МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Кафедра конструкції літальних апаратів

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
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_____________ С. Р. Ігнатович
«_____» ___________ 2020 р.

ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)
ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ

"БАКАЛАВР"

Тема: «Аванпроект ближньомагістрального літака вантажопійомністю до 6000 кг»

Виконав: ___________ **В.В. Чернов**

Керівник: к.т.н., доцент ___________ **С.С. Юцкевич**

Нормоконтролер: к.т.н., доцент ___________ **С.В. Хижняк**

Київ 2020

MINISRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

Department of Aircraft Design

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

DIPLOMA WORK

(EXPLANATORY NOTE)

OF EDUCATIONAL DEGREE

«BACHELOR»

Theme: «Preliminary design of short range cargo aircraft with payload 6000 kg»

Performed by: __________ **V.V. Chernov**

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

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

Kyiv 2020

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty

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Academic degree «Bachelor»

Speciality: 134 "Aviation and Rocket-Space Engineering"

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Head of Department
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«___» _______ 2020

TASK

for bachelor diploma work

CHERNOV VLADYSLAV

1. Theme: «Preliminary design of short range cargo aircraft with payload 6000 kg»

Confirmed by Rector's order from 05.06.2020 year № 801/ст.

2. Period of work execution: from 25.05.2020 year to 21.06.2020 year.

3. Work initial data: cruise speed V_{cr}= 470 km/h, flight range L = 1750 km, operating altitude H_{op} = 7,2 km.

4. Explanation note argument (list of topics to be developed): introduction; the project part: choice and substantiations of the airplane scheme, choice of initial data; the calculative part: main parts geometry and aerodynamic calculation, engine selection, aircraft layout, center of gravity position, special part: description and installation of the cargo equipment.

5. List of the graphical materials: general view of the airplane (A1×1); layout of the airplane (A1×1); cargo equipment (A1×1).

6. Calendar Plan

Task	Execution period	Signature
Task receiving, processing of statistical data.	25.05.2020 – 28.05.2020	
Aircraft take-off mass determination.	29.05.2020 – 30.05.2020	
Aircraft centering determination.	29.05.2020 – 31.05.2020	
Graphical design of the aircraft and its layout.	31.05.2020 – 04.06.2020	
Procedure for cargo equipment installation and checking.	02.06.2020 – 10.06.2020	
Completion of the explanation note.	10.06.2020 – 15.06.2020	
Preliminary defence	10.06.2020	

7. Task issuance date: 25.05.2020

Supervisor of diploma work ____________ S.S. Yutskevych

Task for execution is given for ____________ V.V. Chernov

ABSTRACT

Explanatory note to the diploma work «Preliminary design of short range cargo aircraft with payload 6000 kg» contains:

56 sheets, 17 figures, 12 tables, 17 references and 3 drawings

Object of the design is development of the short-range aircraft with commercial cargo payload capacity up to 6000 kg.

Aim of the diploma work is the development of the aircraft preliminary design and characteristic estimation.

The method of design is analysis of the prototypes and selections of the most advanced technical decisions.

The diploma work contains drawings of design of the short-range aircraft with commercial cargo payload capacity up to 6000 kg, calculations and drawings of the aircraft layout, the cargo compartment and equipment.

CARGO AIRCRAFT, PRELIMININARY DESIGN, CABIN LAYOUT, CENTER OF GRAVITY DETERMINATION, CARGO COMPARTMENT, UNIT LOAD DEVICE, BALL MAT, TIE-DOWN BELT.

Format	№	Designation	Name	Quantity	Notes
			General documents		
A4	1	NAU 20 14Ch TT	Task of work	1	
	2		Short-range passenger aircraft	2	
A1		NAU 20 14Ch 00 00 00 62 GV	General view		
A1		NAU 20 10Ch 00 00 00 62 AL	Fuselage layout		
A4	3	NAU 20 14Ch 00 00 00 62 EN	Short-range cargo aircraft	56	
			Explanatory note		
A1	4	NAU 20 14Ch 25 50 00 62 AD	Documentation for assembly units	1	
			Cargo equipment		

Ch.	Sheet	Doc.№	Sign.	Date	NAU 20 14Ch 00 00 00 62 EN		
Performed by	Chernov V.V.				List of diploma work	List	Sheet	Sheets
Supervisor	Yutskevych S.S.							
Adviser						AF 402 134		
Stand. contr.	Khyzhnyak S.							
Head. of dep.	Ignatovych S.							

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Abreviation list

AC – aircraft;

AIL – aileron;

AL – area load;

APU - auxiliary power unit;

CFR - cost and freight;

CG – center of gravity;

CLS – cargo loading system;

CS – Certification Specification;

FEF – fully equipted fuselage;

IATA – International Air Transport Association;

LG – landing gear;

MAC - mean aerodynamic chord;

PDU – power drive unit;

RL – running load;

ULD – unit load device;

VTU – vertical tail unit;

Introduction

During the last decade was significantly observed the growth of the consumerism age and consequently demand of goods and products variety. Obviously, it is necessary to improve the methods of their delivery and notably at the local airlines, which dramatically increased the need for cargo traffic. In this regard there was a need for planes to transport for short distances, which at low load factor allow to avoid financial losses. To ensure profitable operation of aviation technology with high reliability and regularity of flights in the highly competitive global market need for a new aircraft in civil aviation that meet the requirements [1] of the international organization of air transport, and in particular:

- Flight safety;
- Reliability and ease of operation;
- Reducing emissions of harmful gases.

The projected aircraft must also satisfy the following requirements:

- The layout shall meet, as far as possible, the technical and operational requirements;
- To perform takeoff and landing on unequipped unpaved runways;
- Quick cargo loading in limited time periods;
- Operation in a wide overload range;

The purpose of this diploma project is to create an aircraft intended for the carriage of 6000kg payload on short distance routes.

1. PROJECT PART

1.1. Analysis of prototypes and short description of designing aircraft

Choosing the best design parameters for an airplane is a multifaceted optimization task aimed at shaping the "appearance" of an aeroplane. In addition to its configuration, there is also a whole set of flight-technical, weight, geometric, aerodynamic and economic characteristics. In the formation of "plane appearance" in the first stage, widely used statistics, methods of translation, approximate aerodynamic and statistical dependencies. In the second stage, the algorithms of the complete aerodynamic calculation of the aircraft was used, the formulas of aggregate weight calculations, experimental data was specified.

1.1.1. Choise of the projected data

Prototypes of the airplane, taking for the designing aeroplane were in class 5000-7000kg of cargo. Such aircraft like AN 140-100, ATR 42 and IL 114 will compete with projected plane in this market segment. Statistic data of prototypes are presented in table 1.

Table 1 – Operational-technical data of prototypes [2 - 4];

PARAMETER	PLANES		
1	2	3	4
	AN-140	ATR 42	IL 114
The purpose of airplane	Passenger	Passenger	Passenger

End of table 1

1	2	3	4
Crew/flight attend. persons	2/2	2/2	2/2
Maximum take-off weight, m_{tow}, kg	21500	18600	23500
Most pay-load, $m_{к.max}$, kg	6000	5450	6500
Passenger's seat	52	50	64
The height of the flight $V_{w.\ ек.}$, m	7600	5485	7600
Range $m_{к.max}$, km	2320/1300	1555	2000
Take off distance $L_{зл.д.}$, m	880	730	1025
Number and type of engines	ТВ3.117ВМА-СБМ1	PW127E	ТВ7-117С
The form of the fuselage cross-section	circular	circular	circular

Relative position of the airplane units, their numbers and shape determine the scheme. Aircraft layout and aerodynamic scheme of the airpane affect on aerodynamic and operational characteristics. Fortunately chosen scheme allows to increase the safety and regularity of flights, and economical efficiency of the aeroplane.

1.1.2. Brief description of the main parts of the aircraft

The airplane is a cantilever monoplane with a high-wing of big straight elongation of a trapezoidal shape, single-tail empennage with a fixed stabilizer set on the fuselage. The power plant includes two turboprop engines located in the engine nacelles under the wing with pulling, six-bladed, vane reversing propeller.

Auxiliary power unit is a gas turbine engine located in a special compartment of the rear fuselage. The landing gear is tricycle, retractable, with a front support.

1.1.3. Fuselage

The fuselage of the aeroplane is made in a semi-monocoque design and consists of a working skin, reinforced by a lateral and longitudinal power set. The skin is a continuous support for this power set, provides not only the creation of a streamlined aerodynamic shape, but also perceives all types of loads that act on the fuselage. The lateral force set consists formers, frames (reinforced formers) and bulkhead. Formers provide the formation of cross-sectional shapes of the fuselage and are a support for the longitudinal power set and skin. Frames provide the transfer of concentrated forces (from the attachment points of the wing, plumage, etc.) to the working skin in the form of distributed forces. Bulkheads also surround the cutouts in the trim panels under the doors and hatches. Longitudinal power set - stringers and beams (reinforced stringers).

In the fuselage of the aircraft are the crew cabin, cargo compartment, auxiliary power unit compartment (APU). Under the fuselage floor there are technical compartment and compartments of the front and nose landing gear struts. There is also a place for a flight cargo crew member. On the left and right sides of the compartments are windows, there is an emergency exit on the left side and cargo door on the right.

In the cockpit there are seats for the first and second pilots. The first pilot is on the left on the flight, the second pilot on the right. In front of the pilots, instrument panels are installed, and between them an average pilot console. Over the windglass of the cockpit there is an electric switchboard.

Ahead of the first and second pilot's seats there are steering wheels for driving the elevator and ailerons and pedals for steering the rudder. On the dashboard mounted flight-navigational instruments for monitoring the operation of the power plant and other instruments, and signaling devices. Each pilot has its own side console on a port side of the fuselage.

1.1.4. Wing

The wing of the airplane is a highly located, free-carrying. The outer wing contours in sections are formed by a set of aerodynamic profiles of various thicknesses. The dehidral angle is straight, i.e. the ends of the wing are raised upward, equal to + 1 °. Straight dehidral increases the lateral stability of the aeroplane.

The wing is set on the fuselage according to the upper plan and, with the help of four nodes, is mounted to the frames of the fuselage. Two turboprop engines are installed on the wing. The wing has mechanization: flaps, ailerons, spoilers.

The curvature of the wing profile increases and, consequently, the lift also increases when flaps are released. Aircraft is able to fly without stalling at a lower speed at increased lift. Thus, takeoff and landing distances, takeoff and landing velocities are reduced. The flap release leads to an increase in the aerodynamic drag of the wing, which contributes to the effective braking of the aeroplane during the run, when the plane lands. Roll of the aircraft, while the ailerons deviate differentially, that is, in opposite directions is provided by ailerons [5].

The trim and servo tabs located on the aileron are used to regulate the forces on the airplane controls coming from the control surface. Interceptors - surfaces on the upper part of the wing, deflected automatically upwards when the engine fails.

