MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

National Aerospace University
Kharkiv Aviation Institute

Faculty of Aircraft Engineering

Airplane and Helicopter Design Department

Explanatory Note
to the ___ diploma project ___
(type of qualification work)

Master (second)
(degree)

on the topic: ___*Study of Design Features of an Electric Light Aircraft*___

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Applicant of <u>2</u> Year <u>161FD</u> Group

Field of knowledge   *13 «Mechanical Engineering»*

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Wang Zhiyuan
(surname and initials of student)

Supervisor: Buival L. Y.

Reviewer: Kostenko O. I.

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Міністерство освіти і науки України
Національний аерокосмічний університет ім. М. Є. Жуковського
«Харківський авіаційний інститут»

Факультет _____ *Літакобудування* _____

Кафедра _____ *103 «Проектування літаків і вертольотів»* _____

Рівень вищої освіти _____ *другий (магістерський)* _____

Галузь знань _____ *13 «Механічна інженерія»* _____

Спеціальність _____ *134 «Авіаційна та ракетно-космічна техніка»* _____
<div align="center">(код та найменування)</div>

Освітня програма _____ *«Літаки і вертольоти»* _____
<div align="center">(найменування)</div>

<div align="right">

ЗАТВЕРДЖУЮ
Завідувач кафедри

к.т.н., доц. _____ Андрій ГУМЕННИЙ
"____" _____ _____202___року

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З А В Д А Н Н Я
НА КВАЛІФІКАЦІЙНУ РОБОТ

Ван Чжиюань

(прізвище, ім'я та по батькові)

</div>

1.Тема кваліфікаційної роботи *__**Study of Design Features of an Electric Light Aircraft (Дослідження особливостей проектування електричного легкого літака)**__*

керівник кваліфікаційної роботи Буйвал Лілія Юріївна, к.т.н.
<div align="right">(прізвище, ім'я, по батькові, науковий ступінь, вчене звання)</div>

затверджені наказом Університету №_____уч___ від «___» _____ 2023 року

2.Термін подання студентом кваліфікаційної роботи_____18 травня 2023 р.

Вихідні дані до роботи n_{crew} = 1 person, n_{pass} = 3 person, = 0.22, V_{CR} = 220 km/h
H_{CR} = 1000 m, $L_{TO.}$ = 0.38 km, $L_{(mp=max)}$ = 600 km

Зміст пояснювальної записки (перелік завдань, які потрібно розв'язати)

2.6. Management costs.

2.7. Depreciation of equipment.

2.8. Total cost of research.

2.9. Cost profit.

2.10. Wholesale price.

2.11. Results of calculations.

2.12. Conclusion of Economical Section

Reference

3.   Спеціальне завдання

Не передбачено

Перелік графічного матеріалу (з точним зазначенням обов'язкових креслень)

– майстер-геометрія літака,

– креслення загального вигляду або схема в трьох проекціях (формат А1).

Консультанти розділів кваліфікаційної роботи

Розділ	Прізвище, ініціали та посада консультанта	Підпис, дата	
		завдання видав	завдання прийняв
1. Конструкторський розділ	Буйвал Л. Ю., к.т.н., доцент	**08.02.2023**	**17.05.2023**
2. Економічний розділ	Павленко Т. Ю., к.е.н., доцент	**15.05.2023**	**17.05.2023**

Нормоконтроль _____ Лілія БУЙВАЛ «__18__» _травня___2023_ р.

     (підпис)   (ім'я та прізвище)

Дата видачі завдання «__08__» __лютого___ 2023 р.

КАЛЕНДАРНИЙ ПЛАН

№ п/п	Назва етапів кваліфікаційної роботи	Строк виконання етапів кваліфікаційної роботи	Примітка
1	Конструкторський розділ		
2	Економічний розділ		

Здобувач _____ **Wang Zhiyuan**

                 (підпис)   (ім'я та прізвище)

Керівник кваліфікаційної роботи

                         _____ **Лілія БУЙВАЛ**

                 (підпис)   (ім'я та прізвище)

ABSTRACT

The explanatory note contains: 60 p., 7 Table, 58 Fig., 17 References

Object of research: All-electrical aircraft.

The purpose of the work: develop Technical Requirements Specification, research the all electrical assignment, analysis of scientists, who dealt with electrical aircraft and what issues they claim and what problem still have not been solved, do calculations of aircraft parameters in zero approximation, create master-geometry of all-electrical aircraft, discuss the features of electrical aircraft and get the aim is to reduce noise by changing material of fuselage.

Research methods: statistical, analytical methods, Siemens NX software, MATLAB software.

The results of the master's diploma project and its novelty: as a result of the master's diploma project the following results were obtained:

1) The flight assignment of designed all-electrical aircraft is to carry up to 1 pilot and 3 passengers to go sightseeing and also can used as training aircraft, which can be possible due to advantages: zero emission, low cost and low noise.

2) The range of designed electrical airplane is 600 km and cruise altitude is 1000 m. According to that, for example in Ukraine, three basic routes are designed. They are: from Kyiv to Kharkiv, from Kyiv to Odessa and from Kharkiv to Odessa.

3) The take-off weight of the aircraft in the zero approximation is 1143 kg. Aircraft geometrical parameters (wing, fuselage, tail parts) were calculated. It is help to create three-dimensional parametric model of project. After collecting statistical data, it is possible to develop tactical and technical requirements. This stage is based on the analysis of the above statistical materials and Technical Requirements Specification.

4) The master-geometry of designed all-electrical aircraft is build using Siemens NX software.

5) JTCLM is kind of material that has the feature to prevent sound waves of a certain frequency to propagate, so it can be used to reduce noise. Since designed electric plane is used for sightseeing, it is important to consider the passengers' and population feelings, low noise is an important aspect. So the idea appeared to apply JTCLM material in fuselage segments to reduce noise of airplane, which will give passengers a better experience.

ELECTRICAL AIRCRAFT, PUBLICATIONS, THEORETICAL STATEMENTS, SCIENTIFIC RESEARCH, ANALYSIS, SCIENTIST.

Conditions for obtaining: with the written permission of the head of the Department of Aircraft and Helicopter Design of the National Aerospace University «Kharkiv Aviation Institute».

CONTENT

1 DESIGN SECTION

1.1 Technical Requirement Specification

1.1.1 Introduction

For more than a hundred years, the aircraft has made an important influence in our daily life, such as transport, travel, military and so on. The positive effect that aircraft has promoted our society and economy, but it has also brought about negative influences. Among them the most primary one is impact on environment, which can be included as three aspects: 1. Noise pollution at airports. 2. Reduced air quality due to aircraft emissions. 3. The climate damage caused by greenhouse gases from aircraft emissions. With the development of aviation industry, the amount of aircraft has raised rapidly. Assuming that no efforts has been made to technological advancements and optimization of operations in the aviation sector, the constant and steady growth of the aviation sector would bring about an even higher increase in fuel burn and emissions which would result in unsustainable growth of the industry. If the modifications to aircraft performance have done little to improve the environment, we have to think about using green energy on aircraft. Green energy, which also called new energy, it including Solar energy, wind energy, geothermal energy, ocean energy etc. The most prominent feature of these kinds of energy is environmentally friendly, which means they won't emit the polluting gases such as carbon dioxide and NOx, and they such energy won't damage our surroundings.
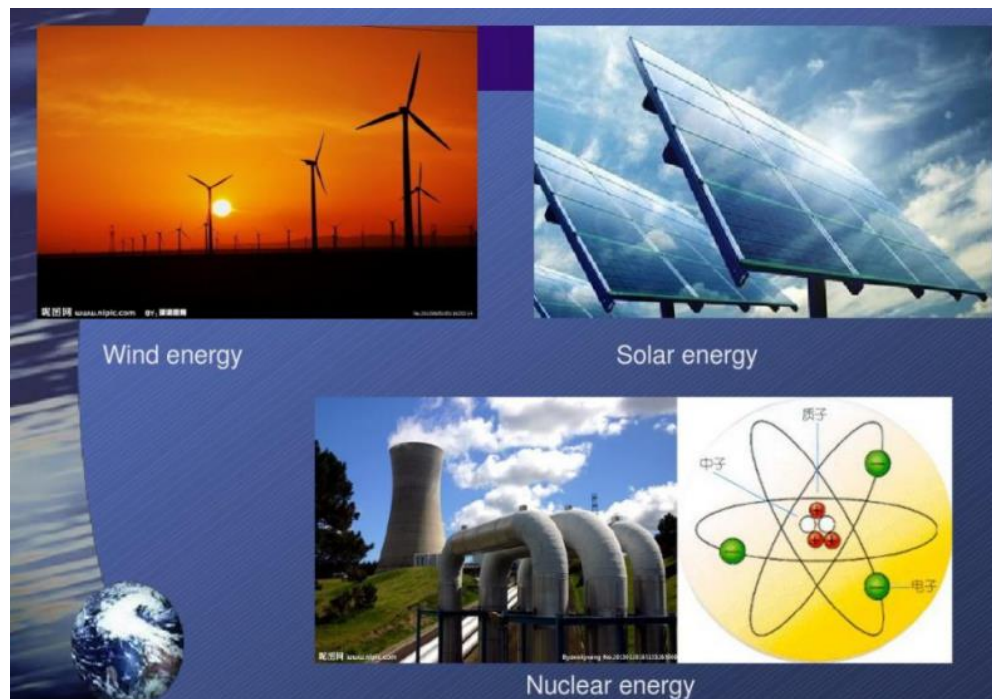

Figure 1.1 – Some kinds of new energy

There we consider about electrical aircraft. Electric aircraft is an aircraft with electrically driven propellers, bypass fans or other devices to generate forward power. The more-electric aircraft (MEA) and the all-electric aircraft (AEA) is two categories of research, the all-electric aircraft (AEA) refers to an aircraft fully powered by electric and where no fuel is involved, the MEA aims to utilize an improved aircraft electrical system that uses electrical power to power the non-propulsive subsystems onboard the aircraft. The electrical aircraft has many advantages such as: zero emissions, low noise, almost no negative impact on the environment, it represents the future of aircraft development.

