clearer audio reception, is primarily used for station identification. In some regions, certain L/MF stations employ an interrupted carrier for identification purposes. To facilitate the identification of these stations, a Beat Frequency Oscillator (BFO) function is included. Activating the BFO switch produces a 1000 Hz tone whenever a radio carrier signal is present at the selected frequency, and it also illuminates the BFO message in the center of the display.

When the ADF button is depressed, the unit switches to ADF mode, activating the loop antenna. The ADF message on the left side of the display will illuminate, and the indicator needle will point to the relative bearing of the selected station. To determine if the signal strength is adequate for navigation, the pilot can revert the ADF to ANT mode, causing the indicator needle to park at 90°. When switching back to ADF mode, the needle should move smoothly to the station bearing without excessive delay, wavering, or reversals.

The active frequency is shown in the left-hand window. This frequency can be adjusted using the concentric knobs when either timer mode (FLT or ET) is displayed in the right-hand window. An exception occurs when the ET message is flashing. To set the tens digit, push in the small knob and rotate it. Turning it clockwise will increment the digit, which will roll over from 9 to 0 and roll under from 0 to 9 when turned counterclockwise. With the small knob pulled out, the ones digit can be set similarly.

The standby frequency is displayed in the right window when the FRQ message is illuminated. This frequency can be adjusted using the knobs in the same manner as described for the active frequency.

If the standby frequency is not currently displayed, it can be brought up in the window by pressing the FRQ button. Pressing this button when the standby frequency is already displayed will cause the current standby and active frequencies to be swapped.

When elapsed time (ET) is displayed, pressing the FLT/ET button will switch the display to show the flight timer. Pressing this button again will toggle between the two timers in the display. If the standby frequency is being shown, pressing the FLT/ET button will bring back the most recently displayed timer.

The flight timer is shown in the right-hand window when the FLT message is illuminated. This timer counts up to 59 hours, 59 minutes, and 59 seconds. Upon powering on, this timer starts at 0. It displays minutes and seconds until reaching 59 minutes and 59 seconds, at which point it shifts to displaying hours and minutes.

The elapsed timer has two modes: Count Up and Count Down. When power is applied, it starts in Count Up mode at 0. Like the flight timer, it counts up to 59 hours, 59 minutes, and 59 seconds, showing minutes and seconds until one hour has elapsed, then switching to hours and minutes. In Count Up mode, the timer can be reset to 0 by pressing the reset button.

3.5.2 Calculation of the loads on the antenna 1

Choose the material for the Antenna 1:

It was chosen glass-reinforced thermoplastic for the antenna. High-strength fiberglass is characterized by high strength and high modulus. Its single fiber tensile strength is 2800 MPa, which is about 25% higher than that of non-alkali glass fiber. The modulus of elasticity is 8600 MPa, which is higher than that of E-glass fiber.

The basic idea of using glass-reinforced thermoplastic is to reduce the thickness of the used material and save the weight of end assemblies and products and to produce antenna easily in different shapes.

Yield strength: σy= 2227 kg/cm2

Tensile strength: σb =9000 kg/cm2

Elongation at break: $\delta 5$ = 50 %

Choose the material for bolts:

It was chosen steel A4 (AISI 316 = 1.4401 = 10X17H13M2), which differs from steel A2 by adding 2-3% molybdenum. This significantly increases its ability to resist corrosion and acids. A4-80 steel has higher antimagnetic characteristics and is absolutely non-magnetic.

Bolt diameter is 10 mm. Length is equal 32 mm.

Tensile strength: σ_t =7848 kg/cm2 = 800 MPa

Yield strength: σ_y= 4414,5 kg/cm2 = 400MPa

Tensile stress area A_t=58 mm^2

The loads on the antenna according to the manual calculation are presented in the table 3.1.