The wingspan is divided into a center section and two detachable parts

Structurally, the wing consists of parts:

- nose;
- torsion box;
- tail.

The caisson part is the power part of the wing and consists of longitudinal and transverse power sets. The longitudinal power set consists of front and rear spars; top and bottom panels. Lateral force set consists of a set of ribs.

1.1.5. Tail unit

The empennage of the aeroplane is free-bearing, i.e. not having external power elements (struts, racks, stretch marks) that attach it to the fuselage. It consists of a horizontal tail mounted on the fuselage, and a vertical tail located in the plane of symmetry of the aircraft.

The horizontal empennage consists of fixed surfaces: two stabilizer arms, - and elevators pivotally suspended from them. The horizontal tail is designed to ensure stability, controllability and balance of the airplane in a vertical plane (pitch).

Vertical empennage includes fixed surfaces: forkil, keel and rudder articulated to it. The vertical tail is designed to provide directional stability, controllability and balancing of the aeroplane in the horizontal plane (at the heading).

Trim and servo tabs are installed on the elevators and rudder, which designed to regulate the loads and effors on the aircraft controls coming from the control surface. Forkil is an auxiliary aerodynamic surface constructed to increase the directional (lateral) static stability of an airplane. In order to counter the moment from the rotation of the propellers, the rudder is turned to the right by 1.5 ° relative to the longitudinal axis of the aeroplane.

1.1.6. Crew cabin

Configuration of workplaces of pilots provides to any of them safety control of the plane. Characteristics of stability and controllability of the plane, the structure, characteristics and automatization of flight navigation equipment and onboard systems, structure and configuration of equipment of display provide performance by pilots of their functional duties without excess of the existing norms of loading.

Application of conic windshields of a radome of a crew cabin provides o good overview for pilots and satisfy the requirements of flight operation in the expected conditions. There is a possibility of manual and automatic control from any place of pilots.

Placement of devices and light signaling devices on a control panel of pilots is executed according to requirements of standards of the flight airworthiness. On a peak of a control panel in a zone of the best reach and the review quickly used control panels of command radio stations and systems of automatic control are placed.

On the top control panel of onboard systems are placed start of engines and APU, fire extinguishing switches, fuel, hydraulic, power supply, anti-icing, air conditionings, and a board of the warning alarm system.

On the central pilot panel not only traditionally established control levers engines are placed, but also there are panels of the navigation and landing equipment.

1.1.7. Control system

The aircraft control system is a set of devices providing the necessary trajectory of its movement in air and on the ground. The airpane control system is divided into: primary and secondary. The main control system includes elevator, rudder and ailerons control systems. Auxiliary control is a control of spoilers, rudder trimmers, wing mechanization means, landing gear, brakes, etc.

Ailerons and elevators are controlled manually by the commander or co-pilot (without boosters, that is, without the use of hydraulic or other amplifiers) from the control columns or according to the commands of the automatic flight control system. Rudder is controlled by pedals.

Flaps are controlled by pilots from the flaps control handle. Control of spoilers is automatic, release of the spoiler is provided by a signal about engine failure with flaps released and rejected engine control handles.

1.1.8. Landing gear

The landing gear is designed to provide aeroplane parking on the ground, movement during take-off, landing and taxiing, as well as to absorb kinetic energy during landing and braking.

The aircraft is equipped with a tricycle landing gear retractable in flight, which consists of: a one-pillar front support with steered wheels; two single-column main bearings with brake wheels; mechanisms for controlling the shutters of the compartments of the main and front supports. The struts of the front and main supports are two-wheeled.

The main landing gear is located beyond the center of gravity of the airplane so that the parking load of the nose strut is near 10% of the weight of the aeroplane, and the rest is perceived as the main supports.

With a relatively large wheel base, the load on the front support and its weight are reduced. The risk of the aircraft tipping over around the axis connecting the front and the main supports is reduced, and the plane swinging in the vertical plane during taxiing, especially when braking the wheels and changing the engine thrust, is also reduced. At the same time, with an excessive increasing of the wheel base and a decrease in the load on the front support, the controllability of the aeroplane during taxiing, during take-off and landing deteriorates.

The wheel track of the landing gear affects the lateral and directional stability and directional controllability of the aircraft when moving along the airfield. Relatively narrow wheel track improves directional stability.

The tricycle landing gear scheme with front support:

- provides good stability of the airplane during take-off and run, as well as steering during taxiing;

- allows efficient use of wheel brakes without fear of nosing;

- provides a good view from the cockpit and comfort for passengers on the ground.

1.2. Geometry calculations for the main parts of the aeroplane

Composing the relative disposition of aircraft parts and constructions, and different types of the compartments (passengers, luggage, cargo, fuel, and so on) creates the concept of airplane layout.

Choosing the scheme of the composition and plane parameters is determined by the best conformity to the operational requirements.

1.2.1. Wing geometry calculation

Main geometrical parameters of the wing are defined from the takeoff weight m_0 and specific wing load P_0.

Full area with extensions is taken from prototype (because of the big difference with formula's result): $S_w=51m^2$

Wing span is:

$$l_w= sqrt(S_w \cdot \lambda_w)= 24.74m^2;$$

Root chord is:

$$b_0=(2S_w \cdot \eta)/((1+ \eta)l_w)= 2.945m;$$

Tip chord is:

$$b_t= b_0/\eta= 1.178m.$$

At a choice of power scheme were defined the number of spars, its position, and the places of wing mounting.

The geometrical method for mean aerodynamic chord determination was used. (fig. 1). Mean aerodynamic chord is equal: b_{MAC}=2.178m.

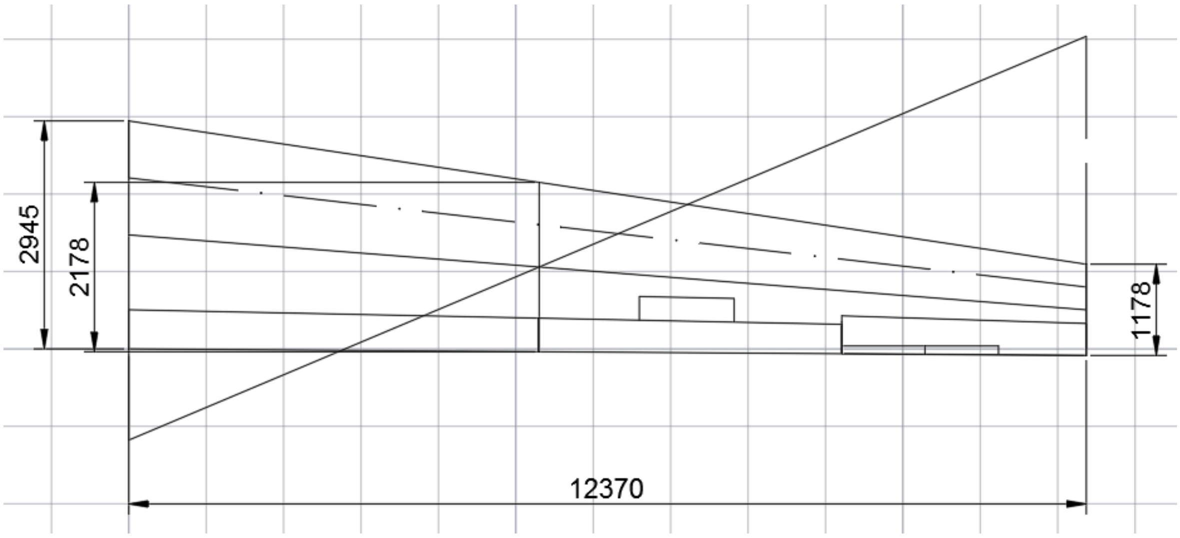


Figure 1 – Determination of mean aerodynamic chord

After determination of the geometrical characteristics of the wing there comes the estimation of the ailerons geometry and high-lift devices.

Ailerons geometrical parameters are determined in next consequence:

Ailerons span is taken from prototype (because of the big difference with formula's result): l_{ail} =3.16m

Aileron area is taken from prototype (because of the big difference with formula's result): S_{ail} =1.55m^2

Increasing of l_{ail} (3.16m) and b_{ail} (0.49m) more than recommended values is not convenient. With the increase of l_{ail} more than given value the increase of the ailerons coefficient falls, and the devices span decreases. With b_{ail} increase, the width of the spar decreases.

Airplanes of the last generation have a tendency to decrease relative wing span and ailerons area. In this case for the transversal control of the aeroplane ailerons are used, which deviate differentially. Due to this the span and the area of devices may be increased, which improves take off and landing characteristics of the aircraft.

Aerodynamic compensation of the aileron:

Hinge balance:

$$S_{hinge} \leq 0.25 \cdot S_{ail} = 0.39 m^2;$$

Area of ailerons trim tab:

For double-engine airplane:

$$S_{trimtab} = 0.05 \cdot S_{ail} = 0.0775 m^2;$$

Range of aileron deflection:

Upward $\delta'_{ail} \geq 20^\circ$;

Downward $\delta''_{ail} \geq 10^\circ$.

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

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

Where C_{ymaxl} is necessary coefficient of the lift force in the landing procedure of the wing by the landing insuring (it is determined during the choice is the air-plane parameters).

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

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

$$b_{2slotted} = 0.3 \cdot b_i = 0.46 m;$$

Effectiveness of high-lift devices (C_{ymaxl}) rises proportionally to the wing span increase, serviced by high-lift devices, so its necessary 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 need to come from the statistics and experience of domestic and foreign aeroplane construction. It is necessary to mention that in the majority of existing constructions elements of high-lift devices are done by spar structurally-power schemes.

1.2.2 Fuselage layout

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

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

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

For transonic airplanes fuselage nose part:

$$L_{nose} = 1.5 \cdot D_f = 1.5 \cdot 2.82 = 4.205 (m);$$

Except aerodynamic requirements consideration during the choice of cross section shape, it is necessary to consider the strength and layout requirements.

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

For cargo aircraft the aerodynamics is not so important in the fuselage shape choice, and the cross section shape is may be close to rectangular one.

To geometrical parameters related: 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 plane scheme, layout and airplane center-of-gravity position peculiarities, and the conditions of landing angle of attack α_{land} ensuring.

Fuselage length is equal:

$$l_f = D_f \cdot \lambda_f = 2.82 \cdot 7.65 = 21.57 (m);$$

Fuselage nose part aspect ratio is equal:

$$\lambda_{nose} = l_{nose} / D_f = 4.205/2.82 = 1.5;$$

Length of the fuselage rear part is equal:

$$l_{rear} = \lambda_{rear} \cdot D_f = 2.84 \cdot 2.82 = 8.034 (m);$$

During the determination of fuselage length are seeking for approaching minimum mid-section from one side and layout demands from the other.