1.1.2 Aircraft Assignment

Since the electrical aircraft has two types – All-electrical aircraft (AEA) and More-electrical aircraft (MEA), the decision to design a kind of all-electrical aircraft has been made. All-electrical aircraft means that the aircraft is fully powered by electric and no fuel is involved, which is the most special feature of it. Because it is powered by electric but not fuel, and electrical energy is much cheaper fuel assumption, so AEA also has the feature with low cost. What's more, the consumption of fuel oil causes the emission of polluting gases CO_2, which causes the intensification of greenhouse effect. When we use new energy such as electric to carry out aircraft propulsion, it could lead to zero emission, which is also the feature of all-electrical aircraft.

The planned maximum range of the electrical aircraft is 500 kilometers, and it is designed for sightseeing and as training aircraft.

Ukraine is a country with beautiful natural landscape and human landscape, the temperature here is suitable for living and the sky is clear, which is a suitable place for developing aircraft sightseeing since we need not to always consider the weather condition. Kyiv is the capital of Ukraine and the center of economic, culture and politics, which makes it possible to manufacture and find potential investors and buyers of electric aircraft. Kharkiv is the second largest city in Ukraine, it has not only many magnificent buildings in the city center but also has very beautiful natural sightseeing, so these two cities fit the condition to develop the sightseeing airplane and also expand the possibilities of using the aircraft among users (passengers). And consider about the height of the buildings in these two cities, the flight altitude should be taller to ensure flight safety, at the same time, the minimum altitude limitations may change depending on the height of possible future buildings. The straight line distance between Kyiv and Kharkiv is approximately 500 kilometers, which is the planning range of designed type of electrical aircraft. According this we can open a sightseeing route between Kyiv and Kharkov and use this type electrical aircraft, and not to pollute the environment with

emissions and not harm flora and fauna due to engines' noise unlike traditional aircraft, taking into account the flight mods at low altitudes, where the majority of birds are concerned. Since these two cities are large cities with many airports, it is convenient for take-off arrange and landing arrange.

Figure 1.2 – Two biggest cities in Ukraine for main routs of electric aircraft

Odessa is the fourth largest city in Ukraine. For the Black Sea coast of the largest port city and important industry, transportation, culture and tourism center, where, as an assumption, air routes on ecological and convenient transport will always be popular and in demand. Odessa has a pleasant climate, moderate temperature and humidity, and is known as the "Pearl of the Black Sea" because its natural harbor is freeze-free all year around. These conditions are also suitable to develop sightseeing aircraft.

Because of the specific climate of Odessa city, we can add a sightseeing line in cold season, for these tourists who want to find suitable, warm places to spend the winter. The straight-line distance between Odessa, Kyiv and Kharkov is all approximately 500 kilometers, which is suitable for such electrical airplane.

Therefore, the normal flight distance without landing for designed electrical aircraft is 500 km.

As base routes, for example in Ukraine, are:
– from Kyiv to Kharkiv;
– from Kyiv to Odessa;
– from Kharkiv to Odessa (according to the customer's wishes or high demand it can be possible route with the changeable layout, considering longer range).
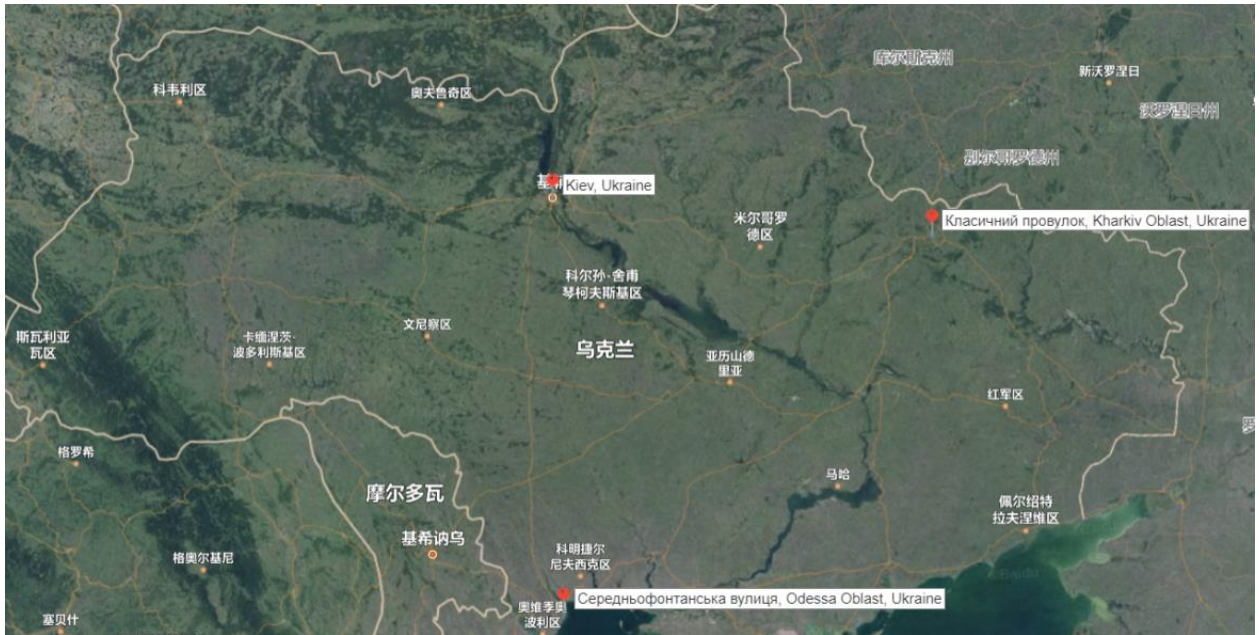
Figure 1.3 – Additional sightseeing line for more routes of electric aircraft

1.1.3 The basis for development

This kind of electrical airplane designed to be able to carry 4 passengers. It can comply with Certification Specifications for Normal-Category Aeroplanes.

➢ Certification Specifications for Normal-Category Aeroplanes(CS-23)
➢ Acceptable Means of Compliance and Guidance Material to the Certification Specification for Normal-Category Aeroplanes(AMC&GM to CS-23)
➢ Commission Regulation(EU) NO748/2012 of 3 August 2012:

implementing rules for the airworthiness and environmental certification of aircraft and related products, parts and appliances, as well as for the certification of design and production organizations (recast) Text with EEA relevance

➢ F3082/F3082M-17 Standard Specification for Weights and Centers of Gravity of Aircraft
➢ F3114-15 Standard Specification for Structures
➢ F3179/F3179M-18 Standard Specification for Performance of Aircraft
➢ F3173/F3173M-17 Standard Specification for Aircraft Handling Characteristics
➢ F3180/F3180M-18 Standard Specification for Low-Speed Flight Characteristics of Aircraft
➢ F3120/F3120M-15 Standard Specification for Ice Protection for General Aviation Aircraft
➢ F3116/F3116M-18 Standard Specification for Design Loads and Conditions
➢ F3061/F3061M-17 Standard Specification for Systems and Equipment in Small Aircraft

➢ F3232/F3232M-17 Standard Specification for Flight Controls in Small Aircraft
➢ F3115/F3115M-15 Standard Specification for Structural Durability for Small Aeroplanes
➢ F3061/F3061M-17 Standard Specification for Systems and Equipment in Small

1.1.4 Expected Operational Conditions

Environmental characteristics and factors:

a. Barometric pressure - for all range of flight altitude; on ground PH=+20 mm HG.
b. Temperature of ambient air represents the temperature change in dependence of altitude. Temperature deviation from mean value for different altitudes along the following lines:

   "Minimum arctical";

   "Maximum tropical",

   In this case the aircraft and its systems operability shall maintain within the mentioned range after aircraft stay at ground down to minus 60C.
c. Relative humidity on ground is of 98% at an ambient air temperature of +35C.
d. Air mass density shall correspond to ranges of ambient air temperature (It. 3.1.2) and barometric pressure (It.3.1.1) according to international standard atmosphere .
e. Maximum wind components at takeoff and landing on dry paved RWY:

   lateral component – 12 m/s (friction coefficient $\mu \geq 0.6$);

   following component – 5 m/s;

   headwind – 30 m/s.

   Note: under the highest unfavorable RWY conditions (u$\geq$0.6), reduction of lateral wind component limiting values is allowable.

Operational factors:

a. Crew: pilot, 3 passengers
b. No altitude and altitude restrictions for take- off and landing
c. Condition of paved RWY:

   dry;

   wet;

   waters; occupied by water;

   Covered with snow up to 10 cm thick
d. Characteristics of unpaved RWY:

   with or without turf;

   loamy, clay;

    sandy, sandy-loam,

    rocky, crushed-stone;

    chernozem soil.

e. Condition of paved RWY:

   dry;

   snow-covered (up to 10 cm thick).

f. Aircraft operation features.

