МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ

УКРАЇНИ НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ

Кафедра конструкції літальних апаратів

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
д-р техн. наук, проф.
_____________ С. Р. Ігнатович
«_____»___________2021 р.

ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)
ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ

"БАКАЛАВР"

Тема: «Аванпроект пасажирського середньомагістрального літака пасажиромісткістю до 100 осіб»

Виконав: ___________ **Ван Вей**

Керівник: к.т.н., доцент ___________ **В.І. Закієв**

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

Київ 2021

MINISRY OF EDUCATION AND SCIENCE OF

UKRAINENATIONAL AVIATION UNIVERSITY

Department of Aircraft Design

APPROVED
Head of Department
Professor, Dr. of Sc.
_________S.R. Ignatovych
«__» ______ 2021

DIPLOMA WORK

(EXPLANATORY NOTE)

OF EDUCATIONAL DEGREE

«BACHELOR»

Theme: «Preliminary design of mid-range aircraft with 100 passenger capacity»

Performed by: _________ **Wang Wei**

Supervisor: PhD, associate professor __________**V.I. Zakiev**

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

Kyiv 2021

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty

Department of Aircraft Design

Educational degree «Bachelor»

Major 134 "Aviation and space rocket technology"

APPROVED
Head of Department
Professor, Dr. of Sc.
_________S.R. Ignatovych
«__» ______ 2021

TASK

for bachelor diploma work

Wang Wei

1. Theme: «Preliminary design of mid-range passenger aircraft with 100 passenger capacity» Confirmed by Rector's order from 21.05.2021 year No 815/ст.

2. Period of work execution: from 24.05.2021 year to 20.06.2021 year.

3. Work initial data: cruise speed V_{cr}= 825 km/h, flight range L = 3000 km, operating altitude H_{op} = 10.5 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, design and analysis of an height-adjustable tray table.

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

layout ofthe airplane (A1×1); tray table drawing (A1×1)

6. Calendar Plan

Task	Execution period	Signature
Task receiving, processing of statistical data.	25.05.2021 – 27.05.2021	
Aircraft take-off mass determination.	28.05.2021 – 29.05.2021	
Aircraft centering determination.	28.05.2021 – 29.05.2021	
Graphical design of the aircraft and its layout.	30.05.2021 – 03.06.2021	
Development of height-adjustable tray table	02.06.2021 – 04.06.2021	
Completion of the explanation note.	03.06.2021 – 09.06.2021	
Preliminary defence	09.06.2021	

7. Task issuance date: 25.05.2021

Supervisor of diploma work __________V.I. Zakiev

Task for execution is given for ___________ Wang Wei

ABSTRACT

Explanatory note to the diploma work «Preliminary design of mid-range passenger aircraft with 100 passenger capacity» contains:

62 sheets, 14 figures, 8 tables, 12 references and 3 drawings

Object of the design is development of the mid-range aircraft with passenger capacity up to 100.

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 calculations of the most practical technical solutions.

The diploma work contains drawings of design of the mid-range aircraft with 100 passenger capacity, calculations and drawings of the general view and fuselage layout, design and analysis of aircraft seat table.

PASSENGER AIRCRAFT, PRELIMININARY DESIGN, CABIN LAYOUT, CENTER OF GRAVITY DETERMINATION, AIRCRAFT TRAY TABLE, STRENGTH ANALYSIS

Format	№	Designation	Name	Quantity	Notes
			General documents		
A4	1	NAU 21W 04W TT	Task of work	1	
	2		Mid-range passenger aircraft	2	
A1		NAU 21 04W 00 00 00 17 GV	General view		
A1		NAU 21 04W 00 00 00 17 AL	Fuselage layout		
A4	3	NAU 21 04W 00 00 00 17 EN	Mid-range passenger aircraft	50	
			Explanatory note		
A1	4	NAU 21 04W 25 50 00 17 AD	Documentation for assembly units	1	
			Height-adjustable tray table		

Ch.	Sheet	Doc.№	Sign.	Date	NAU 21 04W 00 00 00 17 EN		
Performed by	Wang Wei				List of diploma work	List	Sheet	Sheets
Supervisor	V.I. Zakiev							
Adviser						AF 402 134		
Stand. contr.	Khyzhnyak S.							
Head. of dep.	Ignatovych S.							

CONTENT

Department of Aircraft Design				NAU 21 04W 00 00 00 17 EN		
Performed by	Wang Wei			Content	Sheet	Sheets
Supervisor	V.I. Zakiev					
Adviser					AF 402 134	
Stand. contr.	Khizhnyak S.V.					
Head of Dep.	Ignatovych S.R.					

Introduction

With the development of aviation industry and the innovation of aircraft models in recent ten years, higher requirements are put forward for the structural strength, carrying capacity and service life of aircraft. Airliner as a means of transport, transport passengers is its main responsibility. With the continuous As the number of passengers is continuously increasing, new challenges arises in its airworthiness and comfort, reasonable hydrodynamics and overall stability.

The mission of the designed airplane is to create a mid-range airliner with not big quantity of passengers which is competitive in modern global air traffic market. To some extent, it has to satisfy some characteristics such as airworthiness, low cost, comfortable passenger experience, flight safety and reliability and ease of operation.

With safety and integrity taken in consideration, it's necessary to perform the calculation and structure accurately. Based on the present airline models, the designed aircraft combine the advantages and remain some proper characteristics.

There's also a part of new concept design of an height-adjustable tray table which is aimed at meet demand of people who have different demands towards the height of table.

The purpose of diploma project is to design a mid-range passengers aircraft which is capable of 100 passengers and an height-adjustable tray table.

1. PROJECT PART

1.1. Analysis of prototypes and short description of designing aircraft

Prototypes offer initial data and the comparison with the design. In analytical and mathematical methods, the usual engineering design process, the technique is highly iterative, involving a mixture of analysis and testing and the detailed examination of the adequacy of every part of the structure. For some types of aircraft, the design process is regulated by national airworthiness authorities. All the parameters in designing aircraft is based on initial data and calculated by specific formulas, and some of the parameters are flexible which means the performance of prototypes and experience also contribute to the design. The calculation is separated to several parts and each of them forms an important unit of the aircraft. Finally sum up all the data and the performance of the designed aircraft is clear.

1.1.1 Choice of the project data

There are three phases of aircraft design; conceptual, preliminary, and detail phases. Among them, the conceptual design phase is characterized by the initial definitions that come from requirements established by market needs.

With completing the conceptual design, the next phase is preliminary design. Engineers may use the existing designs to conduct wind tunnel testing and fluid dynamic calculations. Furthermore, structural and control analyses are performed during this stage.

During these phase, engineers must use the existing designs to fabricate the actual aircraft. It specifically determines the design, location and quantity of elements such as ribs, spars, sections and more.

The selecting of the optimal design parameters of the aircraft is the multidimensional optimization task. In its configuration mean the whole complex flight-technical, weight, geometrical, aerodynamic and economic characteristics.

The table 1.1 and 1.2 shows operational–technical and geometric parameters of three different passenger aircraft which have similar characteristic and parameters to the designed aircraft. Prototypes that were chosen for comparison are as following:

Table 1.1 - Technical data of plane prototypes

Name and dimensions	Trident 1E	ARJ21-700	A318
Cockpit crew	3	2	2
Passenger capacity	108	168	136
Flight Range with MTOW, km	3540	3700	5741
Cruise speed, km/h	937	828	829
Cruise altitude, km	11	12	12
Number and type of engines	3 Spey RB163-25 Mk511-5	2 General Electric CF34-10A	2 PW6000A
Take off run at MTOW, m	-	1900	1780
Thrust (each engine), kN	51	78.5	100
MTOW, t	58	43.5	68

Table 1.2 - Geometrical parameters of prototypes

Name and dimensions	Trident 1E	ARJ21-700	A318
Length of the fuselage, m	35	33.5	31.4
Wingspan, m	29	27	31.4
Wing area, m^2	131	80	124
Aspect ratio	6.4	9	7.8
Sweepback angle, degree	35	25	25
Max cabin width, m	3.4	3.1	3.7
Seat pitch, inch	-	31（1-class) 36（2-class）	30（1-class） 38（2-class）

Hawker introduced the Trident 1E which offered increased passenger capacity (115 - 139), a much increased fuel capacity with a higher take-off weight. This would be powered by 11,400 lbf (50.7 kN) Spey 511s, have a gross weight of 128,000 lb (58,000 kg), an increased wing area by extending the chord.

The MD-80 series molds made by McDonnell Douglas in 1980s are used in ARJ21. Therefore, the fuselage diameter, nose configuration and engine layout of ARJ21 are the same as those of MD-80 series airliners. The wing of ARJ21 is a new supercritical wing designed with 25° backward sweep and Wingtip sail.

The A318 was born out of mid-1990. The engines were to be supplied from two Rolls-Royce BR715s, CFM56-9s, or the Pratt & Whitney PW6000s; with the MTOW of 53.3 t (118,000 lb) for the smaller version and 58 t (128,000 lb) for the AE317, the thrust requirement were 77.9–84.6 kN (17,500–19,000 lbf) and 84.6–91.2 kN (19,000–20,500 lbf), respectively [1]. Range was settled at 5,200 km (2,800 nmi) and 5,800 km (3,100 nmi) for the high gross weights of both variants.

A318 narrow-body aircraft with a retractable tricycle landing gear and are powered by two wing pylon-mounted turbofan engines.It is low-wing cantilever monoplanes with a conventional empennage with a single vertical stabilizer and rudder. Its wing sweep is 25 degrees. Compared to other airliners of the same class, the A318 features a wider single-aisle cabin of 3.95 meters outside diameter, compared to 3.8 m of the Boeing 737 or 757, and larger overhead bins.