Width of cabin is equal:

$$W_c = D_f - 0.2m = 2.82 - 0.2 = 2.62 (m).$$

1.2.3. Layout and calculation of basic parameters of tail unit

One of the most important tasks of the aerodynamic layout is the choice of tail unit placing. For ensuring longitudinal stability during overloading its center of gravity should be placed in front of the aeroplane focus and the distance between these points, related to the mean value of wing aerodynamic chord, determines the rate 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. If $m^{Cy}_x = 0$, than the plane has the neutral longitudinal static stability, if $m^{Cy}_x > 0$, than the plane is statically instable. In the normal aircraft scheme (tail unit is behind the wing), focus of the combination wing – fuselage during the install of the tail unit of moved back.

Static range of static moment coefficient: horizontal A_{htu}, vertical A_{vtu} given in the table with typical arm HTU and VTU correlations. Using table it is possible to find the first approach of geometrical parameters determination.

Determination of the tail unit geometrical parameters:

Area of vertical tail unit is equal:

$$S_{vtu}= (l_w \cdot S_w/H_{vtu}) \cdot A_{vtu}=10.2m^2;$$

A_{vtu}, A_{htu} for turboprop a/c are equal 1.

Area o horizontal tail unit is equal:

$$S_{htu}= (b_{MAC} \cdot S_w/L_{htu}) \cdot A_{htu}=12.55m^2$$

Values L_{htu} (8.85m) and H_{vtu} (5.145m) depend on some factors. First of all their value are influenced by: nose part and tail part length, sweptback and wing location, conditions of airplane stability and controllability.

Determination of the elevator area and direction:

Altitude elevator area:

$$S_{el}= 0.2765 \cdot S_{htu}= 3.47m^2;$$

Rudder area:

$$S_{rud}= 0.2337 \cdot S_{vtu}= 2.384m^2;$$

The area of altitude elevator trim tab:

$$S_{te}= 0.08 \cdot S_{el}= 0.278m^2;$$

Area of rudder trim tab is equal:

$$S_{tr}= 0.06 \cdot S_{rud}= 0.143m^2.$$

1.2.4. Landing gear design

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

Main wheel offset is:

$$e= 0.2673 \cdot b_{MAC} = 0.582m;$$

With the large wheel 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 plane comes first.

Main landing gear wheel base expression:

$$B_m = 0.15\cdot b_{MAC} = 0.327m;$$

Wheel base is taken from prototype (because of the big difference with formula's result): B= 8.125m

Nose landing gear wheel base:

$$B_n = B- B_m = 7.798m;$$

The last equation means that the nose support carries near 10% of plane weight.

Front wheel axial offset will be equal:

$$D_{rg} = B\text{-}e= 7.543m;$$

Wheel track ia taken from prototype (because of the big difference with formula's result): T= 3.18m

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

Wheels for the landing gear is chosen by the size and run loading on it from the take off weight; for the front support was considered dynamic loading also.

Type of the pneumatics (balloon, half balloon, arched) and the pressure in it is determined by the runway surface, which should be used. Breaks are installed on the main wheel.

The load on the wheel is determined:

$$K_g = 1.5...2.0 \text{ – dynamics coefficient};$$

Nose wheel load is equal:

$$F_n= B_m\cdot m_0\cdot k_g/(B\cdot z)= 1150N;$$

Main wheel load is equal:

$$F_m= B_n\cdot m_0/(B\cdot n\cdot z)= 6855.8N;$$

Table 2 – Aviation tires for designing aeroplane [6];

Main gear		Nose gear	
Tire size	Ply rating	Tire size	Ply rating
810x320-330 mm	14	600x220-254 mm	6

1.2.5. Choice and description of power plant

ТВ3-117ВМА-СБМ1, PW127E, ТВ7-117С are typical turboprop engines, in various modifications installed on aircraft AN-140, ATR-42 and IL-114 correspondently.

Table 3 – Examples of engines;

Model	Maximum power output	Dry weight
ТВ3-117ВМА-СБМ1	2200 hp	295kg
PW127E	2450 hp	400kg
ТВ7-117С	2800 hp	360kg

Empical analysis shows that the best choise will be ТВ3-117 engine family, which has:

•dustproof device;

•axial 12-stage compressor with adjustable inlet guide vane and guides of the first four stages;

•annular once-through combustion chamber;

•axial 2-stage compressor turbine;

•axial 2-stage free turbine for power take-off.

1.3. Center of gravity calculation

1.3.1. Trim-sheet of the equipped wing

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

The example list of the mass objects for the aeroplane, where the engines are located under the wing, including the names given in the table 4.The example list of the mass objects for the aircraft, where the engines are located in the wing, included the names given in the table 4. 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 4 - Trim sheet of equipped wing;

N	Name	Mass		C.G. coordinates x_i (m)	Moment m_i x_i (kgm)
		Units	total mass m_i (kg)		
	1	2	3	4	5
1	Wing (structure)	0,14532	4152,2	0,96	3979,16

End of table 4

	1	2	3	4	5
2	Fuel system	0,004	114,3	0,96	109,53
3	Control system, 30%	0,00297	84,9	1,31	110,90
4	Electrical equip. 30%	0,007545	215,6	0,22	46,95
5	Anti-icing system 70%	0,01284	366,9	0,22	79,91
6	Hydraulic system, 70%	0,01715	490,0	1,31	640,37
7	Power units	0,11395	3255,9	-0,25	817,23
8	Equipped wing without fuel and LG	0,303775	8679,8	0,67	5784,05
9	Nose landing gear	0,00332	94,9	-6,82	646,79
10	Main landing gear	0,03821	1091,8	1,31	1426,73
11	Fuel	0,13899	3971,4	0,96	3805,83
	Equipped wing	0,484295	13837,8	0,84	11663,40

1.3.2. Trim-sheet of the equipped fuselage

Origin of the coordinates is chosen in the projection of the nose of the fuselage on the horizontal axis. For the axis X the construction part of the fuselage is given. The example list of the objects for the AC, which engines are mounted under the wing, is given in table 5.

The CG coordinates of the FEF are determined by formulas:

$$X_f = \frac{\Sigma m_i' X_i'}{\Sigma m_i'};$$

After the C.G. of fully equipped wing and fuselage determination, the moment equilibrium equation relatively to the fuselage nose was constructed:

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

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

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

where $\boldsymbol{m_0}$ –airplane takeoff mass, kg; $\boldsymbol{m_f}$ – mass of fully equipped fuselage, kg; $\boldsymbol{m_w}$ – mass of fully equipped wing, kg; ***C*** – distance from MAC leading edge to the C.G. point, determined by the designer.

C = (0,23...0,32) $\mathbf{B_{MAC}}$ – high wing;

X_{MAC} = 9,4758367;

Table 5 – Trim sheet of equipped fuselage;

№	Objects	Mass		Coordinates of C.G.	Moment (kgm)
		Units	Total (kg)		
	1	2	3	4	5
1	Fuselage	0,1267	4114,5	10,88	39397,48
2	horizontal tail	0,01871	534,6	0,80	427,73
3	vertical tail	0,01849	528,3	1,16	611,71
4	radar	0,0045	128,6	0,5	64,29
5	radio equipment	0,0033	94,3	1,5	141,44
6	instrument panel	0,0078	222,9	3,5	780,04
7	aero navigation equipment	0,0067	191,4	3,75	717,90
8	aircraft control system 70%	0,0693	1980,1	10,88	21543,58
9	hydro-pneumatic sys 30%	0,00735	267,0	15,23	4112,23

End of table 5

	1	2	3	4	5
10	electrical equipment 70%	0,01760	646,7	10,88	7035,54
11	not typical equipment	0,0017	62,4	2,18	135,88
12	furnishing equipment	-	-	-	-
13	anti ice and airconditioning system 30%	0,00546	200,6	17,41	3491,20
14	cargo equipment	0,0008	29,4	10,88	319,71
15	additional equipment				
16	equipped fuselage without payload	0,28844	8510,3	9,35	78778,72
17	cargo	0,20999	6000,0	10,88	65280,48
18	crew	0,00761	225	3,15	708,75
	Total	0,49843	14735,3	9,82	144767,95

1.3.3. Calculation of center of gravity positioning variants

The list of mass objects for centre of gravity variant calculation given in Table 6 and Center of gravity calculation options given in table 7, completes on the base of both previous tables.

Table 6 – Calculation of C.G. positioning variants;

Name	Mass, kg	Coordinates	Moment
Object	m_i	C.G. M	kgm
Equipped wing (without fuel and landing gear)	8679,8	10,14	88032,06
Nose landing gear (extended)	94,9	2,66	252,58
Main landing gear (extended)	1091,8	10,78	11772,21
Fuel	3971,4	10,43	41437,81
Equipped fuselage (without payload)	8510,30	9,35	79528,71
Cargo	6000	10,88	65280
Crew	225	3,15	708,75
Nose landing gear (retracted)	94,9	1,66	157,72
Main landing gear (retracted)	1091,8	10,78	11772,21

Table 7 – Airplanes C.G. position variants;

№	Variants of the loading	Mass, kg	Moment of the mass, кg·m	Centre of the mass, m	Centering, %
	1	2	3	4	5
1	Take-off mass (L.G. extended)	28573,1	287012,12	10,04	26,12

End of table 7

	1	2	3	4	5
2	Take-off mass (L.G. retracted)	28573,1	286917,26	10,04	25,97
3	Landing variant (L.G. extended)	24601,6	245574,31	9,98	23,24
4	Transportation variant (without payload)	22573	221637,26	9,82	15,74
5	Parking variant (without fuel and payload)	18601,6	180294,31	9,69	19,94

1.4 Conlusions for project part

During this analytical aircraft design were defined next achivements:

- preliminary desing of the short-range cargo airplane with maximum payload of 6000kg;
- cabin layout of the short-range cargo aircraft with maximum payload of 6000kg;
- center of gravity position for five different load situations in the range from 15.7 to 26.1, listed in table 7;
- selection of wheels that meet a requirement for theoretical load of 180 km/h: tire size for main wheel 810x320-330 mm and for nose wheel 600x220-254 mm;
- applying of turboprop engines type ТВ3-117ВМА-СБМ1, which are located on the wing, provides high cruise speed and good power-to-weight ratio.

Current design of short-range cargo aircraft shows relatively nicely aerodynamic parameters, which positively influence on commercial cargo goals, and subsequently on competitiveness within airline market.

2. SPECIAL PART

2.1. Description and installation of the cargo equipment

A cargo aircraft (also known as freight aircraft, freighter, airlifter, or cargo jet) is a fixed-wing aircraft that is designed or converted for the carriage of goods, rather than passengers [7].

Aircraft designed for cargo flight usually have features that distinguish them from conventional passenger aircraft: a wide/tall fuselage cross-section, a high-wing to allow the cargo area to sit near the ground, a large number of wheels to allow it to land at unprepared locations, and a high-mounted tail to allow cargo to be driven directly into and off the aircraft [7].