     The aircraft is intended to perform the flight:

    according to visual and instrument flight rules;

    under simple and difficult weather conditions, under icing;

    in daytime and in nigh;

    above plain and mountain surface of local airlines;

    above water distanced from ground for up to 30 min. of flight;

    range of geographical latitudes-up to 70° north and 55° south latitude.

g. Operational meteorological minimums for takeoff and landing:

   -minimum for takeoff: visibility range on RWY of at least 300 m;

   -minimum for landing: 1 category (decision altitude 60 m at visibility range on
RWY of at least 800 m),

h. Components and characteristics of ground facilities for flight provisions – in
accordance with civil aviation considering It.3.2.8 and 3.2.9.

i. Maintenance periodicity is equal to 300 flight hours of airframe.

j. Service life and life time for:

   1. aircraft (up to discarding)

   Landings – 50000

   flight hours – 40000

   service life – 25 years.

   2. engine:

   the service life and overhauls time depends on the performance of battery.

   In general, we should recharge the battery after every flight mission to ensure the
enough energy while flying.

   3. vendor items – as a rule the vendor items service life shall correspond to aircraft
service life or they shall be multiple of repair periodicity.

    Th expected take-off distance is 300 meters, the landing distance is 600 meters,
the maximum range is 600 kilometers, which is enough for our arranging lines. Since
this electrical airplane is designed for sightseeing, it needn't flight at very extreme
weather such as thunderstorms, heavy snow days and so on.

1.1.5 General Requirement

A. Maximum passenger capacity: one pilot and three passengers

B. Distance between the seats is 400 mm

C. Maximum payload: 500 kg

D. Cruising speed: 250 km/h

E. Maximum speed: 300 km/h

F. Cruising altitude: 1800 m

G. Maximum altitude: 3000 m

H. Required runway length:

Takeoff distance 300 m

Landing distance 600 m

I. Maximum flight range: 1200 kilometers

Maximum payload range: 600 kilometers

1.1.5.2 The wheels are equipped with a shock-absorbing cushioning system that allows the electrical airplane to land on unpaved runways in emergency condition since this kind of electrical airplane needed to be as training airplane, and we should ensure their safety.

1.1.5.3 The cockpit and passenger compartment are sealed with honeycomb sound absorbing material.

1.1.5.4 The main frame structure and wing beams are made of titanium alloy to increase the strength and improve the impact resistance, while the body shell and wing skin are made of carbon fiber composite material in order to reduce weight, and the windshield panel is made of unbreakable plastic material with a waterproof coating to achieve waterproof effect.

1.1.5.5 Each seat of pilot and passengers are equipped with seat belts and shoulder belts to ensure the safety of them.

1.1.5.6 The doors and emergency escape doors open from the roof and can be opened and closed manually.

1.1.5.7 The body mezzanine and cockpit interior are made of fireproof materials and equipped with small extinguishers.

1.1.5.8 Passenger seats maybe removed and replaced with luggage racks and infant seats.

The aircraft, its engines, equipment and other parts, and operational publications shall meet the following requirements:

- AMC & GM to CS-23 together with mentioned requirements;

- engine - the electrical airplane does not have traditional engines, the battery gives the energy to propeller and propeller could generate the power ;

-APU

- the present performance specification.

As for perceivable noise the aircraft shall meet the requirements of Section 4 of international standards environmental protection "Application16 to International Aviation Convention (Volume l. Noise 2001)". But for electrical aircraft, since it doesn't have engine, it has the feature that while flying, the noise would be very low.

As for engine emission the aircraft shall meet the requirements of Appendix 16 to International Aviation Convention (Volume II "Aviation engines emission", "Edition 1981" Revisions 1 to 4) and requirements of AMC & CM to CS-23. For electrical aircraft, because of not need to combust the fuel, the energy is made by using battery electric, so it doesn't let out carbon dioxide and it could realize zero - emission.

As for protection against hijacking the aircraft shall meet the requirements ICAO Appendix 6,8,17(with Revisions 97 and 98), Ukrainian Air Law (Section 8).

Characteristics of reliability, maintenance workability and testability shall meet the "General requirements for operational and maintenance characteristics of civil aircraft".

Ground facilities and repair requirement shall correspond to this performance specification.

Simulators and training devices should be designed for aircraft according to individual performance specifications. The programs for training of flight and technical staff should be developed up to completion of certification tests.

Processing and analysis of flight data using the ground personal computer shall be provided to control the correctness of maintaining of preset flight modes and the pilot technique, to evaluate the pilots' professional level, technical state of the aircraft, its equipment and functional systems in monitoring of operation conditions within life time limits.

1.2 Statistical data analysis

1.2.1 What issues and problems unexplored

This part is collection information, which means working with collecting some scientists who have done works in aspect of electrical aircraft. And then by reading their articles and works we can conclude what issues and what problems unexplored.

Following list is the scientists' name, countries and their works:

➢ Eric Greenwood, the US.

(1) Development of "Aria", a compact, ultra-quiet personal electric helicopter.

(2) A new distributed electric propulsion aircraft simulation tool for coupled flight dynamics, free wake, and acoustic predictions.

(3) Challenges and opportunities for low noise electric aircraft

➢ Telikapalli Srikar ,the US

Electric Aircraft Fueled by Liquid Hydrogen and Liquefied Natural Gas

➢ Faiyaz Doctor, the UK

Modelling the effect of electric aircraft on airport operations and infrastructure

➢ Yang Fengtian, China

Review: Development and challenges of electric aircraft with new energies

The analysis of their works is as below:

Eric Greenwood described a kind of electric helicopter. The aircraft were scored by compact size, speed, low noise, and endurance. The team chose a coaxial electric helicopter configuration to maximize rotor area and reduce disk loading for efficiency and acoustic benefits [1]. And he described that the major barrier to certification and public acceptance of emerging distributed electric propulsion (DEP) aircraft is their noise. This work describes a software to predict the noise of DEP aircraft [2]. He also described a new class of electric aircraft is being developed to transport people and goods as a part of the urban and regional transportation infrastructure. To gain public acceptance of these operations, these aircraft need to be much quieter than conventional airplanes and helicopters [3].

Telikapalli Srikar published a review of the opportunities and challenges of cryogenic power devices of electric aircraft, and the ongoing research and development efforts of the government agencies and the industry. Liquid Hydrogen (LH2) and Liquefied Natural Gas (LNG) are compared to support high temperature superconducting (HTS) and normal metal devices, respectively. The emission reductions would be substantially higher with LH2, particularly when H2 is produced using renewable energy sources [4].

Faiyaz Doctor mentioned that electric aircraft offer the potential for emissions savings towards decarbonising air transport and reducing its contribution to climate change. However, the characteristics of these novel technologies pose questions about how they can be integrated with existing airport infrastructure. Key considerations

relate to the time needed to recharge electric aircraft whilst on the ground without adversely affecting operational capacities, and the requirement for airport operators to install electric charging capabilities [5].

Yang Fengtian has reviewed the impact of aviation on the environment, the application of electricity in aircraft and the development of electric aircraft are briefly described. The energy classification, electric propulsion system and its overall efficiency of new energy electric aircraft are studied. The energy demand of electric aircraft is analyzed, the range and limit range of manned electric aircraft with battery as energy are studied [6].

There are some problems that still unexplored. The biggest problem is limited by battery capacity. All-electric aircraft (AEA) technology is mainly used in UAV (unmanned aerial vehicle), light aircraft and ultra-light aircraft, so it is used for general aviation and the seats is limited less than 4. For larger airplane, MEA technology can help airplane have better fuel efficiency, lowered maintenance costs, less noise and more efficient power generation. More-electric aircraft (MEA) aims to promote change and improvements in small steps, with the eventual aim of achieving AEA in the future [4]. Battery performance, like battery energy density, charge-discharge performance, cycle life, is the biggest challenge for electric aircraft development, but much depends on how the world's battery industry evolves. From an aircraft design point of view, how to make airplane has high lift-drag ratio, further weight reduction while ensuring reliability and improve the overall efficiency of the electric propulsion system is aspects that we should consider.

1.2.2 Prototypes of airplane

Several kinds of electrical aircrafts are shown at following table, including the name of aircraft, its figure and some description.

Table 1.1 – Information of prototypes

Prototype	Figure	Description
N3-X A revolutionary aircraft concept from NASA	Figure 1.4 – N3-X concept	The N3-X concept is a fully turbo-electric aircraft with a hybrid wing body airframe. Sixteen small aft distributed fans driven by electric motors are located on top of the aircraft and provide

	propulsion.

End of Table 1.1

Prototype		Description
ES-30 Planned to enter into service at 2028	Figure 1.5 – ES-30 concept [14]	It is developed by Heart Aerospace.It's kind of regional electric aircraft that seats 30 passengers. The all-electric range is 200 km. It has 4 electric motors as propulsion.
RX4E It made first flight in October 2019	Figure 1.6 – RX4E from China [15]	It is developed by Liaoning General Aviation Academy in China. It has 4 seats. The take-off weight is 1200 kg, range is 300 km, cruising altitude is 1000m.
eFlyer 4 A modified concept of the former two-seater electric plane eFlyer 2	Figure 1.7 – eFlyer4 concept [16]	It is developed by Bye Aerospace, the US. Aerodynamic efficiency is over twice that of a typical legacy aircraft of similar size. It has 4 seats, the payload is 390 kg, flight speed from 113 km/h to 370 km/h.
Alice The first flight was completed on September 27, 2022	Figure 1.8 – Photo of Alice that developed by Eviation [17]	It is developed by Eviation, an Israeli company. The speed can be 444 km/h, range is 1046 km and it has 10 seats. Alice is equipped with three 900 W electric motors and a 3,500kg lithium-ion battery that can provide 900 KWH of energy.