Fig. 1.2. View of A318.

1.1.2. Brief description of the aircraft the main components

There are 5 main components of an aircraft: Wings, Fuselage, Empennage, Power Plant and Landing Gear [2]. The fuselage is one of the major aircraft components with its long hollow tube that's also known as the body of the airplane, which holds the passengers along with cargo. The wings, also commonly known as foils, are aircraft parts that are imperative for flight. The airflow over the wings is what generates most of the lifting force necessary for flight. The empennage is the tail end of the aircraft. It helps with the stability of the plane and has two main components called the rudder and the elevator. The rudder helps the aircraft steer from right to left, and the elevator helps with the up and down movement. The power plant of an airplane structure includes the engine and the propeller. Not only are these parts imperative in order to land, but the landing gear is also used to help an aircraft take-off and taxi. The landing gear includes shock absorbers for a smooth landing and takeoff as well as the wheels on the plane.

1.1.3. Wing

The wing is the main part of the aircraft used to generate lift. It is generally divided into left and right wings, symmetrically arranged on both sides of the fuselage. Some parts of the wing (mainly the leading and trailing edges) can move. By controlling these parts, the pilot can change the shape of the wing and control the distribution of lift or drag to increase lift or change the attitude of the aircraft. There are many kinds of moving surfaces on the wing, such as front and rear edge high lift devices, ailerons, spoiler, flaps and so on.

The role of wings is to generate lift to support the aircraft in the air. In addition, it also plays a certain role of stability and manipulation.

The wing is composed of skin and inner frame. The basic function of the wing structure is to form the streamline shape of the wing and transfer the external load to the fuselage.

The wing structure should have enough strength, stiffness and life under external load. Sufficient stiffness not only refers to the ability of the skin to maintain the shape of the airfoil under aerodynamic loads, but also includes the ability of the wing to resist torsion and bending deformation.

1.1.4. Fuselage

The fuselage, or body of the airplane, is a long hollow tube which holds all the pieces of an airplane together. The fuselage is hollow to reduce weight. As with most other parts of the airplane, the shape of the fuselage is normally determined by the mission of the aircraft. An airliner has a wide fuselage to carry the maximum number of passengers. On an airliner, the pilots sit in a cockpit at the front of the fuselage. Passengers and cargo are carried in the rear of the fuselage and the fuel is usually stored in the wings. For a fighter plane, the cockpit is normally on top of the fuselage, weapons are carried on the wings, and the engines and fuel are placed at the rear of the fuselage [3].

In conventional aircraft the fuselage serves to accommodate the payload. The wings are used to store fuel and are therefore not available to accommodate the payload. The payload of civil aircraft can consist of passengers, baggage and cargo. The passengers are accommodated in the cabin and the cargo in the cargo compartment. Large items of baggage are also stored in the cargo compartment, whereas smaller items are taken into the cabin as carry-on baggage and stowed away in overhead stowage compartments above the seats. The cockpit and key aircraft systems are also located in the fuselage.

Today's passenger aircraft have a constant fuselage cross-section in the central section. This design reduces the production costs and makes it possible to construct aircraft variants with a lengthened or shortened fuselage.

In order to accommodate a specific number of passengers, the fuselage can be long and narrow. As the fuselage contributes approximately 25% to 50 % of an aircraft's total drag, it is especially important to ensure that it has a low-drag shape, which is connected to the fineness ratio.

Functions of fuselage:

- provision of volume for payload (passengers & cargo).
- provide overall structural integrity.
-possible mounting of landing gear, power plant and antennas.
-Pressurized for passenger comfort.
- Optimize / compromise: maximize volume, access, minimize weight, drag.

1.1.5. Tail unit

The tail of aircraft is mainly composed of horizontal tail and vertical tail.

Horizontal tail is also referred to as flat tail, its main feature is used for aircraft longitudinal balance and stability. The horizontal tail is mainly installed in the tail of the aircraft, which is a horizontal structure. The hinged part can also be adjusted by deflection. In many large aircraft or airliners, the function of horizontal tail is not only to enhance the balance ability of the aircraft itself, but also to adjust the center of gravity, because in the process of flight, the lift position can change at any time, and it is impossible to remain unchanged, and the lift can not pass through the center of gravity in all States, so a balance tool is needed to break the deadlock, The main function of the horizontal tail is to correct the moment and achieve balance.

The function of the vertical tail of the aircraft's wing is mainly to maintain the balance and stability of the aircraft's course. It is as easy to operate as the rudder. Its rear part is also known as the rudder, which can deflect through control. Therefore, many times when the aircraft turns its course, it will operate it. In addition, the role of the vertical tail is to keep the aircraft turning without side slip. It can also make the nose aim at the runway more accurately when there is crosswind, so that the aircraft does not deviate from the route.

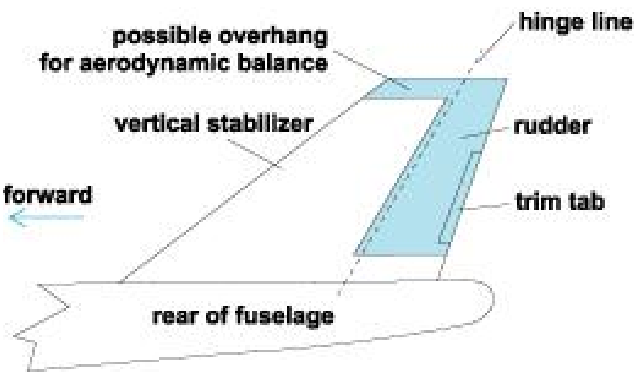

Fig. 1.3. Structure of tail unit.

Trim tab is an adjustable small airfoil which is used to trim the aircraft in flight. It can correct some unnecessary flight attitude trends of the aircraft.

The trim adjustment piece can control the balance of the aircraft. By adjusting the position of the trim tab, the rudder pressure on the three rudders can reach 0, that is, the pilot's hand can not feel the existence of rudder pressure, so as to reduce the fatigue of the aircraft [4].

The trim tab is controlled by the balancing control mechanism and deflects relative to the main control surface to change the hinge moment of the main control surface. When the main control surface is deflected, the adjusting plate has no relative deflection. The movement of aircraft center of gravity and the asymmetric change of aerodynamic force and thrust (for example, when there is an engine in a multi engine aircraft parking in the air) will destroy the balance of the aircraft. The pilot can restore the balance by manipulating the corresponding control surface, but it also increases the stick (or pedal) force. In order not to affect the normal operation of the aircraft, the pilot uses the trim control hand wheel or button to control and trim the adjustment plate to restore the original lever force. The trim tab can also be used to reduce the stick (or pedal) force in the stable flight state, so as to reduce the physical burden of the pilot for a long time flight [5].

1.1.6. Crew Cabin

Crew cabin provides the passengers a safe and comfortable environment during the flight. Except for the furnishing of the cabin, the cabin pressurization is also of great importance. Cabin pressurization is the active pumping of compressed air into the cabin of an aircraft in order to ensure the safety and comfort of the occupants. It becomes necessary whenever the aircraft reaches a certain altitude, since the natural atmospheric pressure would be too low to supply sufficient oxygen to the passengers. Without pressurization, one could suffer from altitude sickness including hypoxia.

Requirements to the equipment of passenger cabin:

Design criteria:

- Fire safety: flammability, smoke, toxicity

- Component design: Strength, weight, appearance, comfort, configuration, architecture

-Airline operations: cleanability, durability, maintainability, repairability, customization

- Manufacturing: materials availability, facilities and equipment, process complexity, reproducibility, instalation factors, cost

1.1.7. Control System

Flight control system is composed of control surface, cockpit control device, hinge and necessary mechanical mechanism to control aircraft flight.

Aircraft control system or flight control systems can be categorized into two:

Primary flight control system:

- Primary flight control system;
- Secondary flight control system.

Primary control system:

- Lateral control: ailerons.
- Longitudinal control: elevator.
- Directional control: rudder.

Secondary flight control system

- Trim control: lateral, longitudinal and directional primary flight control systems.
- High lift control: trailing edge flaps, leading edge flaps.
- Thrust (power) control: engine fuel controls (throttles), manifold gates.

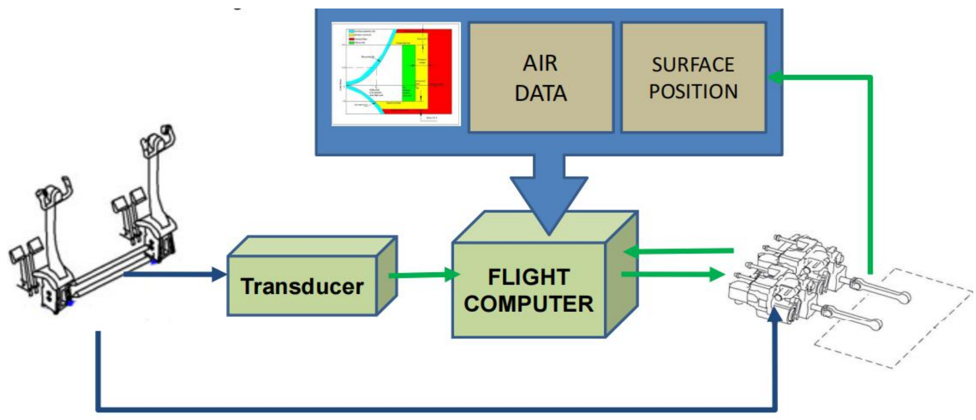

Fig. 1.4. Simplest fly-by-wire system with mechanical backup [6].