There are several methods to the development of cargo aircraft:

- cargo aircraft as a derivative of a new or existing passenger or military airplane;
- cargo aircraft as development of a dedicated civilian cargo aircraft designed without regard for either passenger or military requirements;
- cargo aircraft as a development of a joint civil-military air cargo plane that would satisfy both commercial and military requirements [8].

In this work the first method was used.

Each derivative freighter has the benefit of having most of its development costs already assessed against the transaction of its passenger equivalent. Furthermore, the financial arrangements for buying the airplane have already been established and there is a quite short lead time before production (as compared to all new aircraft) [8].

A main drawback of existing air cargo aircraft is that they represent older technology; thus their direct operating costs are higher than what might be achieved with current technology. Additionally, since they generally have not been designed specifically for air cargo, loading and unloading can cause problems; the aircraft may be pressurized more than necessary, and there may be apparatus manufactured for passenger safety that is not necessary for cargo [8].

Most conversions are carried out on older aircraft no longer suitable for passenger use, often due to changing safety or noise requirements, or when the aircraft type is considered to have become uncompetitive in passenger airline service, but there is also a market for new-build freighter designs. Freighter aircraft normally have strengthened cabin floors and the inclusion of a broad top-hinged door on the port fuselage in addition to an absence of passenger cabin windows which was "plugged" [8].

The main modification inside aircraft:

- strengthening the compartment floor structure;
- installation of a ball mat and roller loading system;
- shifting from the “canonical” unit load devices to the more eco-friendly agents.

Cargo compartment sizes:

- L_c= 11410mm - length;
- W_c= 2620mm - width;
- H_c= 1890mm - height.

2.1.2 Unit Load Device

While in the ocean cargo busubess the term “container” is widely spreaded, in aviation the tight term is Unit Load Device (ULD). ULD is used as container for baggage and cargo carried in the holds of suitably dimensioned and equipped aircraft and is secured so that it cannot move within the hold in flight [9].

In this work was used use so-called *Container E*, which is IATA rate class 9 ULD (advanced EH-type). Because sertified LD-types are too massive for our airplane cargo door with sizes 1535mm x 1155 mm.

It is a large, sturdy, cost-effective, and easy to handle box, which is designed for easy packing and unpacking. An ideal combination of structural durability and strength together with ease of use. It is designed from kraft corrugated material, which provides superior protection from drops and impacts, which naturally result while handling air freight ships. This double-walled, heavy-duty bulk cargo container provides the required protection against hazards of transportation without compromising on the safety of the goods stored inside [10].

Figure 2 – E container

With an ever-increasing focus on climate change and the environment, this container is designed to be easily recycled and reused, making them an environmentally friendly packaging and transporting solution. The easy recyclability helps to reduce carbon footprint. Made without color-changing dyes or bleaches, they can be disposed of more sustainably than their counterparts [10].

This specific type of container has next characteristics:

- max. extental length(L_0)1060 mm;
- max. extental width(W_0) 730 mm;
- max. extental height(H_0) 660 mm;
- max. gross weight(G_0) 136 kg;
- max. internal volume 5 m^3;
- tare weight allowance 8 kg.

To increase rate of effective volume of cargo hold and decrease number of tie-down equipment these boxes will be combined in a form of right parallelepiped, placing 8 containers for each group. So we will use the following parameters:

$$G= G_0 \cdot 8= 1100(kg);$$

$$L= L_0 \cdot 2= 2120(mm);$$

$$W= W_0 \cdot 2= 1460(mm);$$

$$H= H_0 \cdot 2= 1320 (mm).$$

Mass of commercial payload(m_{comm}) for our airplane is 6000kg, so number of groups is equal:

$$n_{group}= m_{comm}/G= 5;$$

2.1.3. Roller floor system

A cargo loading system (CLS) consists of necessary equipment to provide movement, guiding and restraint of cargo. Power drive units (PDUs) are installed to move ULDs semi automatically. These items are attached via tray assemblies and floor fittings to seat tracks and floor structure. Tray assemblies provide movable restraint for locks and rollers [11].

Structural and cost analysis involves the installation of a cargo floor roller system. The roller system consists of two ball mat trays located in the area of the cargo door, and a series of roller tray assemblies along the rest of the floor after this door [12].

A ball mat for ramp and cargo hold of an aircraft is device to support weights and assist the movement thereof. Ball mat are omni-directional load-bearing spherical balls mounted inside a restraining fixture. They are identical in principle to a ball computer mouse upside-down. The design involves a single large ball supported by smaller ball bearings. They are used in an inverted ball up position where objects are quickly moved across an array of units, known as a ball mat tray, a type of conveyor system [13].

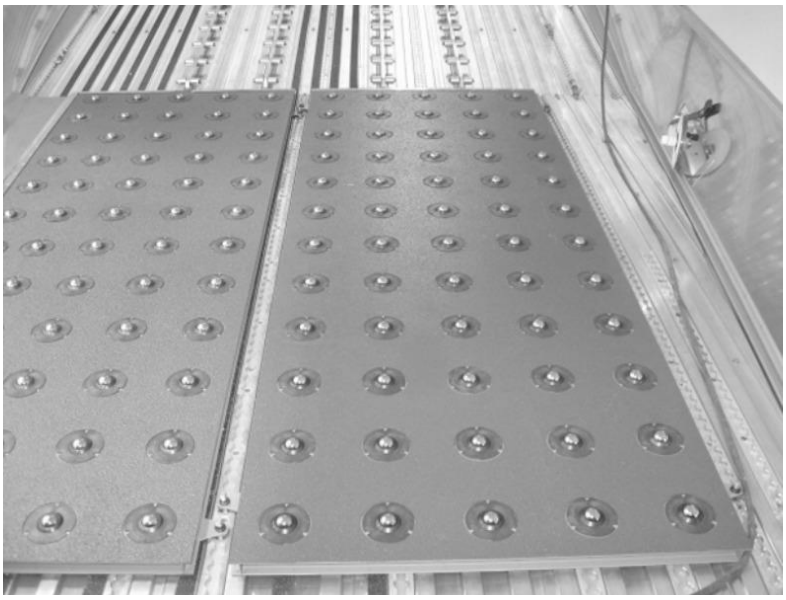


Figure 3 – Ball mat tray [13]

A loader will move a container into the aircraft through the cargo doors. Just inside the door is a ball mat tray will pull the container all the way in the and then start it on its way to the correct location, where it will be locked in place. The container is moved forwards or backwards by motorized rollers in the floor [13].

Rollers allow free movement of ULDs along tracks in both directions. The design of the roller is simple: a cylinder with a bearing. Both are made of chroming steels. The axis of the roller withstands bending and shearing. Brake rollers restrict the movement of ULDs to one direction. They prevent unintended movement of ULDs in cargo compartments with a sloping floor, particularly towards the doorway area. Pallet locks provide restraint for pallets and containers. The mechanism of longitudinal/vertical restraint locks can be retracted below the roll plane to enable loading and unloading [13].

The transition between the ball-mat and the roller tray assemblies is a row of modified roller rail assemblies. The roller rails are modified to have a slope of 1 degree to provide a smooth transition from the ball mat to the roller trays [12].

To select the proper ball met it is necessary to determine structural limitations:

- Running (linear) load (RL) is maximum load acceptable on any given fuselage length of an aircraft floor. The length is the contact ULD's points on the floor.

$$RL_0 = G/L = 1100/2.12 = 520 \text{ (kg/m)};$$

$$RL_0 = G/W = 1100/1.46 = 755 \text{ (kg/m)}.$$

After empirical researches the maximum assumed RL is 1000kg/m. Critical value is not exceeded.

- Area load (AL) is maximun load acceptable on any surface unit of an aircraft floor. It prevents the load from exceeding the capability of the airplane structure. It is aslo known as "Uniformly distributed load". Contact area is the external contour of the contact points on the floor.

$$AL = W/S = 1100/3.1 = 355 \text{ (kg/m}^2\text{)};$$

Aproximate distance between balls on mat tray is 250 mm and rollers in longitudinal direction is 300mm. In lateral direction between 3 rows of rollers the distance is 500mm.

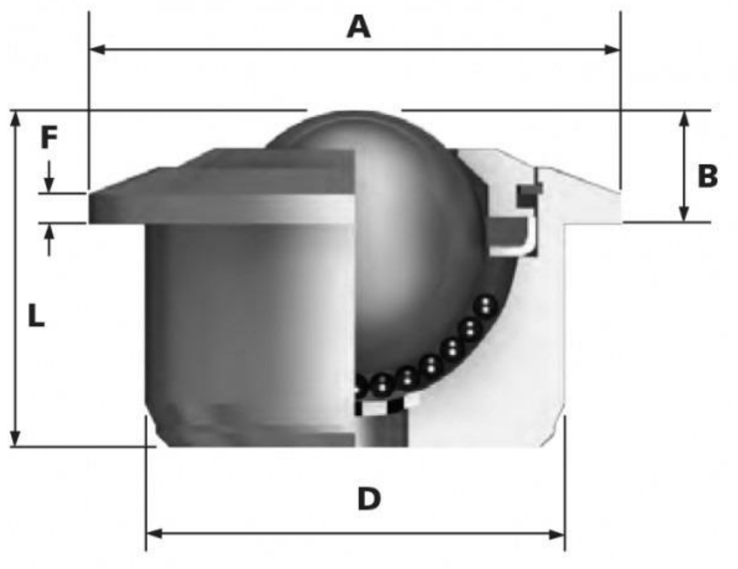
So the next step is defining load on ball and roller cylinder, taking into account cargo sizes, devices position and maximum value of existing loading.

On each lengthwise (OX axis) meter the devices is installed in the amount of three. So the load is:

$$RL_{device}^{OX} > RL_0/3 = 252\ (kg/m);$$

For this purpose the Alwase Heady Dudy Series 888 were used. They carry 350 kg of load and have:

- 60% Reduction in friction;
- 50% Reduction in dB noise level in use;
- Improved Corrosion resistance;
- 10% Greater load ball exposure;
- Tapered body for easier installation [14].



Weight= 0.30 kg; Load ball diameter Ø= 30mm; A=50mm - maximum diameter; B=14mm - ball working height; D=45mm - body diameter; E= 21mm - under flange to base; F=2mm - base thickness; L=35mm - overall height [14].

Figure 4 – Ball met

On transverse(OY) meter the interval between rollers is calculated in quantity of two:

$$RL_{device}^{OY} > RL_0/2 = 380\ (kg/m);$$

For this purpose any Hydraroll or Ancra rollers, which subjected to 400 kg of load, are preferred.