1.2.3 Aircraft tactical-technical requirements development

Based on potential application areas, requirements of aviation industry, development of electrical aircraft and collection information, the type of electrical aircraft here I chose to design a four-seats light aircraft, with cruise speed 220 km/h, range is 600 km and cruise altitude is 1000 m. There is recorder in table 1.2.

Table 1.2 - Tactical- Technical data of designed airplane

L($m_{f\,MAX}$),km	m_p,kg	L_{to},km	H_{max},km	V_{cruise},km/h	n_{crew}	n_{pass}	H_{CR},km
600	300	0.38	1.1	220	1	3	1.0

Based on the processing of statistical data, the assigned basic geometric parameters of the aircraft are listed in table 1.3.

Table 1.3 - Main geometric parameters of designed airplane

λ	$X_{1/4}$	η	$\overline{c}$	$\overline{b_{fl}}$	δ_{fl},degree	$\overline{S_{ail}}$	λ_f	D_F,m	L_F,m
14	15°	2.3	18 %	0.3	10; 20	0.05	3.5	2.4	8.4

End of Table 1.3

$\overline{S_{HT}}$	$\overline{S_{VT}}$	λ_{HT}	λ_{VT}	$X_{1/4HT}$	$X_{1/4VT}$	$\overline{c_{HT}}$	$\overline{c_{VT}}$	η_{HT}	η_{VT}
0.14	0.2	2.9	0.98	13°	13°	0.08	0.08	2	1.4

1.3 Determining the parameters of an airplane

At this item some parameters of designed airplane, such as take-off weight, some geometrical parameters including wing, fuselage and so on, and development of the layout and center of gravity were calculated.

1.3.1 Take-off weight estimation

The take-off mass of the aircraft in the zero approximation is determined after choice the scheme of the aircraft and calculated by the formula (1.1) [7]:

$$m_0^0 = \frac{m_{p.\,load} + m_{op.it.}}{1 - (\bar{m}_{str.} + \bar{m}_{p.pl.} + \bar{m}_{fuel} + \bar{m}_{eq.ctl.})} \qquad (1.1)$$

where $m_{p,load}$ - mass of payload, which calculated

$$m_{p,load} = m_{lug} * n_{pas} = 100 * 3 = 300 \ kg$$

Here $m_{lug} = m_{pas} + m_{bag}$, since the airplane is used to short distance sightseeing, I think is not need to carry a lot of baggage, so 100 kg for one passenger and his or her baggage is enough.

$m_{op,it}$- mass of operational items

$$m_{op,it} = 100 + 80 = 180 \; kg$$

Here $m_{op,it}$ including the weight of the crew member (a pilot), some equipment that used to see the landscape, some pilot training equipment (since the airplane also used for training) and maybe other services for passengers.

For other parameters, the meaning and the values are as following:

$\overline{m_{str}}$ - is the relative mass of the aircraft structure, which includes the relative mass of the wing, fuselage, tail, and landing gear. For subsonic, passenger, light airplane,the ratio of the airplane structure - 0.32

$\overline{m_{p,pl}}$ - mass ratio of the power plant, for my electrical airplane, it include the battery and electrical machine, there I estimate the ratio as - 0.12

$\overline{m_{fuel}}$ - mass ratio of the fuel, since I want to design a kind of AEA (All electrical aircraft), it needn't to use fuel. So there I set it as 0

$\overline{m_{eq.ctl}}$ - is relative weight of equipment and control, which, which includes

hydraulic system, pneumatic system, power supply system, flight-navigation equipment and elevator control, rudder, ailerons, flaps, slats, interceptors. For my light airplane there I set it as -0.14

The take-off weight mass of the aircraft in the zero approximation is calculated by formula (1.1):

$$m_0 = \frac{300 + 110}{1 - (0.32 + 0.12 + 0 + 0.14)} = 1143 \; kg.$$

1.3.2 Airplane geometrical parameters calculation (wing, fuselage, tail, landing gear)

➢ **Determination of the geometric parameters of the wing**

The specific load on the wing during take-off is $p_0 = 86$

The wing area:

$$S = \frac{m_0 g}{10 p_0} = \frac{1143 * 9.8}{10 * 86} = 13.02 \; m^2$$

Wingspan:

$$L = \sqrt{\lambda S} = \sqrt{14 * 13.02} = 13.50 \; m$$

The root chord b_0 and tip chord b_t are determined

$$b_0 = \frac{S}{l}\frac{2\eta}{\eta+1} = \frac{13.02}{13.50} * \frac{2*2.3}{2.3+1} = 1.34 \ \ m$$

$$b_t = \frac{b_0}{\eta} = \frac{1.34}{2.3} = 0.58 \ \ m$$

The mean aerodynamic chord is calculated:

$$b_{MAC} = \frac{2}{3}b_0\frac{\eta^2+\eta+1}{(\eta+1)\eta} = \frac{2}{3}*1.34*\frac{2.3^2+2.3+1}{(2.3+1)*2.3} = 1.01 \ \ m$$

Determine the coordinate MAC on the wingspan:

$$Z_A = \frac{l}{6}\frac{\eta+2}{\eta+1} = \frac{13.50}{6}*\frac{2.3+2}{2.3+1} = 2.93 \ \ m$$

Coordinate of MAC nose along an OX axis

$$X_{MAC} = \frac{l}{6}\frac{\eta+2}{\eta+1}tgx_{LE}$$

Where x_{LE} - Sweep angle of wing leading edge.

$$tgx_{LE} = tgx + \frac{\eta-2}{\lambda(\eta+1)} = tg15° + \frac{2.3-2}{14*(2.3+1)} = 0.27$$

$$X_{MAC} = \frac{13.50}{6}*\frac{2.3+2}{2.3+1}*0.27 = 0.79 \ \ m$$

➢ **Determination of Fuselage parameters**

Fuselage diameter

$$D_f = 2.4m$$

Fuselage length

$$L_f = \lambda_f D_f = 3.5 * 2.4 = 8.4 \ \ m$$

The length of the nose of the fuselage

$$L_N = \lambda_N D_f = 1.05 * 2.4 = 2.52 \ \ m^2$$

The length of the rear fuselage

$$L_T = \lambda_T D_f = 1.75 * 2.4 = 4.2 \ \ m^2$$

➢ **Determination of tail unit parameters**

The horizontal tail is determined according by such dependence:

$$S_{HS} = \overline{S_{HS}}S = 0.14 * 13.02 = 1.82 \ \ m^2$$

Length of horizontal tail:

$$L_{HS} = \sqrt{\lambda_{HS}S_{HS}} = \sqrt{2.9 * 1.82} = 2.3 \ \ m$$

Chords of horizontal tail unit

$$b_{0HS} = (\frac{S_{HS}}{L_{HS}})\frac{2\eta_{HS}}{\eta_{HS}+1} = \frac{1.82}{2.3}*\frac{2*2}{2+1} = 1.04 \ \ m$$

$$b_{tHS} = \frac{b_{0HS}}{\eta_{HS}} = \frac{1.04}{2} = 0.52 \ m$$

Mean aerodynamic chord of horizontal tail

$$b_{MAC \ HS} = \frac{2}{3} b_{0HS} \frac{\eta_{HS}^2 + \eta_{HS} + 1}{(\eta_{HS} + 1)\eta_{HS}} = \frac{2}{3} * 1.04 * \frac{2^2 + 2 + 1}{(2 + 1) * 2} = 0.81 \ m$$

$$Z_{MAC \ HS} = \frac{L_{HS}}{6} \frac{\eta_{HS} + 2}{\eta_{HS} + 1} = \frac{2.3}{6} * \frac{2 + 2}{2 + 1} = 0.51 \ m$$

Horizontal distance between wing root to MAC root

$$X_{MAC \ HS} = \frac{L_{HS}}{6} \frac{\eta_{HS} + 2}{\eta_{HS} + 1} tgx_{LE}$$

Where x_{LE} - Sweep angle of wing leading edge.

$$tgx_{LE} = tgx + \frac{\eta - 2}{\lambda(\eta + 1)} = tg15° + \frac{2 - 2}{14 * (2.3 + 1)} = 0.27$$

$$X_{MAC} = \frac{2.3}{6} * \frac{2 + 2}{2 + 1} * 0.27 = 0.138 \ m$$

The vertical tail is determined according by such dependence:

$$S_{VS} = \overline{S_{VS}} S = 0.2 * 13.02 = 2.604 \ m^2$$

Length of vertical tail:

$$L_{VS} = \sqrt{\lambda_{VS} S_{VS}} = \sqrt{0.98 * 2.604} = 1.6 \ m$$

Chords of vertical tail unit

$$b_{0VS} = \left(\frac{S_{VS}}{L_{VS}}\right) \frac{2\eta_{VS}}{\eta_{VS} + 1} = \frac{2.604}{1.6} * \frac{2 * 1.4}{1.4 + 1} = 1.9 \ m$$

$$b_{tVS} = \frac{b_{0VS}}{\eta_{VS}} = \frac{1.9}{1.4} = 1.36 \ m$$

Mean aerodynamic chord of vertical tail

$$b_{MAC \ VS} = \frac{2}{3} b_{0VS} \frac{\eta_{VS}^2 + \eta_{VS} + 1}{(\eta_{VS} + 1)\eta_{VS}} = \frac{2}{3} * 1.36 * \frac{1.4^2 + 1.4 + 1}{(1.4 + 1) * 1.4} = 1.18 \ m$$

$$Z_{MAC \ VS} = \frac{L_{VS}}{6} \frac{\eta_{VS} + 2}{\eta_{VS} + 1} = \frac{1.6}{6} * \frac{1.4 + 2}{1.4 + 1} = 0.38 \ m$$