Fly by wire (FBW) is a kind of control system in the aviation field, which converts the pilot's control input into electrical signal through the converter, then processes it by computer or electronic controller, and then transmits it to the actuator through cable. It saves the mechanical transmission device and hydraulic pipeline in the traditional control system.

Mechanical and hydraulic flight control systems are heavy and need to use pulley and crank systems to carefully arrange the flight control lines through the whole aircraft. These two systems often require redundant backup devices, which further adds weight. In addition, the two systems can only provide limited compensation for the changing aerodynamic environment, and some dangerous flight characteristics such as stall, spiral and human-machine coupling oscillation may still occur. Because these flight characteristics depend on the aerodynamic and structural characteristics of the aircraft rather than the control system itself. However, by using computers and electronic connections, designers can reduce aircraft weight and improve reliability. At the same time, the use of computers can also prevent the above dangerous flight characteristics.

1.1.8. Landing gear

Aircraft landing gear supports the entire weight of an aircraft during landing and ground operations. They are attached to primary structural members of the aircraft. The type of gear depends on the aircraft design and its intended use. Most landing gear have wheels to facilitate operation to and from hard surfaces, such as airport runways. Other gear feature skids for this purpose, such as those found on helicopters, balloon gondolas, and in the tail area of some tail dragger aircraft. Aircraft that operate to and from frozen lakes and snowy areas may be equipped with landing gear that have skis. Aircraft that operate to and from the surface of water have pontoon-type landing gear. Regardless of the type of landing gear utilized, shock absorbing equipment, brakes, retraction mechanisms, controls, warning devices, cowling, fairings, and structural members necessary to attach the gear to the aircraft are considered parts of the landing gear system.

Numerous configurations of landing gear types can be found. Additionally, combinations of two types of gear are common [7]. Amphibious aircraft are designed with gear that allow landings to be made on water or dry land. The gear features pontoons for water landing with extendable wheels for landings on hard surfaces.

1.2. Main parts of the aircraft geometry calculations

The aim of this part is to calculate the parameters and build the foundation of the performance of aircraft.

1.2.1. Wing geometry calculations

The wing vertical location of designed aircraft is low wing.

The advantages for low wing are:

1. The take off performance is better compared to the high wing due to ground effect.

2. The retraction system inside the wing is an option along with inside the fuselage.

3. The passengers have a better view.

4. The wing has less induced drag. 5. The wing has less downwash on the tail, so the tail is more effective.

Wing is one of the most important components in aircraft, since the wing geometry and its features have direct effects on other components. The basic function of the wing is to generate sufficient lift force or simply lift. However, the wing has two other productions, namely drag force or drag and nose-down pitching moment. Normally, a wing should be optimized to generate more life and less drag. In fact, a wing is considered as a lifting surface that lift is produced due to the pressure difference between lower and upper surfaces.

In order to design a wing with excellent properties, it’s necessary to make it clear that the characteristics of the prototype we refer and do it by regular steps. A qualified wing should be considered the Primary stability and control requirements include lateral-directional stability [8], and aircraft controllability during probable wing stall.

Wing area:

$$S_w = \frac{m_o \cdot g}{P_o} = \frac{48103 \ * 9.8}{5.108\,k} = 92.3\text{m}^2$$

Wing span:

$$l\text{w} = \sqrt{\lambda \cdot \text{S}w} = \sqrt{9.6 * 92.3} = 29.8\text{m}$$

Root chord:

$$\text{b}_o = \frac{2 \cdot S_w \cdot \eta}{(1+\eta)l} = \frac{2*92.3*4.1}{5.1*29.8} = 5\text{m}$$

Tip chord:

$$\text{b}_t = \frac{b_o}{\eta} = \frac{5}{4.1} = 1.2\text{m}$$

Aileron is a part of primary control surface of aircraft, which primarily controls the roll movement. It occupies at least 30 percent of the wing span and the rest is for flap. Three key parameters considered for the design of aileron are aileron span, aileron area and aileron deflection.

Aileron span:

$$L_{ai} = 0.375 * \frac{l_w}{2} = 0.375 * \frac{29.8}{2} = 5.588\text{m}$$

Aileron area:

$$\text{S}_{ai} = 0.065 * \frac{S_w}{2} = 0.065 * \frac{92.3}{2} = 3\text{m}^2$$

Aileron deflection: Upward $\delta'ail \geq 20^\circ$; Downward $\delta''ail \geq 10^\circ$

Aileron chord: for one slotted flap: $b_{ai} = 0.28 \cdot b_i$

Axial $S_{axinail} = 0.26 \cdot S_{ail} = 0.78\ m^2$

Inner axial compensation:

$$S_{inaxinail} = 0.3 \cdot Sail = 0.9\ m^2$$

The aim of high lift device is to make the airplane obtain good characteristics of wing performance. By increasing the length of camber and area of wing, and supplying energy to boundary layer [9], lift coefficient can be largely increased and the stall angle as well. This is the most important idea that HLD is designed for.

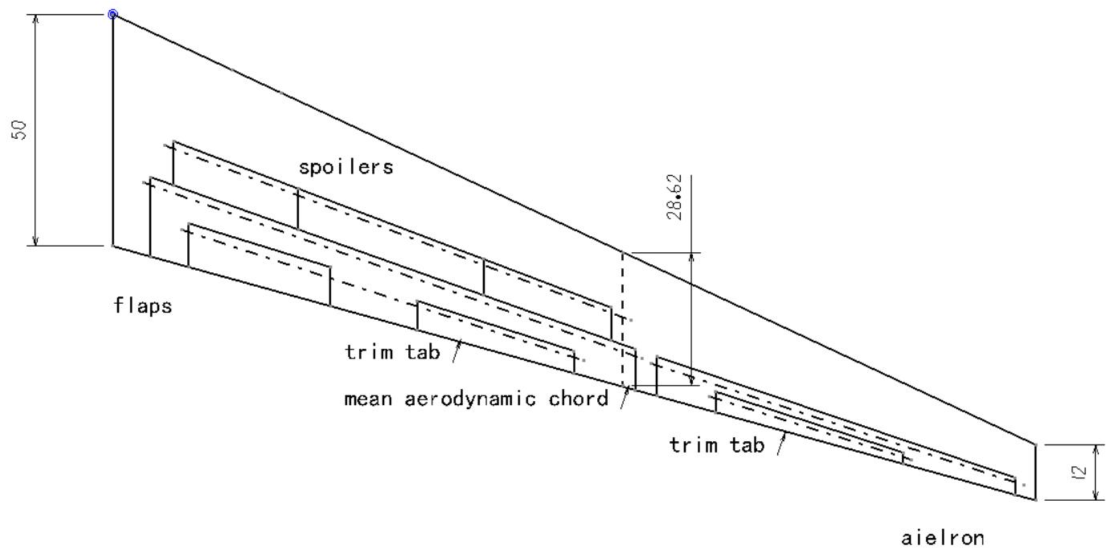

Fig. 1.5. Geometrical graph of right wing.

Mean aerodynamic chord b_{mac} = 2.862 m

1.2.2. Fuselage layout

The designed fuselage cross-section is circular in shape, which is done for two reasons:

1. By eliminating corners, the flow will not separate at moderate angles of attack or sideslip.

2. When the fuselage is pressurized, a circular fuselage can resist the loads with tension stresses, rather than the more severe bending loads that arise on non-circular shapes.

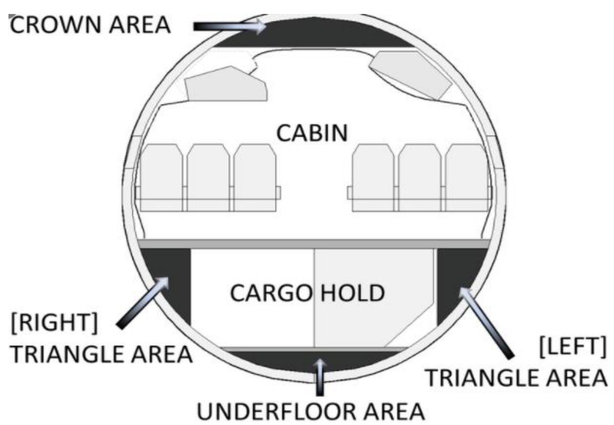

Fig. 1.6. Fuselage cross section.

Fuselage fineness ratio: $\lambda_f = 10.1$

Fuselage length:

$$l_f = \lambda_f \cdot D_f = 9.6 * 3.4 = 32.64m$$

Fuselage nose part aspect ratio:

$$\lambda_{fnp} = \frac{l_{fnp}}{D_f} = \frac{7.14}{3.4} = 2.1$$

Length of fuselage rear part:

$$l_{frp} = \lambda_{frp} \cdot D_f = 3.64 * 3.4 = 12.376m$$

For economy class:

$$B_{cabeconomy} = 2b_{2block} + b_{aisle} + 2\delta = 2*980 + 55 + 2*30 = 3.01m$$

Length of economy cabin:

$$L_{cab} = L_1 + (n_{rows} - 1)L_{seatpitch} + L_2 = 1200 + (22-1)800 + 300 = 18.3m$$

For business class:

$$B_{cabebusiness} = 2b_{2block} + b_{aisle} + 2\delta = 2*1030 + 60 + 2*20 = 3.06m$$

Length of business cabin:

$$L_{cab} = L_1 + (n_{rows} - 1)L_{seatpitch} + L_2 = 1200 + (3-1)900 + 300 = 3.3m$$

Height of cabin:

$$H_{cab} = 1.48 + 0.17 B_{cabeonomy} = 1.48 + 0.17 * 3.01 = 1.99 m$$

1.2.3. Luggage compartment

The max unit load on the floor is K = 500 kg/m²

Area of cargo compartment:

$$S_{cargo} = \frac{M_{bag}}{0.4K} + \frac{M_{c\arg o\ \&\ mail}}{0.6K} = \frac{20*100}{0.4*500} + \frac{15*100}{0.6*500} = 15m^2$$

Volume of argo compartment:

$$V_{c\arg o} = v \cdot n_{pass} = 0.2*100 = 20m^3$$

1.2.4. Galleys and buffets

The galley design is from the international rules that the volume is equal to 0.1 * total passenger number.