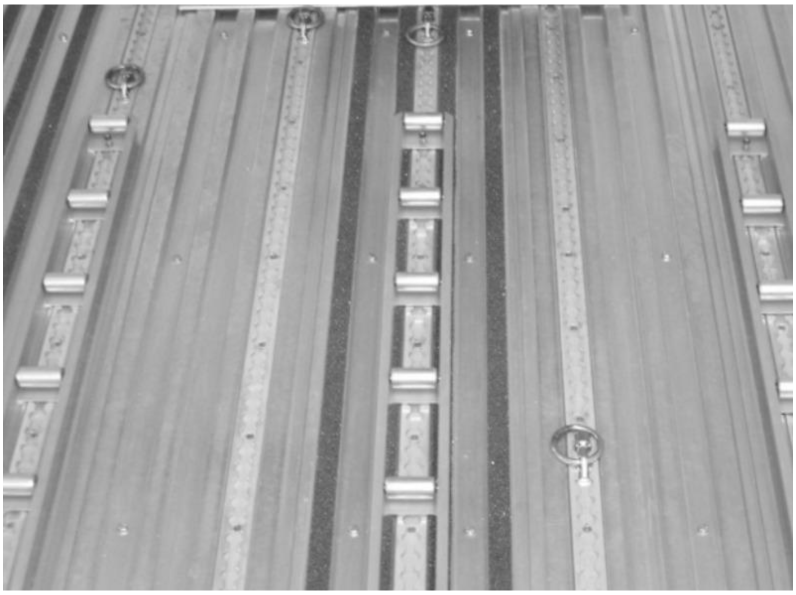


Figure 5 – Roller tray assembly [13]

2.1.4. Tie-down equipment

All cargo must be attached in such a way that during the flight they do not move freely, dangerously, do not shift the center of gravity of the aircraft, do not injure crew members, and do not damage the internal structure of the aircraft during normal flight operations, as well as in the case of emergency landings, and damaged other goods and cargo.

Any cargo carried on board an aircraft is subject to the inertia caused by the acceleration or deceleration of the aircraft. These forces can cause load displacement if they are not properly moored (fitted).

All weights which, by their nature, shape or density, may be dangerous during transport, must be fitted. It is achieved by:

- filling the cargo compartment to the full volumetric capacity, thus protecting the cargo from movement in all directions by the floor, walls and upper ceiling;

Remark: compartment filled at 3/4 of its height is determined fully loaded.

- mooring individual weigth of cargo to fixed tie-down units on the floor by means of fittings, ropes or belts.

The loaded cargo must be secured to withstand the overloads indicated in the table [15]:

Table 8 – cargo overloads;

Direction of force	Load factor
Forward	1.5
Back	1.5
Side	1.5
Up	3.0

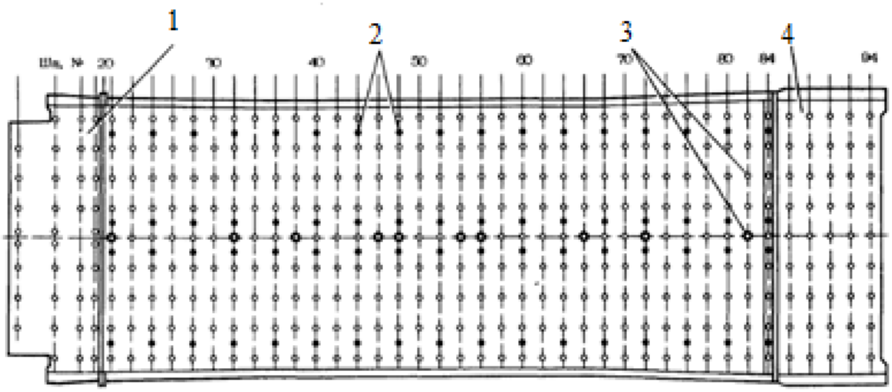
Tie down equipment is intended for the bracing of the cargo inside the cargo hold.

The set of tie-down equipment comprises:

- tie-down units;
- tie-down fittings;
- tie-down devices;
- lashing straps;
- wedge locks;
- adapters;
- tie-down nets;

- tie-down belts;
- boxes for the tie-down nets and tie-down belts storage.

Tie-down units are intended for the fastening of tie-down chains, belts and nets to the floor of cargo hold. These devices are screwed into special jacks on the floor and ramps.



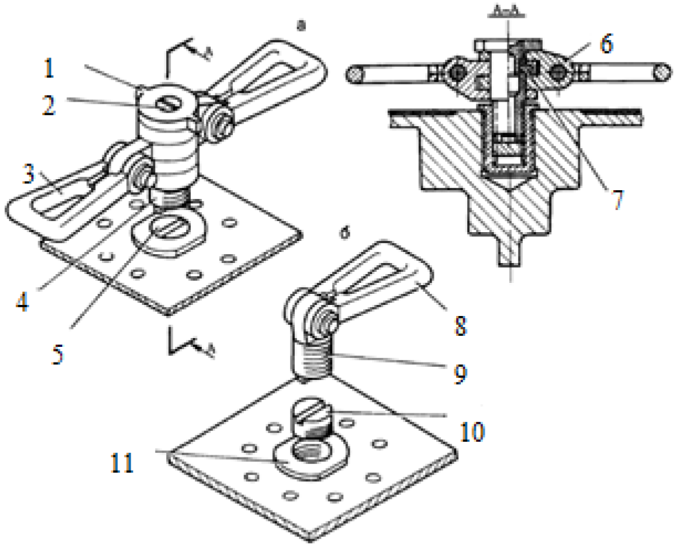
1 – forward cargo door ramp; 2 – fitting jacks for locking beam; 3 - tie-down unit jack; 4 - aft cargo door ramp.

Figure 6 - Tie-down units accommodation [17]

A single tie-down fitting consists of an ear bolt, to which a ring is fixed by a roller.

The double tie-down fitting consists of a threaded pin on which two ears are coaxially mounted. From longitudinal movement along the pin, the ears are held by two stifts inserted into the through hole in the pin and into the ring groove of the ear. The pins are prevented from falling out by a plug screwed into the pin. A ring is pivotally attached to each ear.

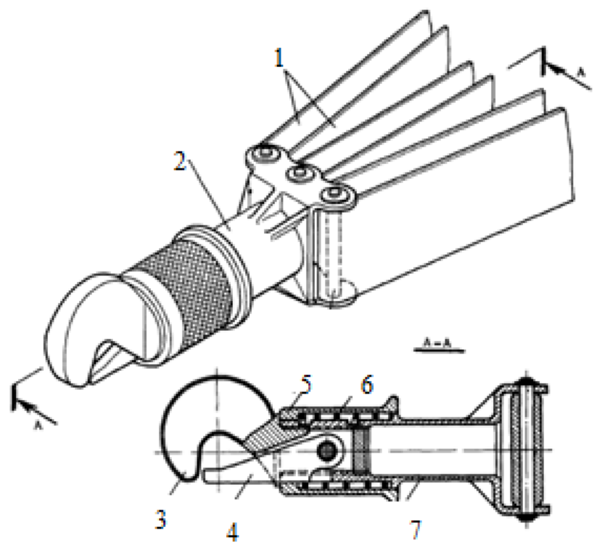
Ropes, belts and fittings must be approved by the airliner. Fittings should be installed with a minimum interval of 50 cm.



1 – lug; 2 – plug; 3, 8 – ring; 4 – pin; 5, 10 – bung; 6 – ear; 7 –stift; 9 - ear bolt; 11 – tie-down unit jack.

Figure 7 - Tie-down fittings: a – twin unit; b – single unit [17]

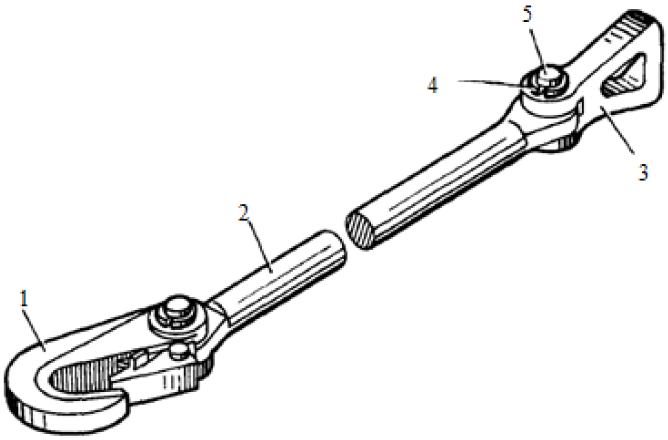
The tie-down device is used to connect belt to the unit. The lock of the tie-down device consists of a housing, a hook with a latch and a coupling. Its mass equals 3 kg.



1 – tie-down belt; 2 – lock; 3 – hook; 4 – latch; 5 – coupling; 6 – spring; 7 – housing.

Figure 8 – Tie-down device [17]

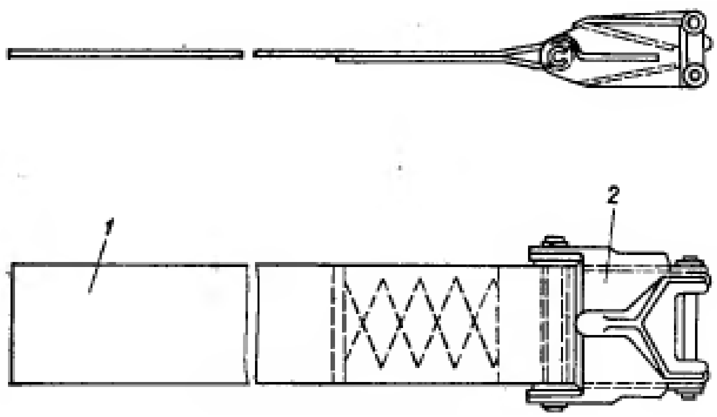
Adapter consists of rod, hook, and ring. The hook and ring are connected with rod by hinge. The hook can be attached to the tie-down unit (if the polispast system is present; then the ring fixed to the hook of the pulley) or net cells.



1 – hook; 2 – rod; 3 – ring; 4 – washer; 5 – roller.

Figure 9 – Adapter [17]

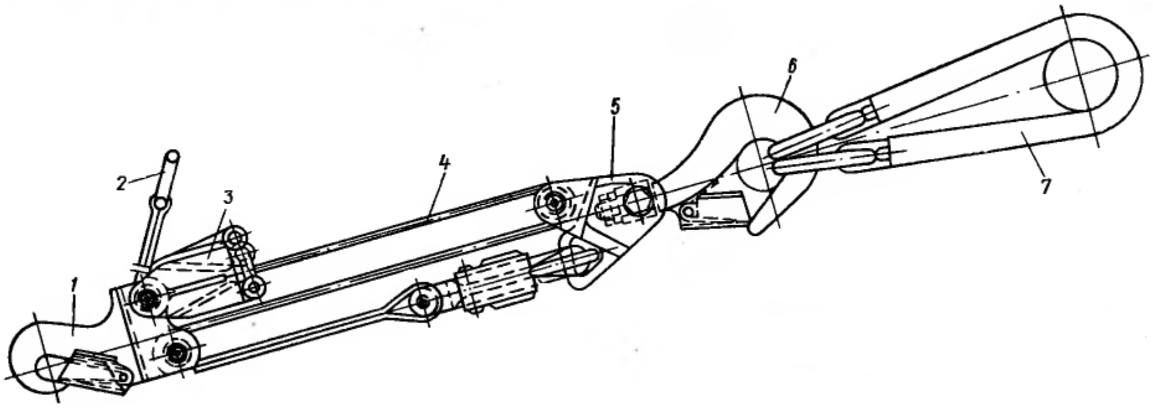
Lashing strap is designed for packaging groups of cargo during mooring. It consists of strip and lock. Straps must be attached and/or tied around a weight or net.