Vertical distance between wing root to MAC root

$$X_{MAC \ VS} = \frac{L_{VS}}{6} \frac{\eta_{VS} + 2}{\eta_{VS} + 1} tgx_{LE}$$

Where x_{LE} - Sweep angle of wing leading edge.

$$X_{MAC} = \frac{1.6}{6} * \frac{1.4 + 2}{1.4 + 1} * 0.27 = 0.102 \ m$$

➢ **Determine landing gear parameters**

The size of offset e is more often determined in share of wing MAC
$$e = (0.15...0.2)b_{MAC} = 0.15 * 1.01 = 0.15 \ m$$
Angle of main wheels set off γ should be higher than angle of a touch down by a tail part
$$\gamma = \varphi + (1...2)°$$
φ is angle of touchdown by the tail part
$$\varphi = \alpha_{max} - \alpha_{wi} - \psi$$
Where $\alpha_{wi} = (0...4)° = 0°$ (angle between a wing chord and longitudinal axis of fuselage), $\psi = 0$(static ground parking angle in zero approximation)
$$\varphi = 10 - 0 - 0 = 10°$$
$$\gamma = 10 + 2 = 12°$$
Regarding the center of mass e with angle φ the greater the value e the greater the front tail support loads and more difficult to take off a front support during take-off. But the less the e reduce γ.

Wheel base of the landing gear b it depends of fuselage length
$$b = (0.30...0.40)L_F = 0.30 * 8.4 = 2.52 \ m$$
Distance between a nose strut and center of mass a is chosen so that during airplane parking loading on nose strut would be equal (6...12%) of airplane mass
$$a = (0.88...0.94)b = 0.9 * 2.52 = 2.268 \ m$$
$$e = (0.12...0.06)b = 0.07 * 2.52 = 0.1764 \ m$$
H - height of landing gear is determined from the condition providing the minimum gap 200...250 mm between the runway surface and the airplane structure.

B - the maximum size of track, which is 3.5 m by statistical range

On the basis of track of landing gear should be in such limits
$$2H < B < 15 \ m$$
Calculation of H:
$$H = \frac{e}{\tan\gamma} = \frac{0.1764}{\tan 12°} = 0.80$$
$$2H = 2 * (0.80) = 1.60 < 3.5 < 15 \ m$$
Chosen size of track is satisfied condition, therefore B = 3.5 m

1.3.3 Development of the layout and center-of-gravity

Development of the layout from one side is such location units (wings, tail, fuselage e.t.) according to each other, which gives the best statically and longitudinal stable of my kind of electrical car, from another side it is inner layout (location pilot/passenger seats, baggage, entertainments, location/way of opening doors, windows, stairs e.t.), which gives the best ergonomic and comfort to do the purpose of

the vehicle.

Position of the airplane center of mass is determined relative to nose part of wing mean aerodynamic chord. The recommendation distance for the center of mass (point 0) from nose part of mean aerodynamic chord X_m has such values for the airplanes with swept wing.

Distance from the center of mass to the nose of the wing MAC is calculated by following formula:

$$X_{C.G.} = (0.26...0.30) * b_{MAC} = 0.26 b_{MAC} = 0.26 * 1.01 = 0.26 \ m$$

For the swept wing $\chi = (30...60)°$ $x_m = (2.5...3.5) b_{MAC} = 2.5 * 1.01 = 2.52 \ m$ − the distance from one - fourth of the MAC horizontal tail to the center of mass.

Operational cases you can find in regulations, such as CS-23, or in regulations of aircraft certification.

The calculation of the center of mass of the designed aircraft was performed for the following operational case:
- aircraft weight − take-off,
- landing gear − Non-retractable landing gear,
- payload − maximum,

Relative to the mean aerodynamic chord is the relative coordinate of the center of gravity $\overline{x_m} = \frac{x_m}{b_{MAC}} = \frac{2.52}{1.01} = 2.5 \ m$

Limit front center of gravity $\overline{x_{l,f}} = 0.157 b_{MAC}$
Limit rear center of gravity $\overline{x_{l,r}} = 0.318 b_{MAC}$

1.4 Modeling the aircraft

At this part, I have created the modeling of the electrical aircraft by using the software NX 7.5. I have divided the aircraft parts into Fuselage part, Wing part, and Tail part including vertical tail and horizontal tail. The steps can be concluding as following:

1. Create planes that we used to create sketches and curves.

2. Create sketches that we should use to help with projecting curves, creating sheets and so on.

3. Creating body surfaces of each section, if needed, they should be trimmed, mirrored and so on.

4. Divided the faces to get separated sections.

The detailed steps are shown as following.

1.4.1 Creating fuselage part

At this stage, a parametric model of aircraft fuselage master-geometry has been created.

The proposed methodology is focused on the use for educational purposes, in the final stages of preliminary design and the initial stages of the schematic design of the aircraft.

The method is realized using integrated SIEMENS NX design system in order to ensure backward compatibility. This version of the SIEMENS NX system has all the necessary for the creation of parametric models features, as well as high performance. Work on the guidelines shown below does not represent essential difficulties in the new versions. The principles of creating a model of master geometry of the fuselage set out in the general technical form that allows you to use the method for other systems integrated design, with sufficient skills to use them.

In accordance with the methodology of integrated design and simulation teams of aircraft structures to create a model of the fuselage master-geometry It is performed based on the results of the preliminary design of the aircraft and the automated formation of his personality [8].

The initial data for creating the fuselage master geometry are: a generalized theoretical drawing. Conventionally, the model is divided into a model of the nose, central and tail part of fuselage.

So we can see that developing a fuselage is not an easy work since it needs many parameters and data, such as :

$$d_f \ - \ Diameters \ of \ fuselage$$
$$L_f \ - \ Length \ of \ fuselage$$
$$L_n \ - \ Length \ of \ fuselage \ nose \ part$$
$$L_t \ - \ Length \ of \ fuselage \ tail \ part$$

There the airplane modelling is created by using the data from zero approximation calculation, so all parameters need to be prepared. The detailed steps are shown following:

The first step is to set the parameters of fuselage according to zero approximation at Expression, as shown at figure 1.9.
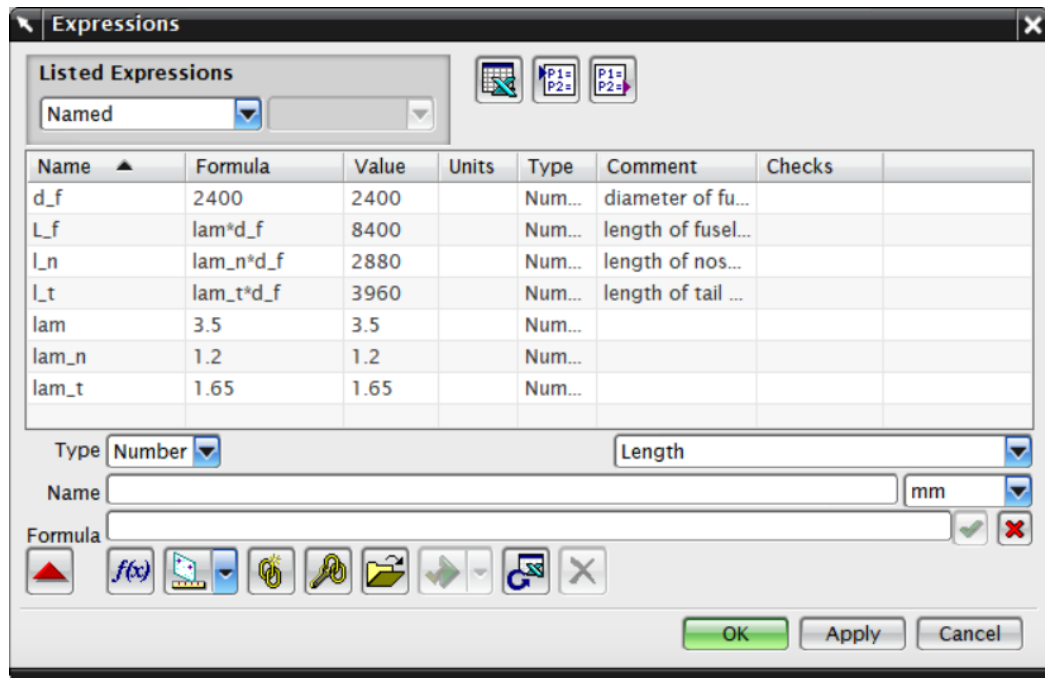
Figure 1.9 - Expression of fuselage