Volume of galley:

$$v_{galley} = 0.1 \cdot n_{pass} = 0.1*100 = 10m^3$$

Area of galley:

$$S_{galley} = \frac{v_{galley}}{H_{cab}} = \frac{10}{2.01} = 5m^2$$

Number of meals per passenger breakfast, lunch and dinner – 0,8 kg; tea and water – 0,4 kg

1.2.5. Lavatories

Number of toilet facilities is determined by the number of passengers and flight duration.

Approximate flight duration:

$$t = \frac{range}{cruise} + 0.5 = \frac{2900}{830} + 0.5 \approx 4h$$

The number of toilet according to the principle that 1 toilet for 50 passengers.

The number of toilets:

$$n_{lav} = 2$$

Area of each lavatory:

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

1.2.6. Layout and calculation of basic parameters of tail unit

Tail unit is an important part of airplane movement control, which controls yaw and pitch movement. To calculate the tail unit, there are two parameters set such such as static coefficient of horizontal and vertical tail unit, and it's also possible to get some parameters from the prototype.

$A_{HTU} = 0.72$; $A_{VTU} = 0.1$

Arm of horizontal tail unit:

$$L_{HTU} = 3*b_{mac} = 8.5 \text{ m}$$

Arm of vertical tail unit:

$$L_{VTU} = 10\text{m}$$

Area of horizontal tail unit:

$$S_{HTU} = \frac{A_{HTU} \cdot S_w \cdot b_{mac}}{L_{HTU}} = \frac{0.72*92.8*2.862}{8.5} = 22.58\text{m}^2$$

Area of vertical tail unit:

$$S_{VTU} = \frac{A_{VTU} \cdot l_w \cdot S_w}{L_{VTU}} = \frac{0.1*29.8*92.8}{10} = 27.65\text{m}^2$$

Area of elevator:

$$S_{ele} = 0.35*S_{HTU} = 6.83\text{m}^2$$

Area of rudder:

$$S_{rud} = 0.4*S_{VTU} = 5.56 \text{ m2}$$

Balance area of elevator:

$$S_{elebalance} = 0.21*S_{ControlSurface} = 7.58 \text{ m}^2$$

Balance area of rudder:

$$S_{rudbalance} = 0.19*S_{ControalSurface} = 6.86\text{m}^2$$

Area of trim tab in elevator:

$$S_{trimEle} = 0.1*S_{ele} = 0.683 \text{ m}^2$$

Area of trim tab in rudder:

$$S_{trimRud} = 0.05*S_{Rud} = 0.278 \text{ m}^2$$

Span of horizontal tail unit:

$$L_{HTUSpan} = 0.4*L_w = 11.92\text{m}$$

Chord of horizontal tail unit:

$$b_{tipHTU} = \frac{2S_{HTU}}{(\eta_{HTU}+1)L_{HTU}} = \frac{2*22.58}{(2.3+1)8.5} = 1.61m$$

$$b_{rootHTU} = \eta_{HTU} \cdot b_{tipHTU} = 2.3*1.61 = 3.7m$$

Chord of vertical tail unit:

$$b_{tipVTU} = \frac{2S_{VTU}}{(\eta_{VTU}+1)L_{VTU}} = \frac{2*27.65}{(2+1)10} = 1.84m$$

$$b_{rootVTU} = \eta_{VTU} \cdot b_{tipVTU} = 2*1.84 = 3.72m$$

Height of horizontal tail unit:

$$H_{HTU} = 0.18*L_W = 5.31m$$

1.2.7. Landing gear design

In the designed aircraft , the main landing gears are attached in the wings, and form a triangle with the nose landing gear. And there are two tyres on each landing gear.

Whale base is determined by the load proportion that nose and main lading gear take and center of gravity [10]. According to the prototype and the designed nose part landing gear takes about 11% total mass, the whale base can be calculated.

$L_f = 32.64m$

Whale base:

$$B = 0.481 \cdot L_f = 15.69 \text{ m}$$

Whale track

$$T = 0.4 \cdot B = 0.4*16.04 = 6.416m$$

Table 1.3 - Landing gear tyre choice

Main gear		Nose gear	
Tyre size	Ply rating	Tyre size	Ply rating
H36×12.0-18	18	20.5 x 6.75-10	1

1.2.8. Choice and description of power plant

The General Electric CF34 is a civilian high-bypass turbofan developed by GE Aircraft Engines from its TF34 military engine. The CF34 is used on a number of business and regional jets, including the Bombardier CRJ series, the Embraer E-Jets, and the Chinese ARJ21.

Table 1.4 - CF34 main technical characteristics

Model	Thrust	Bypass ratio	Dry weight	Thrust-to weight ratio
CFM34-8E	14,500 lbf (64 kN)	5:1	2,600 lb (1,200 kg)	5.6:1
CFM34-10A	17,640 lbf (78.5 kN)	5.4:1	3,700 lb (1,700 kg)	5.1:1
CFM34-10E	20,360 lbf (90.6 kN)	5.4:1	3,700lb(1,700kg)	5.2:1

CF34 series engine is suitable for the choice of power plant. The key design features of CF34-10a include: using wide chord fan to increase thrust and enhance the tolerance against foreign object damage; Three dimensional aerodynamic design is adopted for compressor blades to improve efficiency, achieve surge free operation, reduce fuel consumption and improve exhaust temperature margin; The low emission single annular combustor with high durability meets or surpasses the most stringent emission standard; And the use of single-stage high-pressure turbine to reduce the cost.

1.3. Determination of the aircraft center of gravity position

The mass of the equipped wing consists of the structure, the equipment placed in the wing and the fuel. Despite of the place of mounting (to the wing or to the fuselage), the main landing gear and the front gear are included in the equipped wing. The mass includes some of the objects, mass themselves and their center of gravity coordinates. The origin of coordinate of the mass centers is chosen by the projection of the nose point of the mean aerodynamic chord (MAC).

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

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

1.3.1. Trim-sheet of the equipped wing

Table 1.5 - Centre of gravity calculation of the wing

N	Object name	Mass		G coordinates, X_M	Moment of mass
		Units	total		
1	Wing (structure)	0.12034	5788.71502	1.25928	7289.61305
2	Fuel system	0.0061	293.4283	1.25928	369.5083896
3	Airplane control, 30%	0.00222	106.78866	1.7172	183.377487
4	Electrical equipment, 10%	0.00336	161.62608	0.2862	46.2573841
5	Anti-ice system, 50%	0.01145	550.77935	0.2862	157.63305
6	Hydraulic system, 70%	0.01351	649.87153	1.7172	1115.959391
7	Equipped wing without landing gear and fuel	0.15698	7551.20894	1.213361837	9162.348752
9	Nose landing gear	0.0054	259.7562	-14.45934	-3755.903213
10	Main landing gear	0.03613	1737.96139	1.23066	2138.839564
11	fuel	0.21139	10168.49317	1.44	14642.63016
	Total	0.4099	19717.4197	1.125295074	22187.91527

1.3.2 Trim-sheet of the equipped fuselage

Table 1.6 - Center of gravity of the fuselage

N	Object name	Mass		C.G coordinates Xi, м	Moment of mass
		Units	total		
1	fuselage	0.12654	6086.95362	16.32	99339.08308
2	Horizontal tail	0.01245	598.88235	33	19763.11755
3	Vertical tail	0.01426	685.94878	33	22636.30974
4	Navigation equipment	0.0051	245.3253	2	490.6506
5	Radio equipment	0.0026	125.0678	1	125.0678
6	radar	0.0034	163.5502	0.5	81.7751
7	Instrument panel	0.006	288.618	2.5	721.545
8	Flight control system,70%	0.00518	249.17354	16.32	4066.512173
9	Hydraulic system, 30%	0.00579	278.51637	22.848	6363.542022
10	Anti ice system, 25%	0.005725	275.389675	26.112	7190.975194
	Airconditioning system, 25%	0.005725	275.389675	16.32	4494.359496
11	Electrical equipment	0.0336	1616.2608	16.32	26377.37626
12	Lining and insulation	0.0098	471.4094	16.32	7693.401408
13	Load devices equipment	0.0168	808.1304	16.32	13188.68813
14	Not typical equipment	0.0053	254.9459	14	3569.2426
15	Additional equipment(emergency equipment)	0.01358	653.23874	16.32	10660.85624
16	Operational items		864.76	20	17295.2

17	Furnishing:				
	lavatory1, 20%	0.00146	70.23038	5.15	361.686457
	lavatory2, 20%	0.00146	70.23038	24.87	1746.629551
	galley 1, 30%	0.00219	105.34557	5.15	542.5296855
	galley 2, 30%	0.00219	105.34557	24.87	2619.944326
18	Passenger equipment:				
	passenger seats (economy class) Block of 3 19kg per pair		570	17.9	10203
	passenger seats (business class) Blcok of 2 16 kg per pair		192	8.7	1670.4
	Seats of flight attendances		20	9	180
	Seats of pilots		30	2.5	75
19	Engines(-fuel system)	0.09643	4638.57229	24.88	115407.6786
20	Equipped fuselage without payload		19743.28474	19.08824068	376864.571
21	on board meal		120	15	1800
	Baggage, cargo, mail		2000	18	36000
22	Passengers		6800	17.7	120360
23	crew		310	10	3100
	TOTAL	0.602317626	28973.28474	18.57312955	538124.571

1.3.3 Calculation of center of gravity positioning variants

After fill in the tables which contains the weight and mass moment of every part, the equilibrium of mass moment which is calculated on the nose part of fuselage can be listed:

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

And X_{MAC} is the distance from the nose part of fuselage to the point which is intersected by the leading edge of wing and mean aerodynamic chord.