Calculated case			P_x^P, kg	P_y^P, kg	P_z^P, kg
E	$n_y^P = 3.205$	front	-2700	1370	280
	$n_x^P = 1.2$	aft	-2700	1370	-280
A`	$n_y^P = 3.75$	front	-2050	1600	-350
		aft	-2050	1600	120

Where:

E – loads during landing

A` - loads during curvilinear flight with small positive angle of attack α=4-6 degrees.

The loads on the antenna according to the calculation obtained on a computer are presented in the table 3.2.

Calculated case		P_x^P, kg	P_y^P, kg	P_z^P, kg
E	front	-2920	2640	156
	aft	-2280	1020	-138
A` excluding aerodynamics			1670	

Antenna bolts calculation with symmetrical loading.

Shear force is calculated according to the following formula:

$$\tau = \frac{F}{\frac{\pi * d^2}{4} * i} \leq [\tau]_{sh}$$

where

F – transverse force, H;

d – diameter of the rod in the dangerous section, mm;

i – the number of cutting planes;

$[\tau]_{sh}$ - permissible shear stress for bolt material, MPa.

$$\tau = \frac{2640 * 9.8}{\frac{\pi * 10^2}{4} * 2} = 164{,}7\, MPa$$

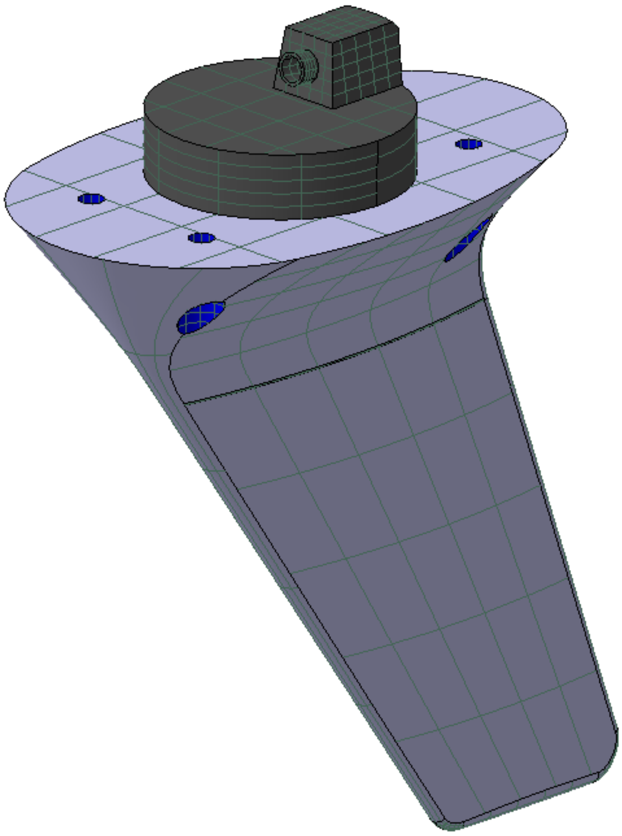
Permissible shear stress for bolt is calculated according to the following formula:

$$[\tau]_{sh} = (0.2 \ldots 0.3)\sigma_t$$

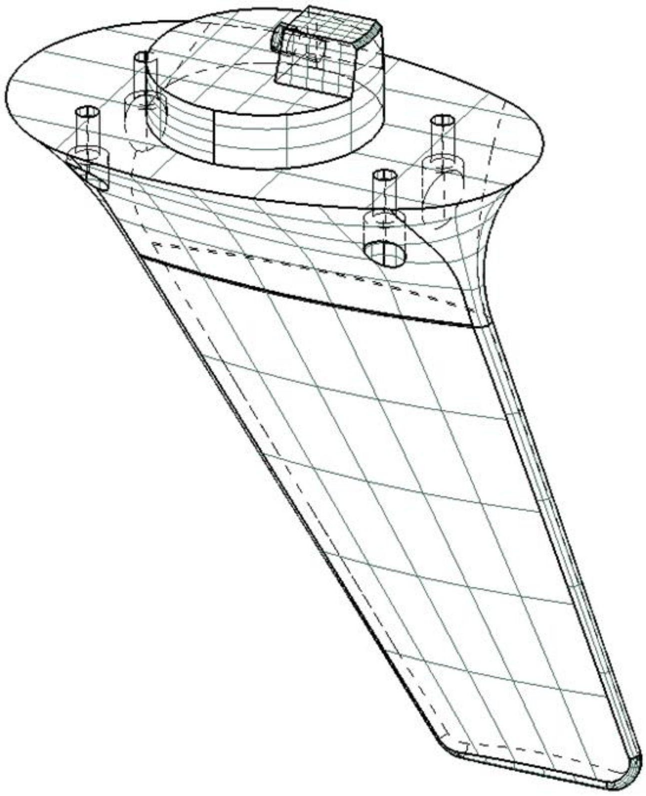
$$[\tau]_{sh} = 0.3 * 800 = 240\, MPa > 164{,}7\, MPa$$

3.6 Calculation of the stress-strain state of nodes Automatic direction finder

Consider the place of attachment of the antenna 1 to the aircraft skin (Fig.3.3)



a)



b)

Fig. 3.3- General view of antenna 1 construction. a) Solid Model Representation; b) Wireframe Representation;

The calculation of the stress-strain state is performed by using the module "Catia V5 Stress Analysis".

Fixing the model in space. The basis antenna is fixed rigidly on the ends of four openings, in places of its fastening to the skin.

When creating a finite element model, the properties of materials are set. The smaller the size of the finite elements, the more accurate the results of the calculation.

The load is applied to the front surface of the antenna 1 (Fig. 3.4). The load acts in the direction of flight of the aircraft.

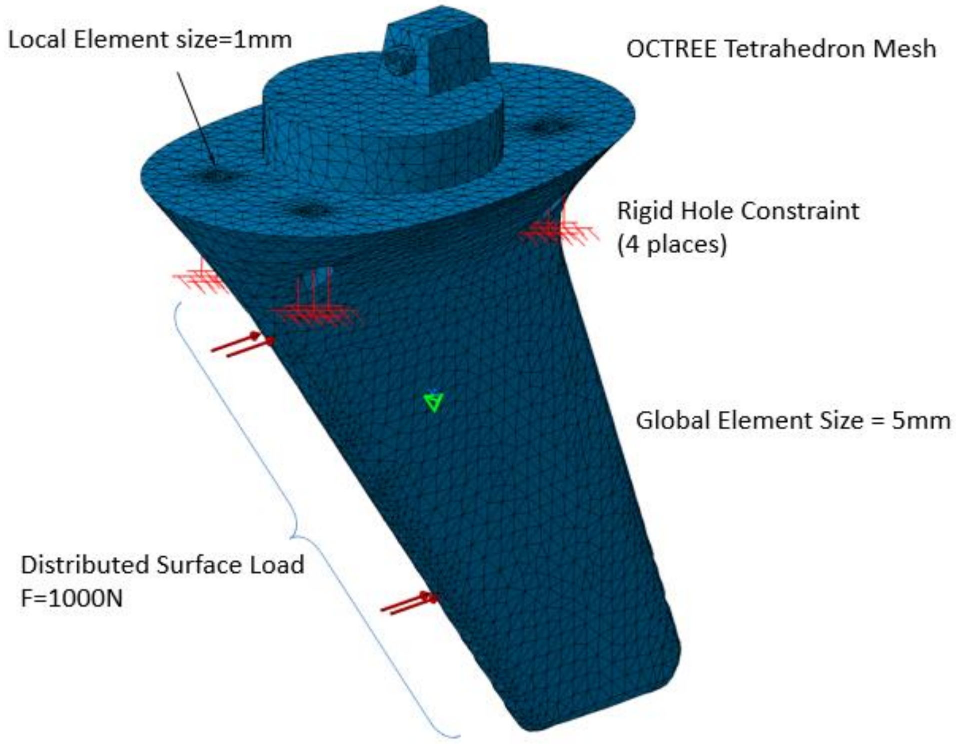


Fig. 3.4 Finite element model and loading of the antenna 1

According to the calculation, the following data were obtained. Von Mises stress Distribution of the model is represented on figure 3.5.