1 – strip; 2 – lock.

Figure 10 – Lashing strap [17]

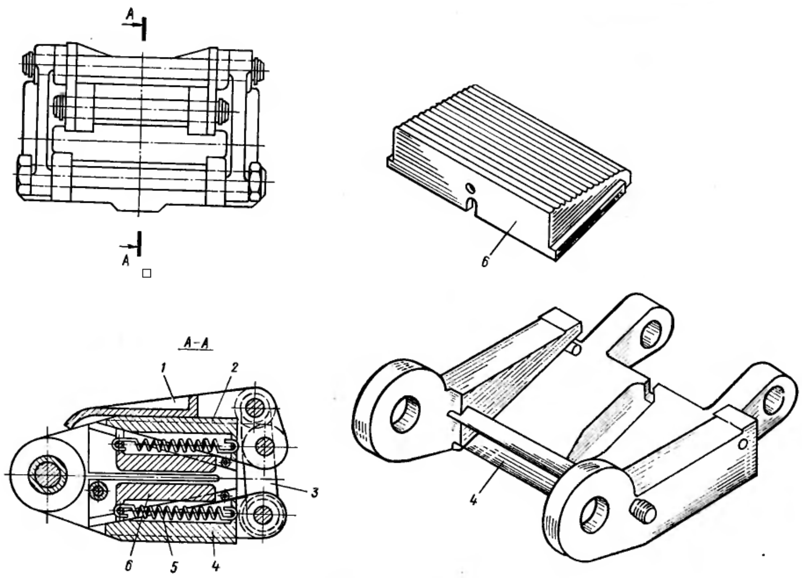
Tie-down belt consists of hook (sometimes it can be tie-down device) for connection with the tie-down fitting, ring, wedge lock, three branches of synthethic (nylon) belt, shackle, another hook for cargo attachment and strap. A maximum of three belts must be attached to one fitting or tie-down device in the same directions.



1, 6 – hooks; 2 – ring; 3 – wedge lock; 4 – nylon belt; 5 – shackle; 7 – strap;

Figure 11 – Tie-down belt [17]

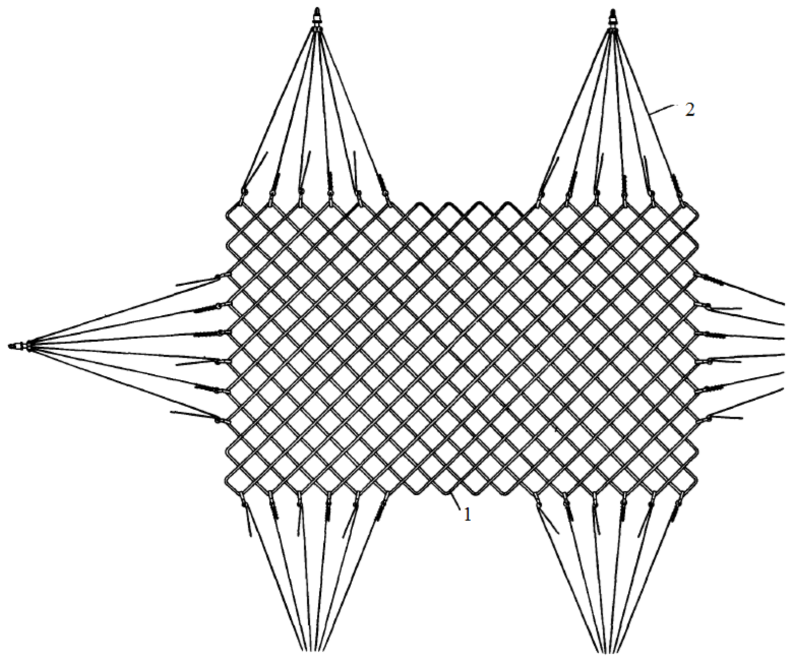
The wedge lock is designed to clamp the belt. The lock consists of upper and lower bodies. In each body there are inclined slots (groove) in which wedge-shaped liners are enclosed. On the plane of the liner facing the belt, there is a patch for reliable grip of the belt. The housings together with the liners are clamped by a lever. The springs tend to move the liners in the inclined grooves of the bodies. In this case, the liners come together and clamp the belt.



1 – lever; 2 – upper body; 3 – shackle; 4 – lower body; 5 – spring; 6 –liner.

Figure 12 – Wedge lock [17]

Tie-down net also made from nylon strip. The net is fixed by tie-down units. The tie-down unit comprises the lock, tie-down belts, pulleys and hooks.



1 – net; 2 – tie-down device.

Figure 13 – Tie-down net [17]

2.2. Stress calculation of the tie-down belt during emergency landing

1) Ranges of weights and C.G. within the aircraft may be safety operated must be established. The weights and C.G. combination is allowable only within certain load distribution limits. Forward and aft C.G. limitation must be established for each operating condition.

2) Each compartment for stowage of cargo, baggage, equipment must be designed for its weight contents and for critical load distribution at the appropriate maximum load factors correspondent to the specified flight and ground load conditions. For emergency landing conditions there must be a means to prevent the goods inside compartment for becoming a hazard by shifting under the loads specified in this section [16].

2.2.1. Mooring requirements

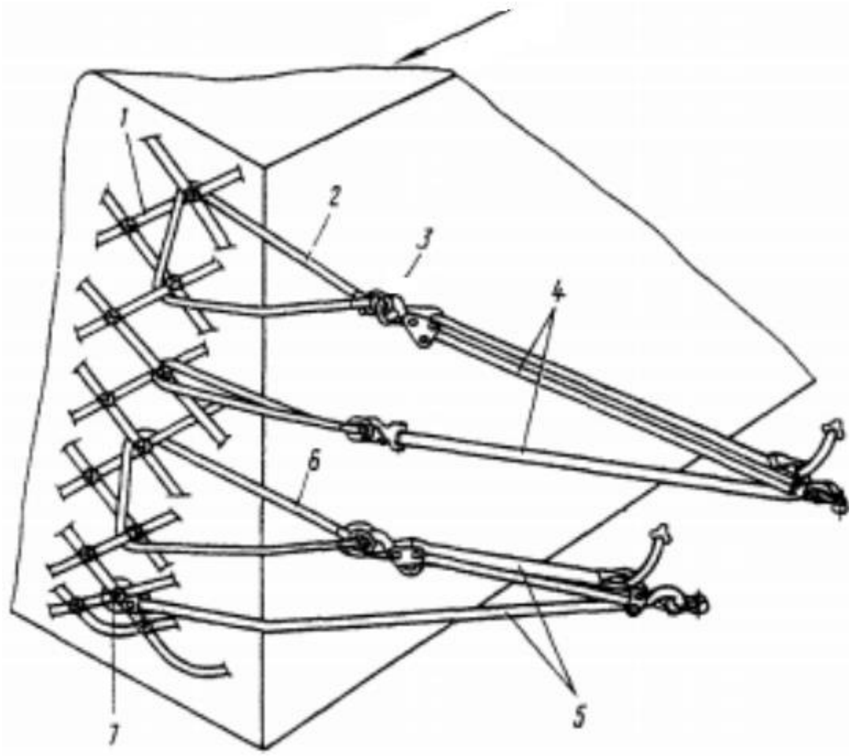
Cargo mooring:

1) Cargo mooring is carried out by tie-down net;

Maximum mass of single moored cargo should not exceed 2500kg;

2) Before mooring, place small (as we have combination of 8 E containers) loads tightly against each other and pull together with lashing straps. The top row of goods may not be pulled together.

3) Group of weights pulled together by lashing straps is necessary to cover by tie-down net, placing it symmetrically with respect to the containers. The edges of the net should overlap the upper border of the lower row of weights by 300-400 mm, so that when the net is pulled with tie-down belt, the bottom row does not appear outside the net. Capture of mesh cells with tie-down belts depending on the direction of overload is shown in the figures.



Arrow shows overload direction.

1 – tie-down net; 2, 6 – strap; 3 – cargo; 4, 5 – tie-down belts; 7 – adapter hook.

Figure 14 - Tie-down belts installation

4) The net should be braced by tie-down belt.

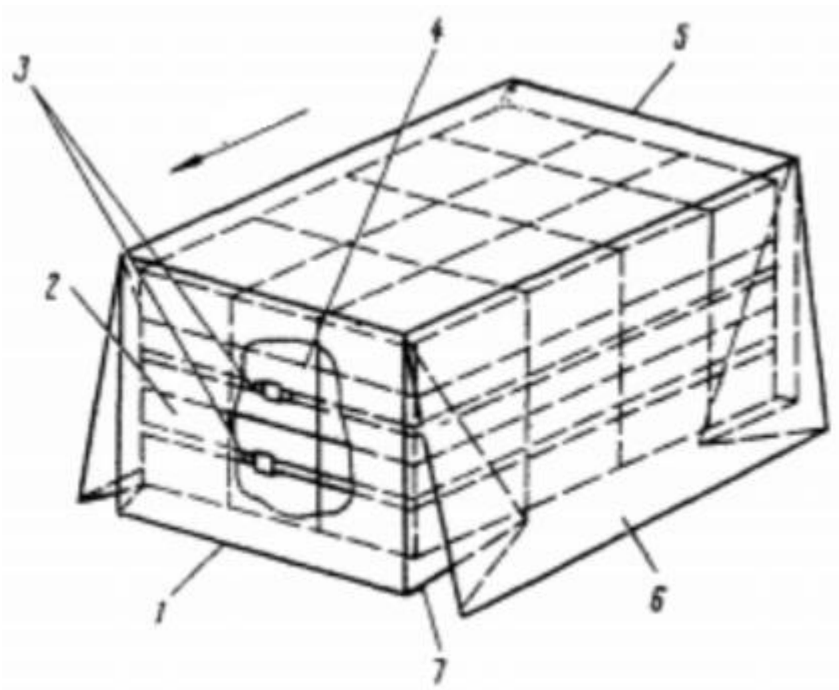
With one tie-down belt its possible to grab three vertically adjacent net cells (one directly with the adapter hook, the other two with a strap, the two rings of which are secured with the free end of the belt with a hook).