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

The result: X_{MAC} = 17.885m

Table 1.7 - Calculation of C.G. positioning variants

Name	Mass, Kg	Coordinate	Mass moment
object	m_i	C.G., M	Kg.m
equipped wing (without fuel and landing gear)	7551.20894	21.45752931	162030.2872
Nose landing gear (extended)	259.7562	4.403303084	1143.785277
main landing gear (extended)	1737.96139	20.09330308	34921.38496
fuel/fuel reserve	10168.49317	19.95920308	202955.0202
equipped fuselage (without payload)	19743.28474	19.08824068	376864.571
on board meal	120	15	1800
Baggage, cargo, mail	2000	18	36000
Passengers	6800	17.7	120360
crew	310	10	3100
nose landing gear (retracted)	259.7562	3.403303084	884.0290766
main landing gear (retracted)	1737.96139	20.09330308	34921.38496
reserve fuel	1787.5	19.78	35356.75
Total	52475.92203	19.25334846	1010337.213

Table 1.8 – Airplanes C.G. position variants

Назва об'єкта	Маса, m_i кГ	mass moment m_iX_i	center of mass $X_{цм}$	center X_C %
take off mass (L.G. extended)	48690.70444	939175.0486	19.28859028	0.268828512
take off mass (L.G. retracted)	48690.70444	938915.2924	19.28325546	0.266964493
landing weight (LG extended)	40309.71127	771576.7784	19.14121322	0.217334081
ferry version	39770.70444	780755.2924	19.63141723	0.388614307
parking version	29292.21127	574960.0284	19.62842692	0.387569476

1.4. Conclusions for the project part

The project part does some analytical and mathematical design and defines these achievements:

- Preliminary design of mid range passenger aircraft with 100 passenger capacity;
- Performance of aircraft and cabin layout;
- Center of gravity with five kinds of situations of aircraft from 21.7 to 38.9;
- Selections of tyres of landing gear. The size of main and nose wheel is H36×12.0-18 cm, 20.5 x 6.75-10 cm.
- Choice of power plant of the aircraft, which is CF34 series;

In this part, several main components of aircraft are mentioned to describe their function and general performance: fuselage, wings, empennage, power plant and landing gear. They forms the integrity of an aircraft and collaborate to maintain the normal state of aircraft.

The geometry parameters are calculated based on the initial data and the formulas. By the scientifically analytical method of structure geometry design and through the optimization and adjustment of the calculation parameters, the relatively reliable aircraft performance is obtained.

The result of preliminary design of mid-range passenger aircraft has shown a relatively optimized geometry shape and aerodynamic parameters compared with the prototypes, which makes it stand a chance in the competition of similar passenger airplane market.

2. SPECIAL PART

Aircraft Seating Market is a huge market all around the world, the market size was valued at over USD 10.26 billion in 2020 and is projected to grow at a CAGR of more than 6.5% from 2021 to 2027. According to ICAO, scheduled passengers are predicted to grow to about 10 billion by 2040 from 4.5 billion in 2019.

Over the past few decades, there's great progress in the airworthiness, aerodynamic configuration and safety of aircraft and so on. And the comfort of passengers have made some progress either, such as the new material and ergonomical shape of seat in use, the more reasonable structure design and space utilization of cabin. However, it is still a challenge to improve the flight experience for passengers. One important reason is the seat pitch is shrinking over the past few decades in order to cut the cost and reverse the loss-making situation.

In the situation of increasing demand of airplane transport and the better experiences of the passengers, the concept of height-adjustable tray table is designed to satisfy the demand. Different from the innovation in material or the functionality of the table, the height-adjustable table focus on the mechanism of the structure, which is friendly to people who have different demands towards the table height.

Tray table is an necessary equipment in the cabin of airliner and is one of the equipment that has been used for a long time. As of the most recognizable aspects of air travel is the folding tray table, they are used by passengers for a variety of purposes including eating meals or as a work space. Except for the comfort of the seat, a well designed tray table can also bring the passengers an excellent flight experience.

The height-adjustable tray table is designed to be able to adjust the height of the table. The property of being retractable is aimed to meet the demand of passengers who have different requirements towards the height of the table.

In the present modern airplane market, the table attached to the back of the seat, can be released to an angle and some of them is designed to be folded in order to save room. Different versions of airplanes have variable manufacture regulation and design concept of the passenger equipment. Although the styles and concept of their tables attached to the passenger seats shows great diversity, they have similar basic function: to make the table foldable and capable of holding certain loads on it. Nevertheless, the height of the tables is fixed, probably causing unsatisfied experience for specially tall people during the flight. So the concept of height-adjustable table (see in Appendix A, Fig, 1.) originates from this view, which provides more comfortable experience when passengers use the table.

2.2. Mechanism Principle of a height-adjustable tray table

The principle of the mechanism is operating-friendly. To make the table movable, there’s a button located right at the back of the support arm.

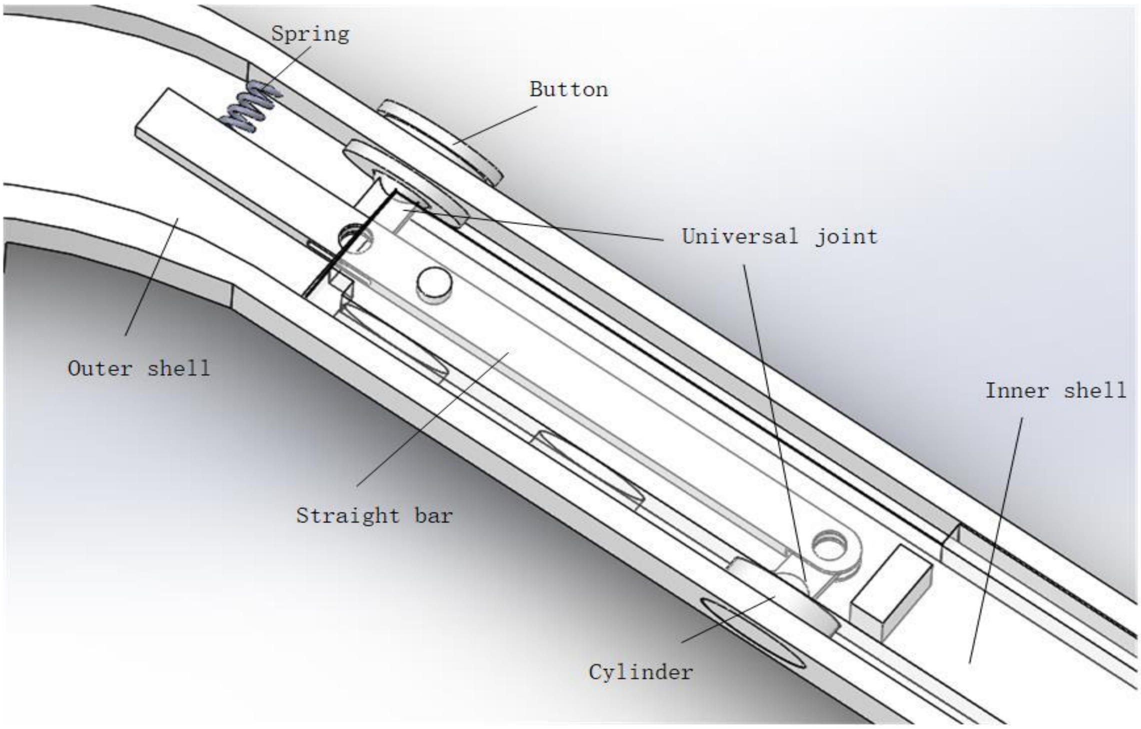

Fig. 2.1. Components and structure of the support arm.

With the button pushed down, the inner and outer shells are separated, and this is the state when the table can be pulled up or pushed down. Also, they can be restricted when the holes coincide and cylinder inserts into the holes. The total span of the arm is 5cm with each 2.5 cm.

The core of the table is the retractable arm which connects the passenger seat and the table. The mechanism system consists of several elements which is shown in the Fig. 2.1. above.

The arm consists of:

- inner shell
- outer shell
- straight bar
- button
- universal joint
- cylinder
- spring

In norm state, the spring is in tension state and it transfers a force to maintain the cylinder inserting into the holes. And when the button is pressed, the cylinder comes out of the hole to make the outer shell able to move.

In the process of moving, there's no force required to press the button, and the cylinder will insert into the next hole by the pushing force which is produced by the spring and transferred by the bar.

The moving span is limited by extruded barrier which is shown in Fig. 2.2. below and is also limited by the small space. Once the cylinder reaches the barrier, the wall around the cylinder holds it still and immobilizes it and that prevents the motion of the outer shell.