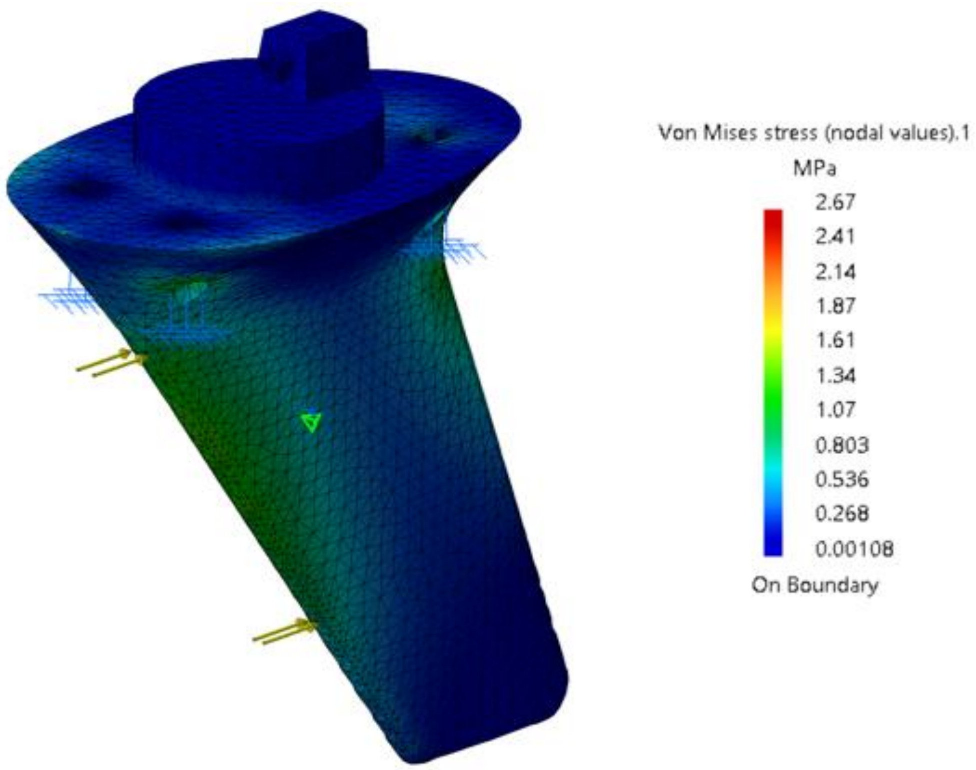


Fig. 3.5 Von Mises stress Distribution

Displacement distribution of the model is represented on figure 3.6. It is obvious that bottom part of antenna is the weakest part of it, but we can see that strength condition of the whole antenna satisfies safety demands.