When mooring from lateral overloads, the straps of the tie-down belts and the hooks of the adapter must capture the cells of the side part of the net (left and right); when mooring from longitudinal overloads - cells of the front and rear parts of the net).

When gripping the cells with a mooring belt elements, select the gripping points, retreating 200-300 mm from the edge of cargo package, so that when the belt is pre-tensioned, the gripping point does not cross the cargo edge.

All tie-down belts should be tighten after installation.

The number of tie-down belts is determined in the same way for monolithic and for a group of cargoes (in our case, 5 belts of different lengths, each have symmetrical copy to the OX axis), and is checked by the method of determining forces during cargo mooring.



Arrow shows overload direction.

1 – tie-down net edge; 2 – net front part; 3 – lashing straps; 4 – cargo; 5 – tie-down net; 6 – net side part; 7 – net pocket.

Figure 15 - Tie-down net installation

Cargo unmooring:

Cargo unmooring should be performed in a reverse order of mooring.

1) To unmoor the tie-down device, remove the free end of the belt from the lock bracket and open the lock lever.

2) To unmoor the lashing strap, pull the thrust sleeve out of the ratchet using a handwheel.

2.2.2. Determination of the forces

Reliable fastening should prevent cargo displacement during transportation (forward, backward, sideways) from overloads arising in flight. Obiously, that in a case of emergency landing tie-down equipment should withstand abnormal stresses. That was the task of next force esmimation. The object for calculation was tie-down belt.

During calculation the fastening of goods and equipment, was consider the case of the simultaneous effect of overloads along the axes: X, Y, Z.

For goods with the mass less than 1 tone:

- forward $n_x^p = 9$
- backward $n_y^p = 2$
- sideways $n_z^p = 1.5$

For goods with the mass more than 1 tone:

- forward $n_x^p = 6$
- backward $n_y^p = 2$
- sideways $n_z^p = 1.5$

Remark: n_x^p, n_y^p, n_z^p - design overloads acting in the direction of the axes X, Y, Z;

If the cargo is located in front of the former No. 17, the sideways overload is equal 3.

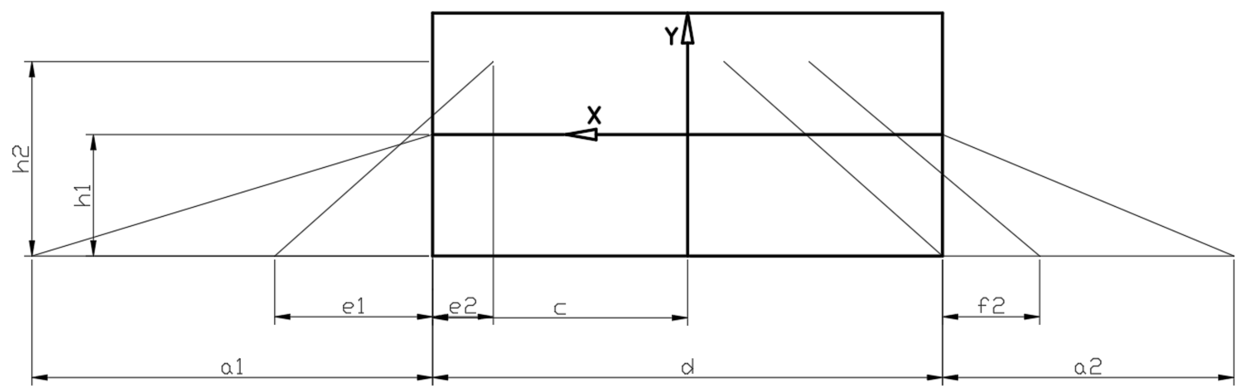


Figure 16 – cargo attachment front view

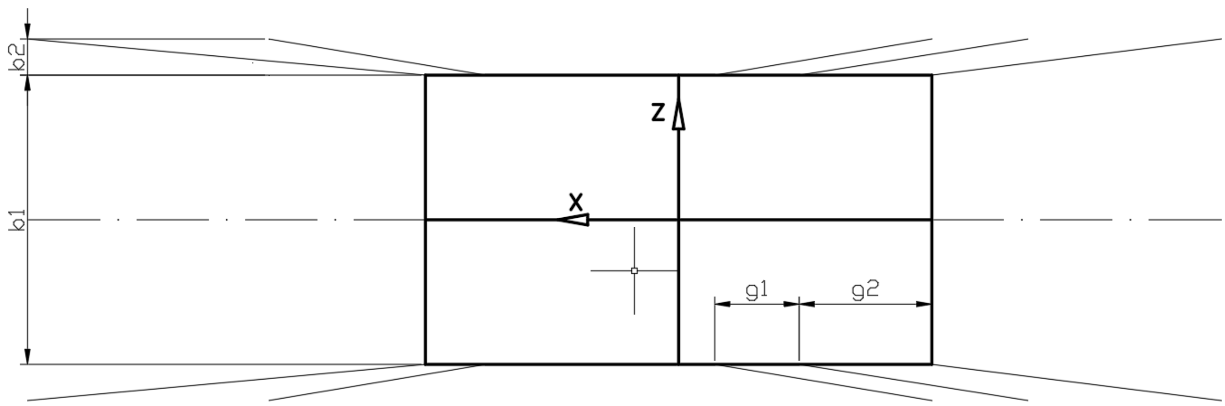


Figure 17 – cargo attachment top view

Given**:**

a_1= 1665 mm; a_2= 1215 mm; b_1= 1460 mm = ULD's length (L); b_2= 185 mm; c= 1060 mm; d= 2120 mm= ULD's width (W); e_1= 660 mm e_2= 255 mm; f_1= 0 mm; f_2= 405 mm; g_1= 355 mm; g_2= 555 mm; h_1= 660 mm; h_2= 1060 mm; ULD's height = 1320 mm; G= 1100 kg= ULD's weight; n_x^p= 6; n_y^p= 2; n_z^p= 1.5.

1) At the beginning its necessary to find out length of each tie-down element *l* and its projections on coordinate axes X, Y, Z.

$$l= sqrt(X^2+Y^2+Z^2)$$

2) And calculate the direction cosines for the respective directions forward, backward, upward, sideways (cosines of the angles between the directions of the tie-down elements and the coordinate axes) for each element:

$$\cos (X,T)= x/l;$$

$$\cos (Y,T)= y/l;$$

$$\cos (Z,T)= z/l.$$

Table 9 – geometrical parameters of tie-down belts;

Group	Tie-down element number	X, mm	Y, mm	Z, mm	l, mm	cos (X,T)	cos (Y,T)	cos (Z,T)
1	1	1665	660	185	1801	0.925	0.367	0.103
	2	915	1060	185	1412	0.648	0.750	0.131
2	3	910	1060	185	1409	0.646	0.752	0.131
	4	960	1060	185	1442	0.666	0.735	0.128
	5	1215	660	185	1395	0.871	0.473	0.133

3) Define stiffness coefficients C_x, C_y, C_z:

$$C_x= \cos^2(X,T)/l;$$

$$C_y= \cos^2(Y,T)/l;$$

$$C_z= \cos^2(Z,T)/l.$$

4) Define force coefficients α_x, α_y, α_z:

$$\alpha_x= \cos(X,T)/l;$$

$$\alpha_y= \cos(Y,T)/l;$$

$$\alpha_z= \cos(Z,T)/l.$$

5) Calculate values of inertia forces Q_x, Q_y, Q_z, acting on a cargo:

$$Q_x= n_x^p \cdot G= 6 \cdot 1100= 6600 \text{ (kgf)};$$

$$Q_y= n_y^p \cdot G= 2 \cdot 1100= 2200 \text{ (kgf)};$$

$$Q_z= n_z^p \cdot G= 1.5 \cdot 1100= 1650 \text{ (kgf)}.$$

6) Determine the force in any tie-down element (belt) from the action of external forces, for i-th component:

- from force Q_x

$$S_{xi}= (Q_x \cdot \alpha_{xi})/2\sum^n_1 C_x;$$

- from force Q_y

$$S_{yi}= (Q_y \cdot \alpha_{yi})/2\sum^{n}_{1}C_y;$$

- from force Q_z

$$S_{zi}= (Q_z \cdot \alpha_{zi})/\sum^{n}_{1}C_z.$$

Last three formulas are valid, when tie-down elements are located symmetrically relative to X, Y, Z axes, passing through cargo's center of gravity. In this task OX axis meet this requirement.

7) In a case of non-symmetrical position of belts (commom situation for OY and OZ axes):

- Divide components (n) into front(m; I) and rear(n-m; II) groups relative to the cargo's center of gravity and for each of them find the center of stiffness:

For elements receiving force Q_y

$$X_{I\ CS}= (\sum^{m}_{1}C_{yi} \cdot X_{CGi})/ \sum^{m}_{1}C_{yi}= 1875\ (mm);$$

$$X_{II\ CS}=(\sum^{n}_{m-n}C_{yi} \cdot X_{CGi})/ \sum^{n}_{n-m}C_{yi}= 1429\ (mm).$$

For elements receiving force Q_z

$$X_{I\ CS}= (\sum^{m}_{1}C_{zi} \cdot X_{CGi})/ \sum^{m}_{1}C_{zi}= 2045\ (mm);$$

$$X_{II\ CS}=(\sum^{n}_{m-n}C_{zi} \cdot X_{CGi})/ \sum^{n}_{n-m}C_{zi}= 1608\ (mm).$$

Table 10 – stiffness coefficients and related center of gravity position;

Group	Tie-down element number	C_x	C_y	C_z	X_{CG}, mm	$X_{CG} \cdot C_y$	$X_{CG} \cdot C_z$
1	1	0.475	0.075	0.006	-2726	0.203	0.016
	2	0.297	0.399	0.012	-1716	0.684	0.021
2	3	0.296	0.401	0.012	1060	0.426	0.012
	4	0.307	0.374	0.011	1462	0.549	0.016
	5	0.544	0.160	0.013	2271	0.364	0.029

- Distribute external forces Q_y and Q_z between groups of elements proportionaly to the distances from the cargo's center of gravity to the groups centers of stiffness.