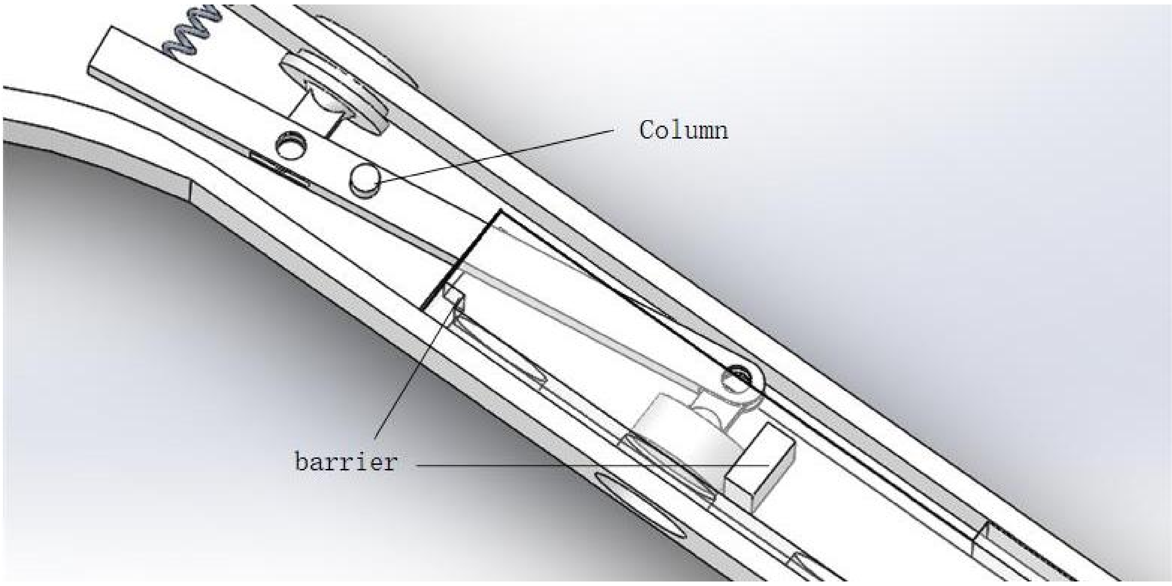

Fig. 2.2. The barrier limitation and column.

As is shown above, the mechanism structure pivots from the column fixed in the outer shell, which forms a lever. The ratio of effort arm to the load arm equals to 5, and this makes it not easy to press the button accidentally in case some unexpected things happen. On the other hand, the arm ratio also save the space, since there's only little space remained for the structure.

2.3. Material choice and analysis

There are several choice of the material, and to make selection for material, it's necessary to compare their characteristic.

Known as "the metal of modern life," aluminum is lightweight yet durable. Its versatile, non-toxic, and corrosion resistant surface makes aluminum the ideal material for more fuel-efficient cars, electronics, and buildings. Finally, its highly recyclable characteristic explains why a large percentage of all aluminum produced in the world is still in use today.

Aluminum alloy is the main material for aircraft manufacturing. Compared with mild steel used in automobile manufacturing, aluminum alloy is more expensive and less dense, with a relative density of 2.8. Compared with mild steel with a relative density of 7.8, it is about one-third lighter. Although the strength difference is not much, for aircraft, light material is the most important, with strong corrosion resistance and convenient processing. Therefore, aluminum alloy is the most ideal material for aircraft manufacturing.

The support arm is the base of the system used to hold and restrain the table in place. It is thus the most fundamental support in providing rigidity for the table, and must be sufficiently stiff to prevent deflection and sufficiently strong to prevent fracture under the varying loads that the table may sustain [11]. Additionally, it is imperative that the support arm is as lightweight as possible to prevent unnecessarily increasing the overall weight of the aircraft. Based on the properties researched above, 6061-T6 aluminum was chosen to be the best suited for the part.

6061 is mainly composed of magnesium and silicon, concentrating the advantages of 4000 and 5000 series. It is a cold-treated aluminum forging product, which is suitable for applications with high requirements of corrosion resistance and oxidation resistance. Good usability, excellent interface characteristics, easy coating and good processability. It can be used in low-pressure weapons and aircraft joints.

6061 T6 Aluminum was considered the best suitable, because of its popularity in the aeronautical industry, ease of machinability and acceptable mechanical properties. It would offer also a compatible interface with the aluminum support tube of the same alloy.

And other components are suitable for low-carbon steel. As one of the most widely used steel metal, carbon steel is highly malleable and comes in a range of carbon content levels. Low-carbon steel is popular for its strength and low-cost, while high-carbon steel finds more niche opportunities in due to lighter weight and ability to hold a finely sharpened edge.

The material for the table is composite material. It is a combination of two materials with different physical and chemical properties. And the created material is specialized to do a certain job, for instance to become stronger, lighter or resistant to electricity. They can also improve strength and stiffness. The reason for their use over traditional materials is because they improve the properties of their base materials and are applicable in many situations.

2.4. Strength calculation of components

The strength calculation is of vital importance to the this design, for it concerns about whether it is usable for passengers. Knowing the material of the structure, it is needed to list a series of equation and the analyze the load direction and distribution of it. Basically, there are two parts of calculation that is necessary to analyze: the support arm and the straight bar.

2.4.1. Strength calculation of the support arm

The support arm is a hollow shell and consists of two pieces of separate shell and still have several holes on them. However, it is too complicated to take the holes into the calculation. So to simply the model as much as possible, the holes are not taken into consideration and the arm is considered as one rod. The load on it is originated from the pressure of the table, and the support is the hinge at the bottom and a small area support which is shown below.

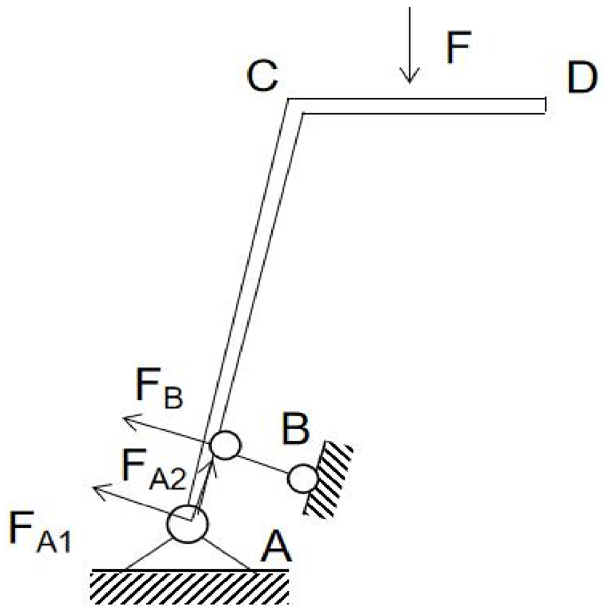

Fig. 2.3. The simplification of model load analysis.

The arm is supported by a hinge A and a wall named B, and the load is F. The force at the point A is decomposed of two parts: one along the rod and the other is perpendicular to the rod.

For the direction along the rod:

$$F_{A2} - F * \cos 23^\circ = 0$$

For the direction perpendicular to the rod:

$$\mathrm{F}_{A1} + \mathrm{F}_{B} - F * \sin 23^\circ = 0$$

Sum of bending moment at A is zero:

$$\mathrm{F}_{B} * |AB| - F * (|\frac{CD}{2}| + |AC| * \sin 23^\circ) = 0$$

Initial data:

|AB| = 0.02m; |AC| = 0.35m (the max length); |CD| = 0.12m

And suppose that the table is subject to a normal weight of 30 kg, after taking the self-weight into consideration, each side takes 16 kg.

Approximately, F = 160 N

Calculation results:

F_{A1} = -1835.24N; F_{A2} = 147.28N; F_B = 1897.76N. The negative value means the F_{A1} goes the opposite direction.

Next to determine the stress distribution of the support arm AC.

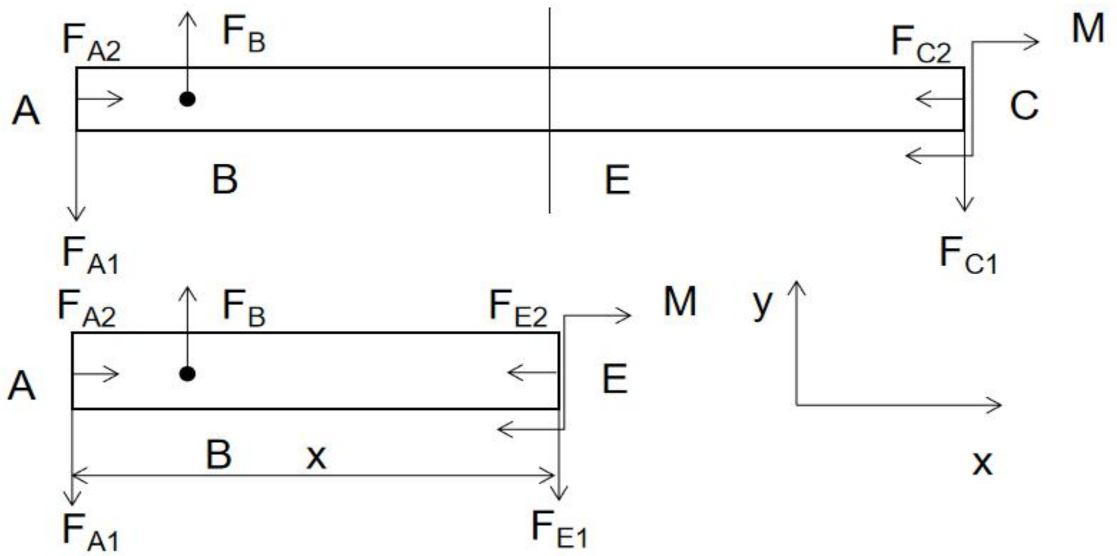

Fig. 2.4. Force analysis of rod AC.

It is necessary to analyze the stress in the two cross sections: AB and BC. And take E as the cross section of BC as an example, list the equations.

For the x axis:

$$F_{A2} - F_{E2} = 0$$

For the y axis:

$$F_B - F_{A1} - F_{E1} = 0$$

Define the distance from A to the cross section is x, then the M is an equation of x:

$$F_B * (x - 0.02) + M - F_{A1} * x = 0$$

Calculation results:

F_{E2} = 147.28N; F_{E1} = 62.52N; M = -62.52x + 36.70 N • m

And do the same calculation to the cross section between AB, then we can draw the graph of the shear force and bending moment.