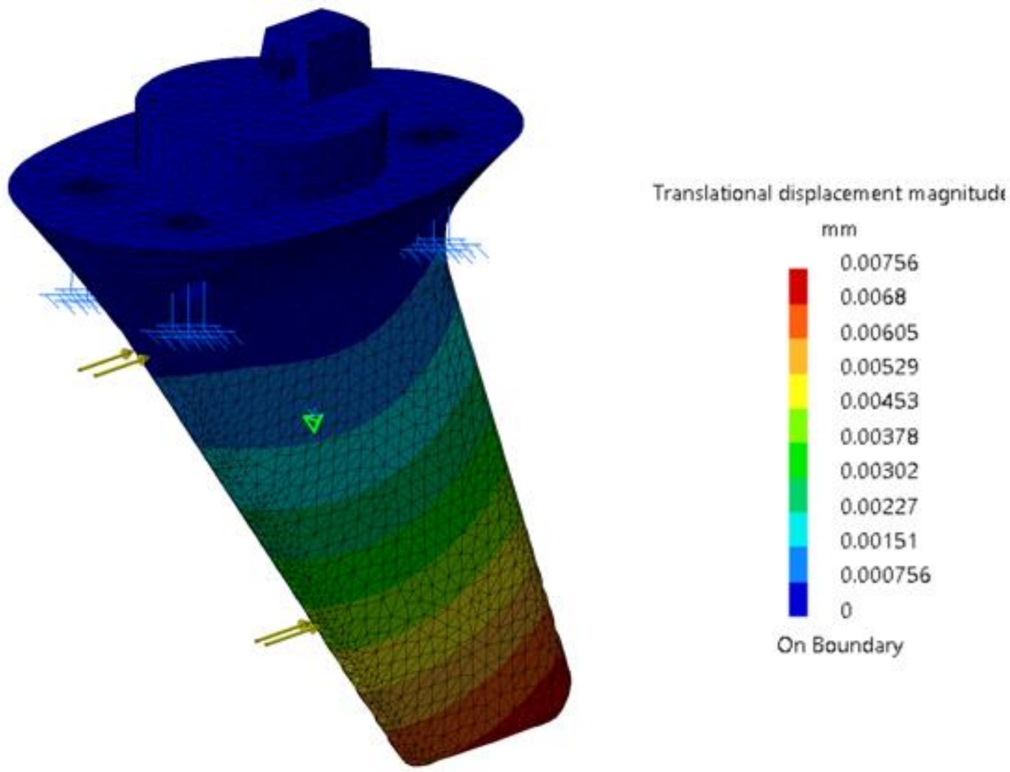


Fig. 3.6 Displacement Distribution

Taking into account all the above data, we conclude that the static strength of the designed structural elements is sufficient.

Conclusions to the special part

It was carried out analysis of the backup navigation system types, their functions and valuated an importance of their usage on the medium-range cargo aircraft. It was investigated various accidents that happened with medium-range aircrafts to prove the critical role of backup navigation systems in ensuring flight safety.

What is more, it was elaborated design of the Automatic Direction Finder (ADF), determined main components of the ADF and calculated strength characteristics of the joining components.

In addition, it was performed calculation of the stress-strain state of the antenna 1 by using the module Catia V5 Stress Analysis.

GENERAL CONCLUSIONS

In this diploma work I've received following results:

- preliminary design of the medium-range cargo aircraft;
- the schematic design of the layout of a medium-range cargo aircraft with a flight range of 1385 km;
- the center of gravity of the airplane calculations;
- the calculation of the main geometrical parameters of the landing gear;
- the chose of the wheels, which satisfy the requirements;
- the joining components strength calculation.

The chosen design of high-wing aircraft with two engines, which are located in the wing is optimal configuration for this type of aircraft, because this provide easier loading and unloading into and outer of cargo airplane, provide sufficient clearance between engine and ground.

The developed aircraft combines sufficient payload with excellent ground maneuverability. The powerful engines gave him the energy to fly in a continuous vortex of updrafts and downdrafts with a continuous alternation of hot and cold air masses. It was carried out calculations of the main parts of an aircraft, such as span of the wing – 30,32 m, area of the wing – 98,58 m, length of the fuselage is 29,95 m. We have also checked the mass position of the main parts of the aircraft and main equipment and furnishing by its distance from the main aerodynamic chord. The wing MAC leading edge position relative to fuselage is equal to 12,061 m, which corresponds to desired values of the designing aircraft. Also in this part it was carried out determination of the center mass position characteristics. Airplane center of gravity position variants are equal from 12,61 m to 12,80 m these values correspond to desire for that type of aircraft.