By using sketch construct, all the center lines and guide curves should be created. Then sketches have been drawn such as Center line sketch, Fuselage central line plan view sketch, Sketch of the top and bottom guide curves nose part of the fuselage, Sketch of the center line of the nose part of the fuselage on the plane of symmetry of the aircraft, Sketch of the top and bottom guide curves of the fuselage tail part, Sketch of the center line of the tail part of the fuselage on the plane of symmetry of the aircraft and so on. As shown at figure 1.10.
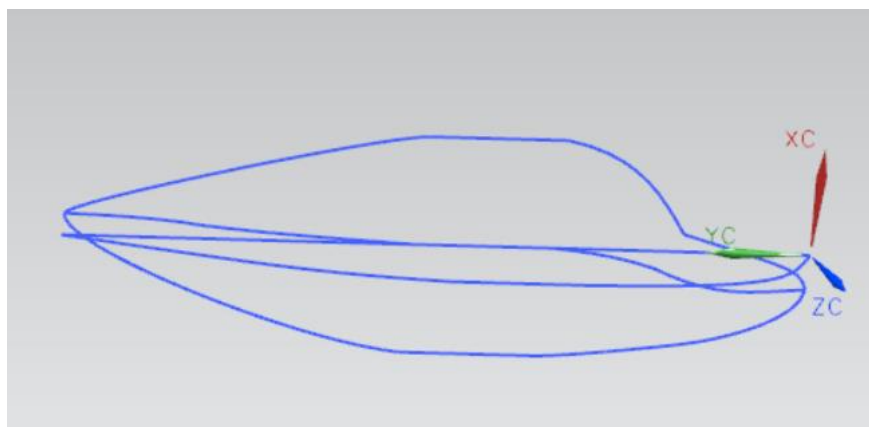
Figure 1.10 – Set of guides and generators of Fuselage

Then some space curves which should be used to build the surface are created by using Combined Curve Projection, as shown at figure 1.11, 1.12.
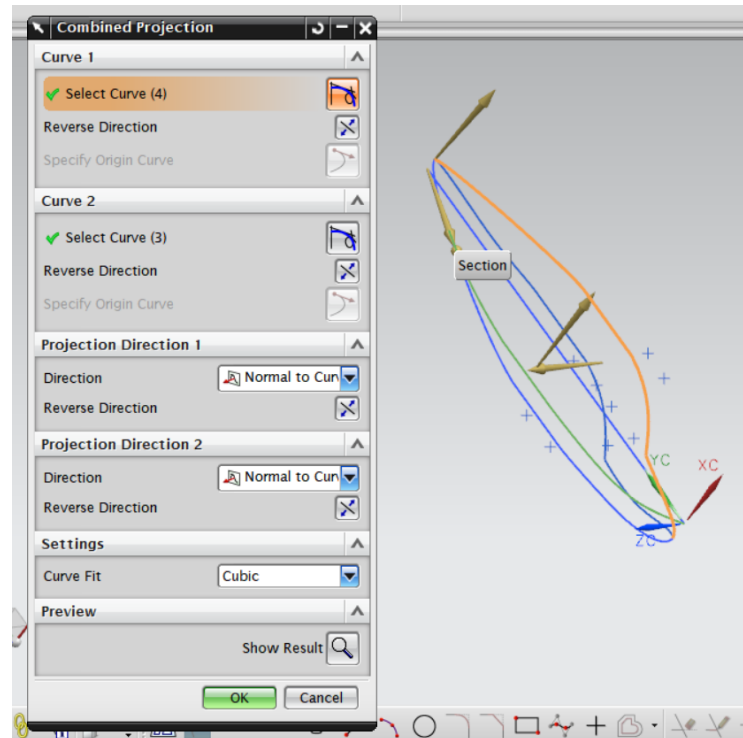
Figure 1.11 - Combined projection option
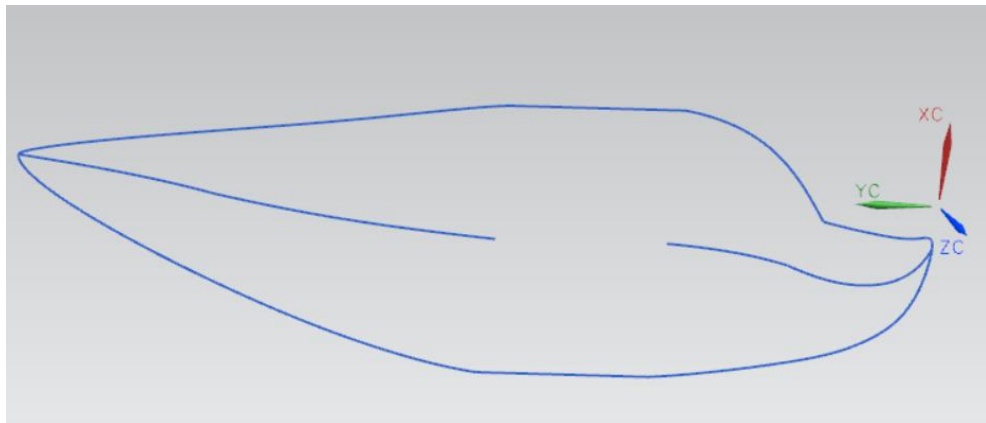
Figure 1.12 - Space Curves

Next step is to create surfaces by using Section Surfaces and Mirror Body. At this step, the first step is to separate the surfaces of fuselage into several faces. There the half of fuselage surface is separated into four segments to ensure the smoothness and accuracy of the connection of these parts, as shown at figure 1.13 - 1.16.

To construct segments 1-4, the Section Surface method is used to provide high accuracy, constancy of the section shape and flexibility in controlling their parameters. The shaping of the surfaces of each of these segments is carried out by continuous displacement of the generatrix of the conic curve along the guides.
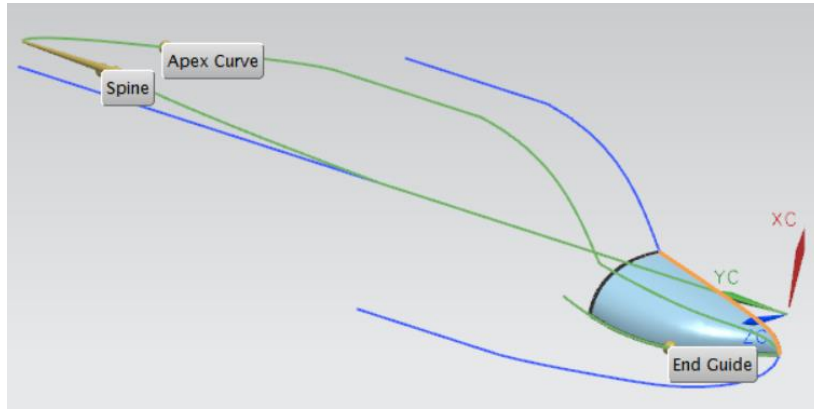
Figure 1.13 - Segment 1 of fuselage surface
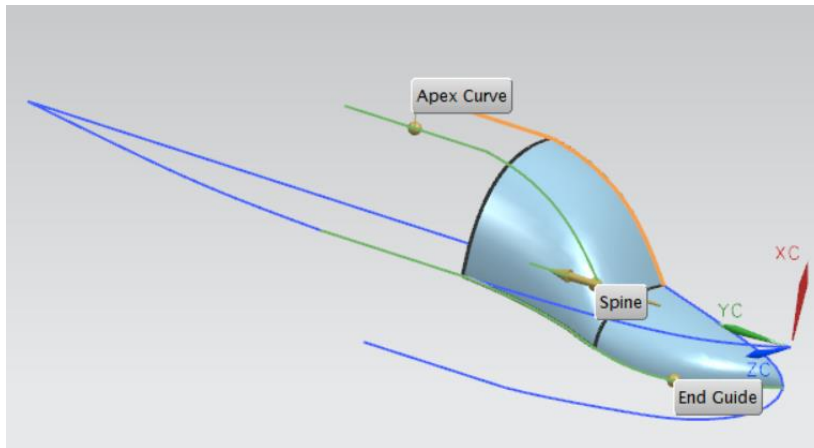
Figure 1.14 - Segment 2of fuselage surface
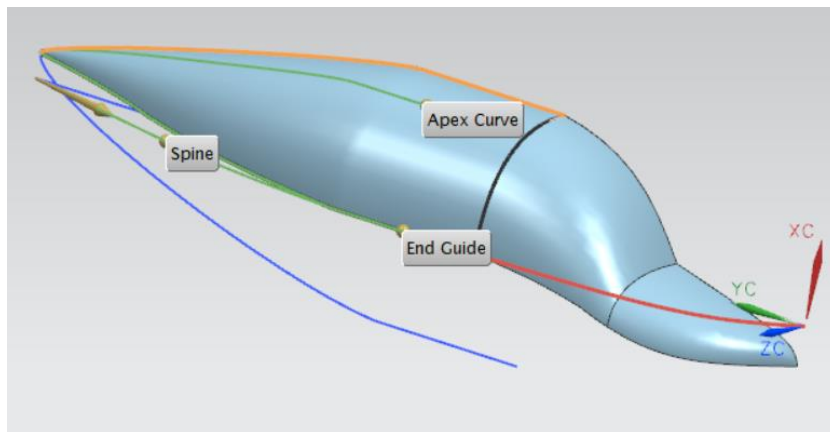
Figure 1.15 - Segment 3 of fuselage surface
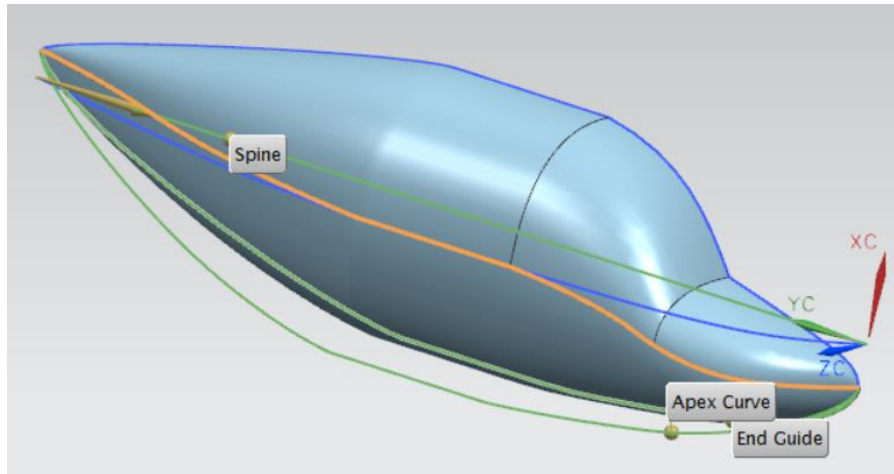
Figure 1.16 - Segment 4 of fuselage surface