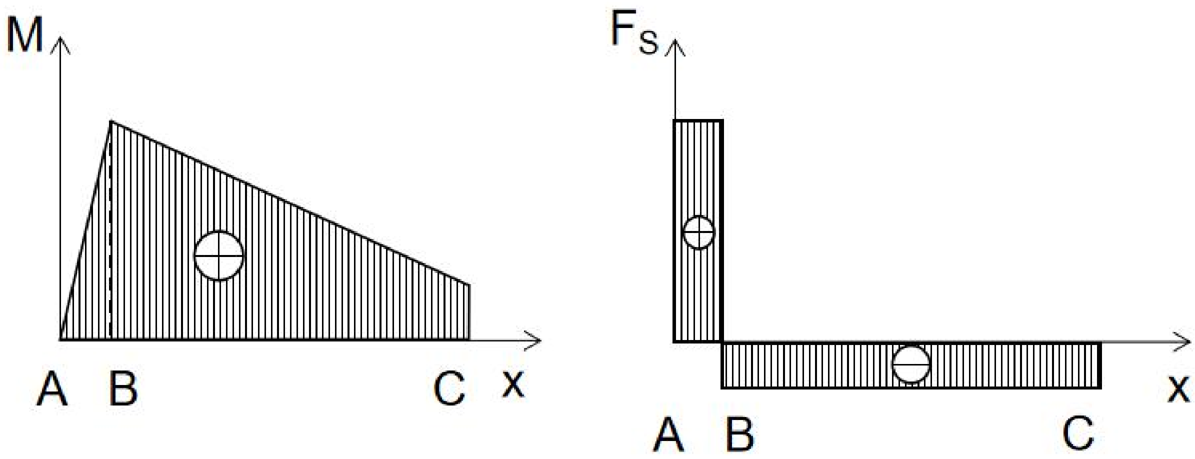

Fig. 2.5. Shear force and bending moment graph.

It is easily seen from it that the dangerous cross section is located at B. The upper surface is subject to tensile stress, the lower surface is subject to compressive stress. There's also a compress stress due to F_{E2}, so the max normal stress point at the cross section B is the lowest point.

Next step is to check the stress. Basically there are several theories of failure, however the most suitable theories in this case are Maximum Shear Stress theory and Maximum Distortion Energy theory. In general, the Maximum Shear Stress theory is safer than the Maximum Distortion Energy theory and the latter is closer to the experiment result. So Maximum Shear Stress theory is the check method of material for the sake of safety.

The criterion of it:

$$\sigma_{r3} = \sigma_1 - \sigma_3 \leq [\sigma]$$

Where [σ] is the allowable stress of material:

$$[\sigma] = \frac{Yield}{N} = \frac{276}{2.5} = 110.4\text{MPa}$$

Where N is the safety factor.

$$\sigma_1 - \sigma_3 = \sqrt{\sigma^2 + 4\tau^2}$$

Where $\tau = F_{A1} = 1835.24$N.

$$\sigma = \frac{F_{E2}}{A} + \frac{My}{I_z}$$

Where A - area of the cross section; y - the distance to neutral surface; I_z - moment of inertia

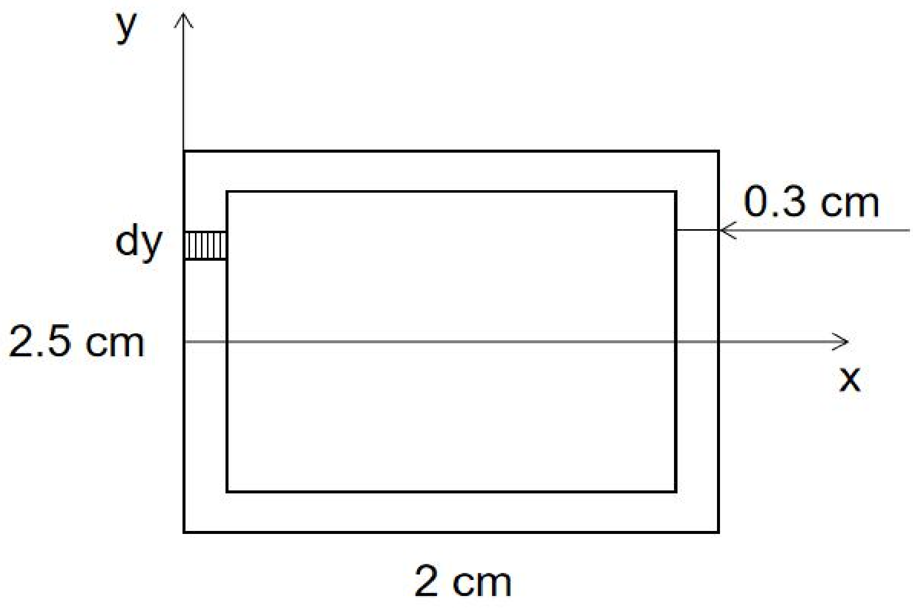

Fig. 2.6. Cross section of the simplified model.

The area of cross section:

$$A = 0.3\times 2.5\times 2 + 1.4\times 0.3\times 2 = 2.34\times 10^{-4} m^2$$

The moment of inertia:

$$I_z = 4\int_0^{1.25} 0.3y^2dy + 2\int_{0.95}^{1.25} 1.4y^2dy = 1.804\times 10^{-8} m^4$$

Finally we get the result of σ_{r3} :

$$\sigma_{r3} = \sigma_1 - \sigma_3 = 30.4\text{MPa} < 110.4\text{MPa}$$

So according to the Maximum Shear Stress theory, the stress of material is within a safe scale.

2.4.2. Strength calculation of the transfer bar

The transfer bar connects the button and the cylinder which is under the pressure of the outer shell. So if the passenger wants to press the button, he needs to get over the friction transferred through the transfer bar (see the model in Appendix A, Fig. 2.). To make the calculation simpler, the holes are removed and the cross section uniformly remains as square.

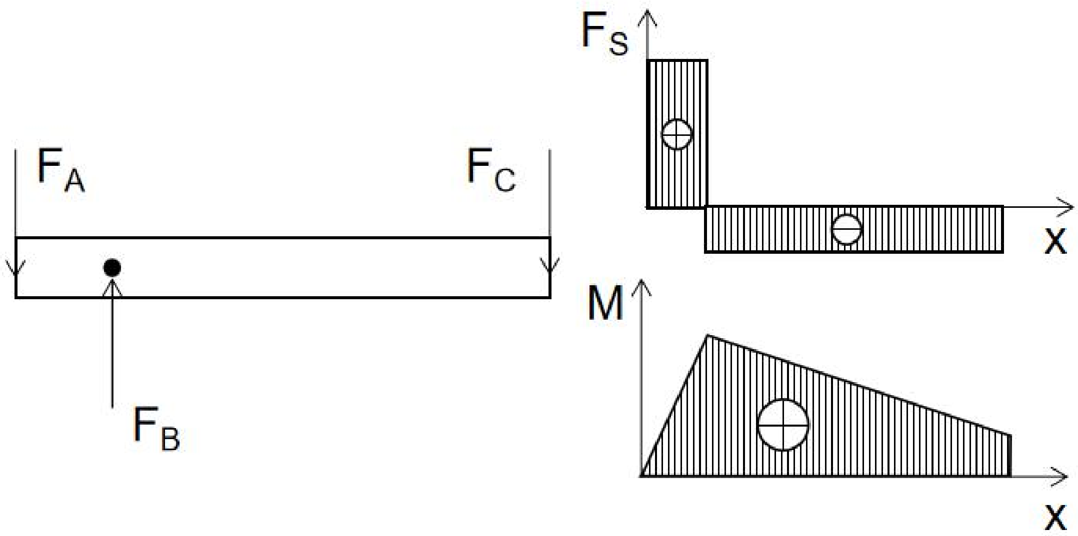

Fig. 2.7. Force analysis of transfer bar.

The max stress cross section is B. And here use Von Mises yield criterion to check the strength of transfer bar. Suppose the cylinder takes a load 60N, the friction coefficient μ between cylinder and the hole is 0.24.

F_C is equal to the friction force:

$$F_c = F_N * \mu = 160 * 0.24 = 38.4\text{N}$$

The force along the y axis:

$$F_A - F_B + F_C = 0$$

Sum of bending moment at C is zero:

$$F_A * |AC| - F_B * |BC| = 0$$

Where |AC| = 0.06m; |BC| = 0.05m

The force calculation results:

F_A = 192 N; F_B = 230.4N; F_C = 38.4N

The criterion of it:

$$\sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]} \le [\sigma]$$

To obtain the principle stresses σ_1 σ_2 σ_3:

$$\begin{matrix}\sigma 1 \\ \sigma 3\end{matrix} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}{}^2}$$

$\tau_{xy} = F_A = 192N$; $\sigma_y = 0$

The inertia moment of the cross section:

$$I_Z = \frac{bh^3}{12} = 1.118 \times 10^{-10}\,\mathrm{m}^4$$

Where b - the width, 0.008m; h - the height, 0.0056m

$$\sigma_x = \frac{My}{I_Z} = \frac{1.92 \times 2.8 \times 10^{-3}}{1.118 \times 10^{-10}} = 45.6\mathrm{MPa}$$

The results of principle stresses:

$$\sigma_1 = 46.0\mathrm{MPa};\quad \sigma_2 = 0;\quad \sigma_3 = -0.4\mathrm{MPa}$$

Check of the strength:

$$\sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]} = 46.4\mathrm{MPa} < [\sigma]$$

According to the Von Mises yield criterion, the design strength of transfer bar is safe [12].