For Q_y

$$Q_{y\,I}= Q_y\cdot(X_{II\,CS}/(X_{I\,CS}+X_{II\,CS}))= 951.5 \text{ (kgf)};$$

$$Q_{y\,II}= Q_y\cdot(X_{I\,CS}/(X_{I\,CS}+X_{II\,CS}))= 1248.5 \text{ (kgf)}.$$

For Q_z

$$Q_{z\,I}= Q_z\cdot(X_{II\,CS}/(X_{I\,CS}+X_{II\,CS}))= 726.4 \text{ (kgf)};$$

$$Q_{z\,II}= Q_z\cdot(X_{I\,CS}/(X_{I\,CS}+X_{II\,CS}))= 923.6 \text{ (kgf)}.$$

- The effort for each group of elements is determined by the formulas in Section 6, replacing the forces Q_y and Q_z, respectively by forces $Q_{y\,I}$, $Q_{y\,II}$, $Q_{z\,I}$, $Q_{z\,II}$ and summing the terms within each group:

For Q_y

$$S_{yi\,I}= (Q_{yI}\cdot\alpha_{yi\,I})/\sum^{m}{}_{1}C_y;$$

$$S_{yi\,II}= (Q_{yII}\cdot\alpha_{yi\,II})/\sum^{n}{}_{n-m}C_y.$$

For Q_z

$$S_{zi\,I}= (Q_{zI}\cdot\alpha_{zi\,I})/\sum^{m}{}_{1}C_z;$$

$$S_{zi\,II}= (Q_{zII}\cdot\alpha_{zi\,II})/\sum^{n}{}_{n-m}C_z.$$

- After strength calculation, it is necessary to compare the forces determined by the formula $S_i= S_{xi}+S_{yi}+S_{zi}$ with the destructive force of the tie-down belt (for this specific type of aircraft force should not exceed 7000 kgs) and define the safety factor of the element $\eta= 7000/S_i$ [17].

Table 11 – forces, their coefficients and safety factor;

Group	Tie-down element number	α_x	α_y	α_z	S_x, kgf	S_y, kgf	S_z, kgf	S, kgf	η
1	1	0.514	0.204	0.057	-	204.6	2301.8	2506.4	2.79
	2	0.459	0.531	0.093	-	534.0	3740.6	4274.6	1.64
2	3	0.458	0.534	0.093	1318.3	355.7	2373.4	4047.5	1.73
	4	0.462	0.510	0.089	1328.2	339.7	2266.7	3934.6	1.78
	5	0.624	0.339	0.095	1796.2	226.0	2422.0	4444.3	1.57

Results show that all tie-down belts will withstand excessive loads and stresses during emergency landing.

But some percentage of goods is braced in front of 17th former (see Remark), so for this portion has sideway overload n_z^p= 3. Let's follow above mentioned steps and recalculate values in table 11.

$Q_z = n_z^p \cdot G = 3 \cdot 1100 = 3300$

$$Q_{z\,I} = Q_z \cdot (X_{II\,CS}/(X_{I\,CS}+X_{II\,CS})) = 1452.9 \text{ (kgf)};$$

$$Q_{z\,II} = Q_z \cdot (X_{I\,CS}/(X_{I\,CS}+X_{II\,CS})) = 1847.1 \text{ (kgf)}.$$

Table 12 – final results for cargo before 17th former ;

Group	Tie-down element number	S_x, kgf	S_y, kgf	S_z, kgf	S, kgf	η
1	1	-	204.6	4603.7	4808.3	1.45
	2	-	534.0	7481.2	8015.2	0.87
2	3	1318.3	355.7	4781.8	6420.8	1.09
	4	1328.2	339.7	4533.3	6201.3	1.12
	5	1796.2	226.0	4844.0	6866.3	1.02

Here the 2nd belts will fail, because here safety factor shows only the state of belt (will it brake or not), so it is necessary either to strengthen them, to change its material, to increase their number, to lengthen belt body or to fix some safety equipment near crew cabin door like net.

2.3. Conclusions for special part

During this analytical aircraft desing were defined next achivements:

- the concept and main principles of dedicated freighter development (its pros and cons) were reviewed;
- analytics of new eco unit load device (E container), its parameters and arrangment were considered;
- modified cargo loading system (combination of ball mat tray and roller tray assembly) was depicted and choosen by cargo floor structural limitations: ball mat Alwase Heady Dudy Series 888, Hydraroll or/and Ancra rollers;
- the requirement and structural features of usable tie-down equipment were described;
- mooring and unmooring step procedures for small weights by tie-down belts, nets and fittings were observed;
- the strength analysis for tie-down belts during emergency situations was conducted, taking into account several variant of sideways overload (n_z^p= 1.5; n_z^p= 3). In each test safety factor was calculated, which shows the condition of belt (will it broke or not: η>1). In a case of critical state alternative ways of safety factor increasing, like belt material substitution or strengthening, were offered.

General conclusions

During this analytical aircraft design were defined next achivements:

- preliminary desing of the short-range cargo airplane with maximum payload of 6000kg;
- cabin layout of the short-range cargo aircraft with maximum payload of 6000kg;
- center of gravity position for five different load situations in the range from 15.7 to 26.1;
- applying of turboprop engines type ТВ3-117ВМА-СБМ1, which are located on the wing, provides high cruise speed and good power-to-weight ratio;
- the concept and main principles of dedicated freighter development were reviewed;
- analytics of new eco unit load device (E container), its geometrical parameters and arrangement were considered: 5 groups of 8 containers in a form of right parallelepiped;
- modified cargo loading system was depicted and choosen by cargo floor structural limitations. Each element of the system must withstand Running Load more than 252kg/m^2.
- the requirement and structural features of usable tie-down equipment were described (acc. Freight Manual Part B Rules and Procedures Issue);
- the strength analysis for tie-down belts during emergency situations was conducted. In a case of critical state alternative ways of safety factor increasing, like belt material substitution or strengthening, were offered;

Current design of short-range cargo aircraft shows relatively nicely aerodynamic parameters, which positively influence on commercial cargo goals, and subsequently on competitiveness within airline market. All parts of the designed aircraft serve to facilitate the loading and unloading. Such cargo transportation meets all requirement according EASA guidelines and CS-25 [1].

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Appendix 1

П Р О Е К Т
С А М О Л Е Т А С Т В Д
Н А У, кафедра К Д А

ПРОЕКТ Diploma Расчет выполнен 23.09.19
Исполнитель Chernov V.V. Руководитель

ИСХОДНЫЕ ДАННЫЕ И ВЫБРАННЫЕ ПАРАМЕТРЫ

Количество пассажиров	0.
Количество членов экипажа	2.
Количество бортпроводников или сопровождающих	1.
Масса снаряжения и служебного груза	598.63 кг.
Масса коммерческой нагрузки	6000.00 кг.
Крейсерская скорость полета	470. км/ч
Число "М" полета при крейсерской скорости	0.4184
Расчетная высота начала реализации полетов с крейсерской экономической скоростью	7.200 км
Дальность полета с максимальной коммерческой нагрузкой	1750. км.
Длина летной полосы аэродрома базирования	1.90 км.
Количество двигателей	2.
Оценка по статистике энерговооруженности в квт/кг	0.1920
Степень повышения давления	12.00
Относительная масса топлива по статистике	0.1800
Удлинение крыла	12.00
Сужение крыла	2.50
Средняя относительная толщина крыла	0.120
Стреловидность крыла по 0.25 хорд	6.5 град.
Степень механизированности крыла	0.800
Относительная площадь прикорневых наплывов	0.000

Профиль крыла - Ламинизированный типа NACA
Шайбы УИТКОМБА - не применяются
Спойлеры - установлены

Диаметр фюзеляжа	2.82 м.
Удлинение фюзеляжа	7.65
Стреловидность горизонтального оперения	18.0 град.
Стреловидность вертикального оперения	22.0 град.

Р Е З У Л Ь Т А Т Ы Р А С Ч Е Т А
Н А У, КАФЕДРА "К Д А"

Значение оптимального коэффициента под'емной силы в расчетной точке крейсерского режима полета Cy 0.48656

Значение коэффициента Сх.мин. 0.00976

ОПРЕДЕЛЕНИЕ КОЭФФИЦИЕНТА Dм = Мкрит - Мкрейс

Число Маха крейсерское	Мкрейс	0.41839
Число Маха волнового кризиса	Мкрит	0.68383
Вычисленное значение	Dm	0.26545

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

при взлете	2.542
в середине крейсерского участка	2.390
в начале крейсерского участка	2.481

Department of Aircraft Design				NAU 20 14Ch 00 00 00 62 EN			
Performed by	Chernov V.V.			Appendix 1	List	Sheet	Sheets
Supervisor	Yutskevych S.S.						
Adviser					AF 402 134		
Stand. contr.	Khizhnyak S.V.						
Head of Dep.	Ignatovych S.R.						

Относительная масса электрооборудования	0.0299
Относительная масса локационного оборудования	0.0046
Относительная масса навигационного оборудования	0.0067
Относительная масса радиосвязного оборудования	0.0033
Относительная масса приборного оборудования	0.0078
Относительная масса топливной системы (входит в массу "СУ")	0.0040
Дополнительное оснащение:	
Относительная масса контейнерного оборудования	0.0000
Относительная масса нетипичного оборудования [встроенные системы диагностики и контроля параметров, дополнительное оснащение салонов и пр.]	0.0017

ХАРАКТЕРИСТИКИ ВЗЛЕТНОЙ ДИСТАНЦИИ

Скорость отрыва самолета	179.43 км/ч
Ускорение при разбеге	1.66 м/с*с
Длина разбега самолета	744. м.
Дистанция набора безопасной высоты	578. м.
Взлетная дистанция	1322. м.

ХАРАКТЕРИСТИКИ ВЗЛЕТНОЙ ДИСТАНЦИИ ПРОДОЛЖЕННОГО ВЗЛЕТА

Скорость принятия решения	170.46 км/ч
Среднее ускорение при продолженном взлете на мокрой ВПП	0.13 м/с*с
Длина разбега при продолженном взлете на мокрой ВПП	1579.67 м.
Взлетная дистанция продолженного взлета	2114.89 м.
Потребная длина летной полосы по условиям прерванного взлета	2191.08 м.

ХАРАКТЕРИСТИКИ ПОСАДОЧНОЙ ДИСТАНЦИИ

Максимальная посадочная масса самолета	26608. кг.
Время снижения с высоты эшелона до высоты полета по кругу	14.5 мин.
Дистанция снижения	18.98 км.
Скорость захода на посадку	180.00 км/ч.
Средняя вертикальная скорость снижения	1.56 м/с
Дистанция воздушного участка	490. м.
Посадочная скорость	164.70 км/ч.
Длина пробега	407. м.
Посадочная дистанция	896. м.
Потребная длина летной полосы (ВПП + КПБ) для основного аэродрома	1497. м.
Потребная длина летной полосы для запасного аэродрома	1273. м.

ПОКАЗАТЕЛИ ЭФФЕКТИВНОСТИ САМОЛЕТА

Отношение массы снаряженного самолета к массе коммерческой нагрузки	3.0922
Масса пустого снаряженного с-та приход. на 1 пассажира	0.00 кг/пас.
Относительная производительность по полной нагрузке	164.02 км/ч
Производительность с-та при макс. коммерч. нагрузке	2609.7 т*км/ч
Средний часовой расход топлива	822.351 кг/ч
Средний километровый расход топлива	1.89 кг/км
Средний расход топлива на тоннокилометр	315.109 г/(т*км)
Средний расход топлива на пассажирокилометр	0.0000 г/(пас.*км)
Ориентировочная оценка приведен. затрат на тоннокилометр	1.8233 $/(т*км)