The final result of created fuselage surface is shown as following figure 1.17.
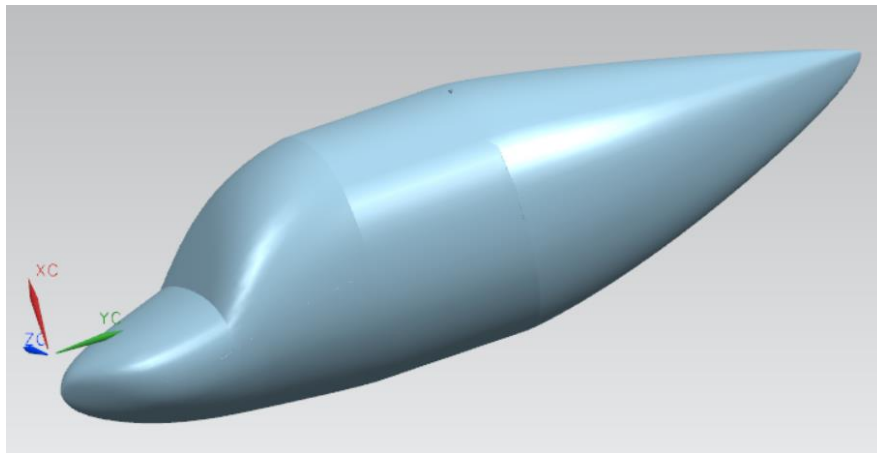
Figure 1.17 - Fuselage body sheets

The next step is to create sketches of windows and doors, which is shown at figure 1.15. There to make sure pilots and passengers were able to enter the plane without incident, and also to keep the skin strong, the height of door is set with 1.4 meter with chamfer. Since the aircraft is designed to sightseeing, the window here should be as large as possible to give visitors a better view, there set with 50 centimeters.
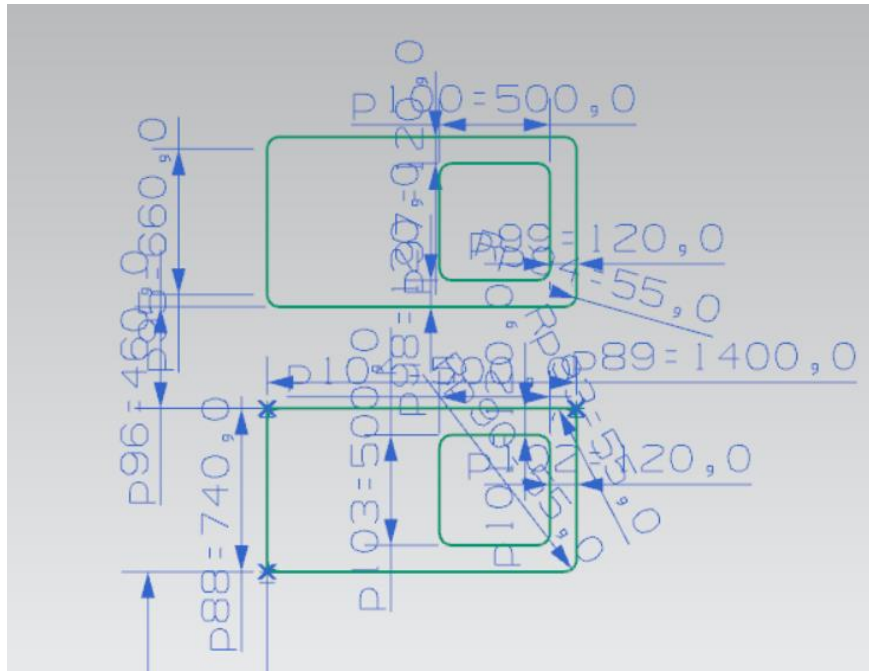
Figure 1.18 - Sketch of doors and windows

After half of fuselage has been built, then Mirror Body instruct should be used to build the whole fuselage body. The bodies are selected which have been created in last step, and the mirror plane used existing XC-YC plane, as shown at figure 1.19.
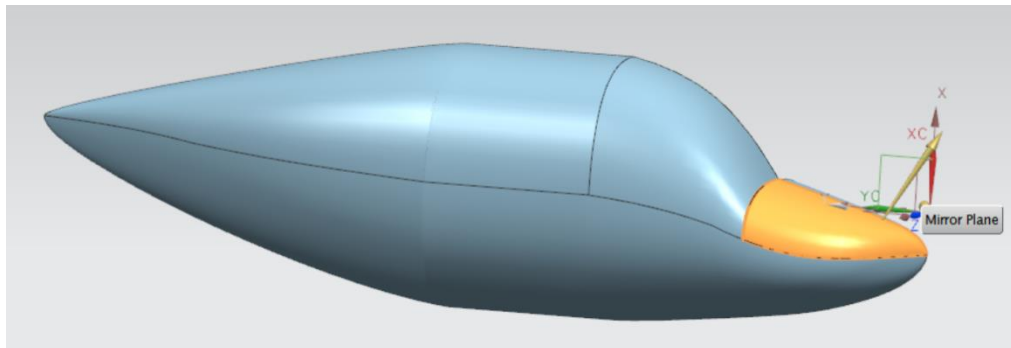
Figure 1.19 - Mirror fuselage body

Then the curves which in sketch should be projected to the fuselage body to get some curves in the fuselage sheets, as shown at figure 1.20. Since the idea is to design a four seats airplane, in addition to the cockpit and the passenger seats next to the cockpit, there are also two seats in the back for passengers. So in addition to the cockpit doors on both sides of the nose part, also needed to arrange the passenger doors at the center section. Since there were only two passengers, it would not be too hard to get them on one side, so the passenger door only set on one side and the Windows on the both sides.
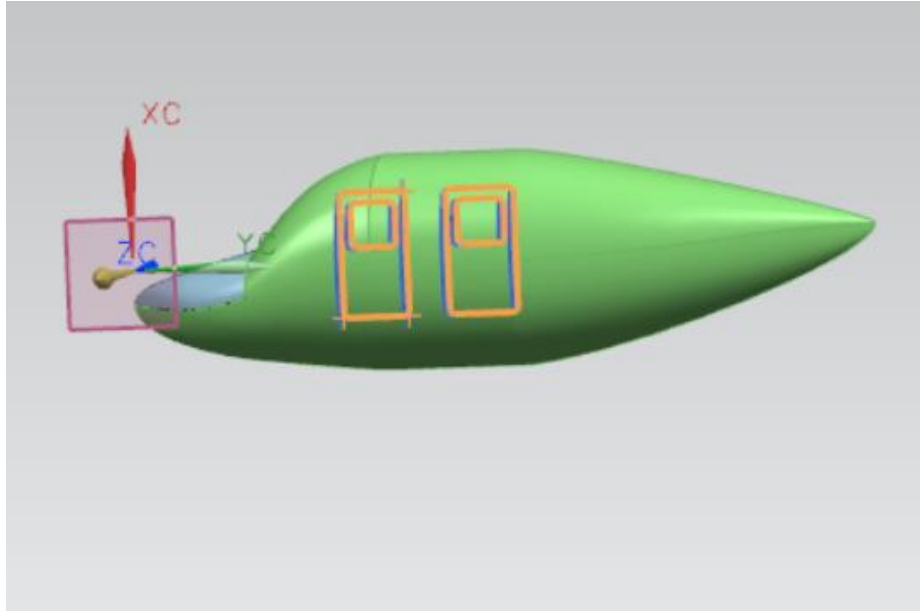
Figure 1.20 - Project curves on fuselage body