General Conclusion for special part

In the situation of increasing demand of airplane transport and the better experiences of the passengers, the concept of height-adjustable tray table arises to satisfy the demand to people who have different demands towards the table height.

This special part analyzes and concludes it from the perspectives of market view, mechanism principle, material and strength calculations. According to the research of tray table market and relevant innovation, it has a relatively large market now and future. And it also differs from main kinds of innovation which focus on the functionality of table itself and material. To sum up, there are two main advantages of the height-adjustable tray table.

The first advantage is operating-friendly. With a safe weight of 30kg, the support arm of the table is able to retract freely. The operation requires pressing the button when holding the arm, and the cylinder inserted into the hole will goes inside, and the outer shell is loosed. If the passenger wants to stop at the middle gear, he doesn't need to keep pressing it when finishing the first step. Just by slowly moving the arm upward, the arm will stop when the cylinder coincides with the middle gear hole.

The second advantage is light weight and space-saving. The number of seats is big in a aircraft and every seat has two table arms, so the weight is a factor to cut the fuel consuming. In this design, the shell dimension is relatively normal as others in market, and the structure is hallow. So there's not much differences in weight compared with general tray table. Additionally, the mechanism is installed inside, which means the extra structure doesn't occupy space between seats. It saves the valuable room in space of passengers.

The height-adjustable tray table has its own advantages, operating-friendly, light weight and space-saving. It is a unique product that differs from the innovation which focus on the functionality of table and material. In the journey of the flight, it is a product for passengers to have a better experience.

General Conclusions

The project part and special part does some analytical and mathematical design and defines these achievements:

- Preliminary design of mid-range passenger aircraft with 100 passenger capacity;
- Performance of aircraft and cabin layout;
- Center of gravity with five kinds of situations of aircraft from 21.7 to 38.9;
- Selections of tyres of landing gear. The size of main and nose wheel is H36×12.0-18 cm, 20.5 x 6.75-10 cm;
- Choice of power plant of the aircraft, which is CF34 series;
- The design and modeling of an height-adjustable tray table;
- The choice of material of the height-adjustable tray table;
- The force analysis and strength calculation of tray table components;

The project part and special part complete the preliminary design of mid-range aircraft with 100 passenger capacity, and an design of height-adjustable tray table in aircraft. It introduces and describes the function and the construction and main parts of aircraft, and make calculations of the geometry parameters and define the layout. A parameter-optimized aircraft shows its geometry parameter, the aerodynamic performance and fuselage layout.

The height-adjustable tray table is capable of satisfying the demand of people who have different demand towards the height of table. With its operating-friendly, lightweight and space-saving advantages, it can bring a better flight experience to passengers.

References

1. Airbus A320 family. (2021, June, 5). In Wikipedia. https://en.wikipedia.org/wiki/Airbus_A320_family

2. 5 Main components of an aircraft [Electronic source] - Access mode URL: https://www.sheffield.com/2015/5-main-components-of-an-aircraft.html

3. Aircraft basic construction [Electronic source] - Access mode URL: http://home.iitk.ac.in/~mohite/Basic_construction.pdf

4. Daniel P. Raymer. (2012). Aircraft Design: A Conceptual Approach. Amer Inst of Aeronautics. (Original work published 1920)

5. The function of tail unit and the principle [Electronic source] - Access mode URL: https://www.zhihu.com/question/23038548/answer/859728438

6. Aircraft system: Lecture course / С.С. Юцкевич. – К. :NAU, 2020y.

7. Aircraft Landing Gear Systems [Electronic source] - Access model URL: https://hangarmma.com.br/blog/wp-content/uploads/2019/03/Chapter-13-Aircraft-Landing-Gear-Systems.pdf

8. James Reason. (1997). Managing the Risks of Organizational Accidents. Aldershot: Taylor & Francis Ltd.

9. Martin Simons. (2015). Model Aircraft Aerodynamics. Hemel Hempstead: Special Interest Model Books.

10. The Design of strength of aircraft: Lecture course / M.V.Karuskevich, T.P. Maslak. – K. :NAU, 2019y.

11. Material selection of tray table. [Electronic source] - Access model URL: https://redesignedtraytables.wordpress.com/final-design/material-selection/

12. Four kinds of strength calculation theories. [Electronic source] - Access model URL: https://wenku.baidu.com/view/154d98ff3186bceb19e8bbb4.html

Appendix A

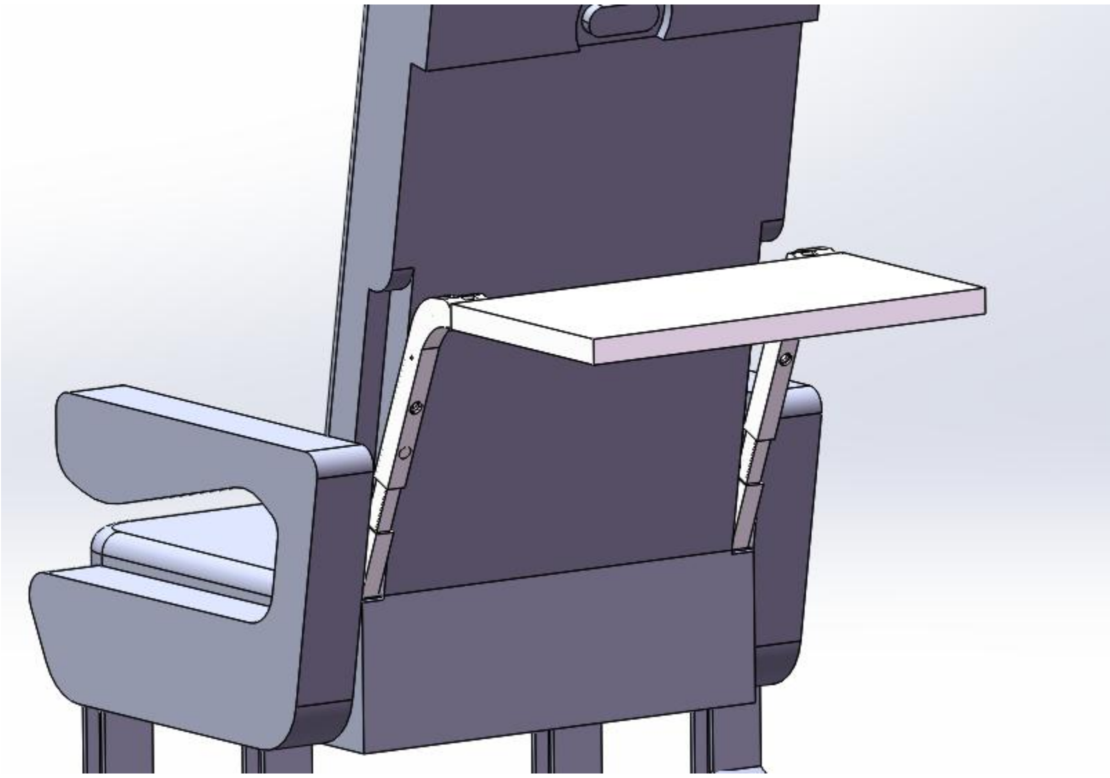

Fig. 1. Concept of height-adjustable tray table.

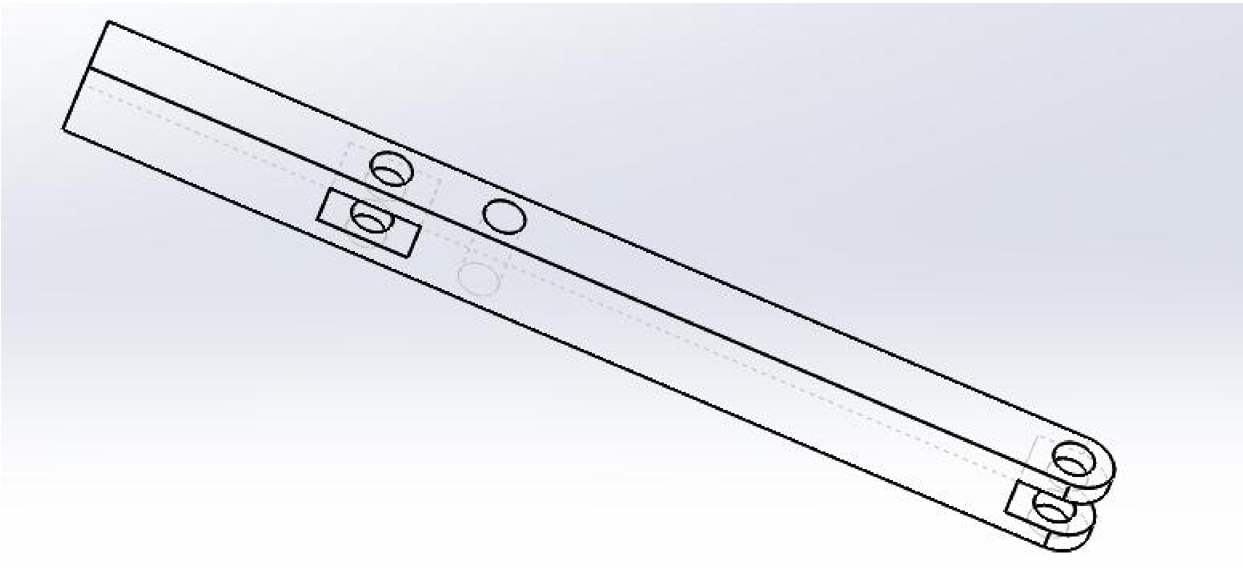

Figure.2. Model of transfer bar.