It was studied various types of the backup navigation systems, their purpose and construction and problems. It was chosen A4-80 steel for bolts that are used for the installation of two antennas, that are components of Automatic Distance Finder. Also, it was calculated share force and it can be concluded that the static strength of the designed structural elements is sufficient.

In addition, it was performed calculation of the stress-strain state of the antenna 1 by using the module Catia V5 Stress Analysis.

REFERENCES

1. O.V. Popov, T. P. Maslak, G.A. Volosovych, M.I. Shpakovych. Methodical recommendation for executing of bachalors diploma work. Ukraine: NAU, 2002 y.
2. M.V. Karuskevich, T.P. Maslak. Aircraft. Design: Lecture course. Ukraine:NAU, 2013 y. - 176p.
3. Bendix/King. Electronic and avionics systems maintenance manual. USA, 1998 y. - 333 p.
4. Global navigation systems - role in modern military conflicts: website. URL: https://defence-ua.com/army_and_war/globalni_navigatsijni_sistemi_rol_v_suchasnih_vijskovih_konfliktah-2538.html (date of the application: 15.05.2024)
5. Crash of Singapore Airlines Flight SQ006: website. URL: https://www.nlb.gov.sg/main/article-detail?cmsuuid=97f13294-0abc-432d-9451-8ad7c6a9b9bd (date of the application: 16.05.2024)
6. The direction finding of radio signals: website. URL: https://habr.com/ua/articles/397175/ (date of the application: 16.05.2024)
7. EASA partners with IATA to counter aviation safety threat from GNSS spoofing and jamming: website. URL: https://www.easa.europa.eu/en/newsroom-and-events/press-releases/easa-partners-iata-counter-aviation-safety-threat-gnss-spoofing (date of the application: 17.05.2024)
8. A.D. King. Inertial Navigation – Forty Years of Evolution. USA, 1998 – 10 p.
9. Micro Inertial Reference System IRS: Product Description: website. URL: https://ru.scribd.com/document/651579494/8225254 (date of the application: 17.05.2024)
10. Flight control systems: website. URL: https://www.flightschoolusa.com /uk (date of the application: 17.05.2024)

Appendix

Appendix A

Performed by: Mykhailenko Illia
Supervisor: Vlasenko Yuriy

INITIAL DATA AND SELECTED PARAMETERS

Passenger Number	0	
Flight Crew Number	2	
Flight Attendant or Load Master Number	2	
Mass of Operational Items	766.94 kg	
Payload Mass		9200 kg
Cruising Speed	500 km/h	
Cruising Mach Number		0.4499
Design Altitude		8 km
Flight Range with Maximum Payload	1270 km	
Runway Length for the Base Aerodrome	1.68 km	
Engine Number		2
Thrust-to-weight Ratio in kWt/kg	0.252	
Pressure Ratio	30	
Assumed Bypass Ratio		
Optimal Bypass Ratio		
Fuel-to-weight Ratio	0.2	
Aspect Ratio		11.37
Taper Ratio		2.62
Mean Thickness Ratio		0.118
Wing Sweepback at Quarter Chord		9 degrees
High-lift Device Coefficient		0.93
Relative Area of Wing Extensions		0
Wing Airfoil Type		laminated type NASA
Winglets		do not apply
Spoilers		established
Fuselage Diameter		2.64 m
Finess Ratio		9.3
Horizontal Tail Sweep Angle		16 degrees
Vertical Tail Sweep Angle		20 degrees

CALCULATION RESULTS

Optimal Lift Coefficient in the Design Cruising Flight Point	0.46937
Induce Drag Coefficient	0.00959

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

Cruising Mach Number	0.44986
Wave Drag Mach Number	0.69433
Calculated Parameter D_m	0.24447
Wing Loading in kPa (for Gross Wing Area):	
At Takeoff	2.487
At Middle of Cruising Flight	2.378
At the Beginning of Cruising Flight	2.425
Drag Coefficient of the Fuselage and Nacelles	0.00526
Drag Coefficient of the Wing and Tail Unit	
Drag Coefficient of the Airplane:	
At the Beginning of Cruising Flight	0.02719

At Middle of Cruising Flight	0.02701
Mean Lift Coefficient for the Ceiling Flight	0.46937
Mean Lift-to-drag Ratio	17.37948
Landing Lift Coefficient	1.859
Landing Lift Coefficient (at Stall Speed)	2.789
Takeoff Lift Coefficient (at Stall Speed)	2.336
Lift-off Lift Coefficient	1.682
Thrust-to-weight Ratio at the Beginning of Cruising Flight	0.095
Start Thrust-to-weight Ratio for Cruising Flight	0.152
Start Thrust-to-weight Ratio for Safe Takeoff	0.124
Design Thrust-to-weight Ratio	0.156
Ratio $D_r = R_{cruise} / R_{takeoff}$	1.219

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

Takeoff	0.2632
Cruising Flight	0.2194
Mean cruising for Given Range	0.2203

FUEL WEIGHT FRACTIONS:

Fuel Reserve	0.02185
Block Fuel	0.08565

WEIGHT FRACTIONS FOR PRINCIPAL ITEMS:

Wing	0.16555
Horizontal Tail	0.01990
Vertical Tail	0.01960
Landing Gear	0.04944
Power Plant	0.11144
Fuselage	0.10273
Equipment and Flight Control	0.12836
Additional Equipment	0.00235
Operational Items	0.02256
Fuel	0.10751
Payload	0.27063

Airplane Takeoff Weight	33994 kg
Takeoff Thrust Required of the Engine	2652.4 kWt

Air Conditioning and Anti-icing Equipment Weight Fraction	0.0186
Passenger Equipment Weight Fraction (or Cargo Cabin Equipment)	0.0009
Interior Panels and Thermal/Acoustic Blanketing Weight Fraction	0.0069
Furnishing Equipment Weight Fraction	0.0166
Flight Control Weight Fraction	0.0092
Hydraulic System Weight Fraction	0.0233
Electrical Equipment Weight Fraction	0.0299
Radar Weight Fraction	0.0044
Navigation Equipment Weight Fraction	0.0066
Radio Communication Equipment Weight Fraction	0.0033
Instrument Equipment Weight Fraction	0.0077
Fuel System Weight Fraction	0.0031

Additional Equipment:

Equipment for Container Loading	0
No typical Equipment Weight Fraction (Build-in Test Equipment for Fault Diagnosis, Additional Equipment of Passenger Cabin)	0.0024

TAKEOFF DISTANCE PARAMETERS

Airplane Lift-off Speed	173.82 km/h
Acceleration during Takeoff Run	1.76 m/s*s
Airplane Takeoff Run Distance	660 m
Airborne Takeoff Distance	578 m
Takeoff Distance	1238 m

CONTINUED TAKEOFF DISTANCE PARAMETERS

Decision Speed	165.13 km/h
Mean Acceleration for Continued Takeoff on Wet Runway	0.13 m/s*s
Takeoff Run Distance for Continued Takeoff on Wet Runway	
Continued Takeoff Distance	1465.29 m
Runway Length Required for Rejected Takeoff	2073.98 m

LANDING DISTANCE PARAMETERS

Airplane Maximum Landing Weight	32715 kg
Time for Descent from Flight Level till Aerodrome Traffic Circuit Flight	15 min
Descent Distance	20.83 km
Approach Speed	175.61 km/h
Mean Vertical Speed	1.53 m/s
Airborne Landing Distance	486 m
Landing Speed	160.31 km/h
Landing run distance	377 m
Landing Distance	864 m
Runway Length Required for Regular Aerodrome	1442 m
Runway Length Required for Alternate Aerodrome	1226 m

ECONOMICAL EFFICIENCY

THESE PARAMETERS ARE NOT USED IN THE PROJECT