Then it goes to step, trimmed windows and doors from fuselage body, the options are shown at figure 1.21 and 1.22.
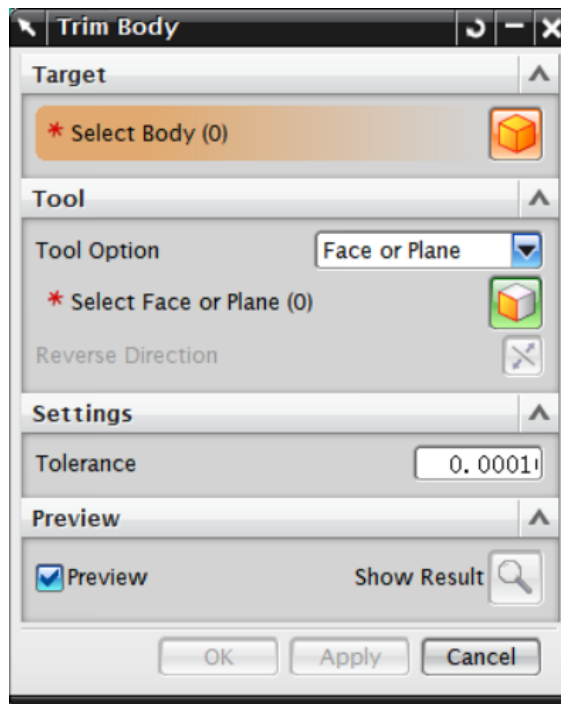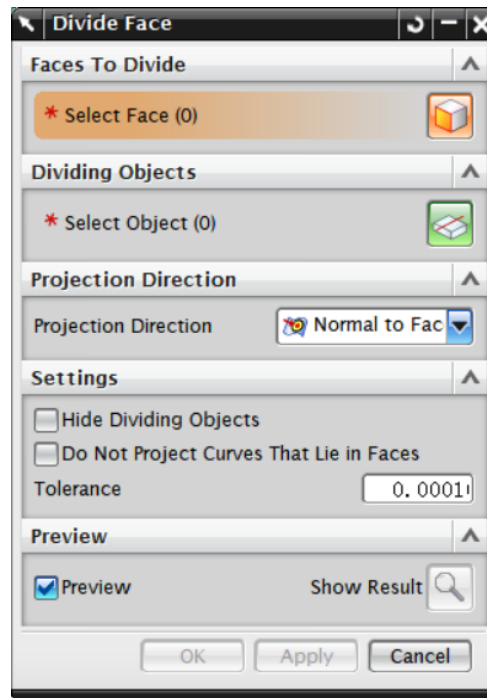

Figure 1.21 - Trim body

Figure 1.22- Divide face

The result is shown at figure 1.23. Different colors are used to show that they are different sections, the segment with gray color is the fixed fuselage section, made of aluminum alloy. Segments with blue color are cabin doors, which are movable. Segments with yellow color are widows, which made with three level to make sure the leakproofness and made by Acrylic resin.
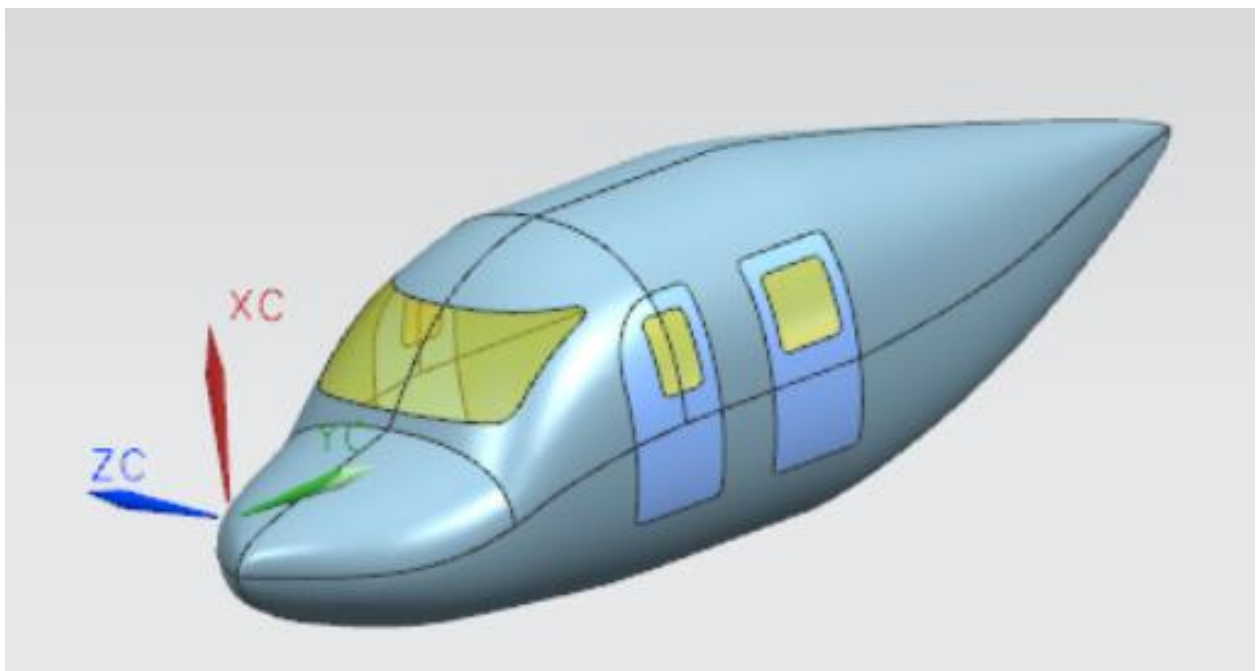

Figure 1.23 - Trimmed fuselage body

1.4.2 Creating wing part

At this item the modeling of wing is created. The initial datas of creating a parametric model of the aircraft wing are:

- l – span, mm;

- b_0 – root chord, mm;

- b_t – tip chord, mm;

- b_{0i} – true root chord, mm;

- b_{0t} – true tip chord, mm;

- α_0 – angle of wing setting in root section, degrees;

- α_t – angle of wing setting in tip section, degrees;

- χ_{LE} – leading-edge sweep angle, degrees.

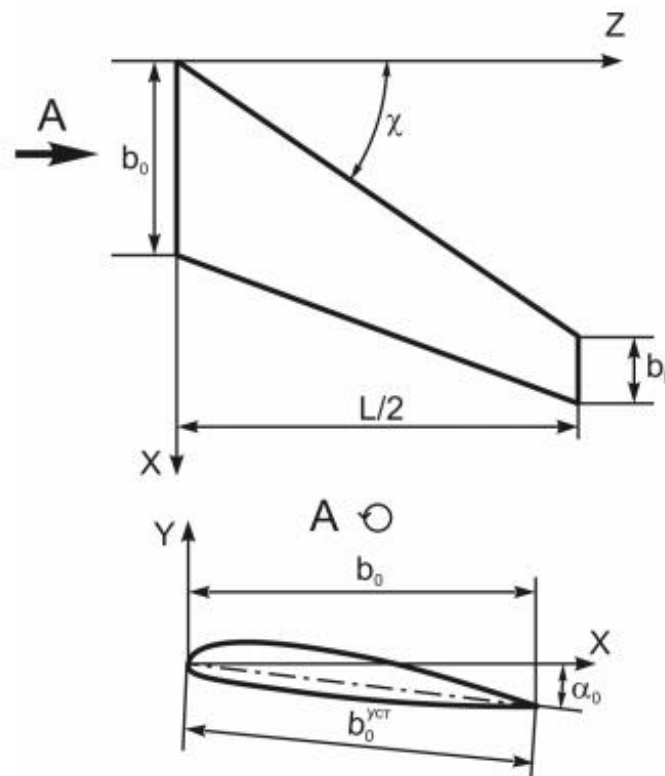A diagram of an airplane wing is shown at following figure 1.24.

Figure 1.24 - Aircraft wing theoretical drawing fragment with the initial dates

The first step is to set the parameters of wing according to zero approximation at Expression, as shown at figure 1.25 and 1.26.
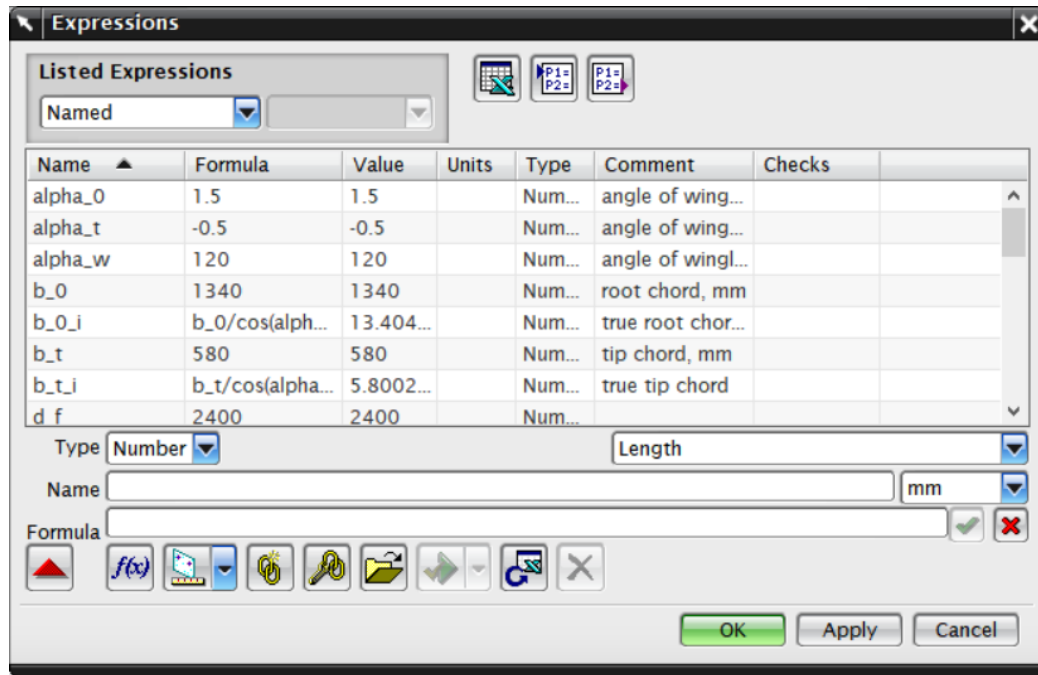
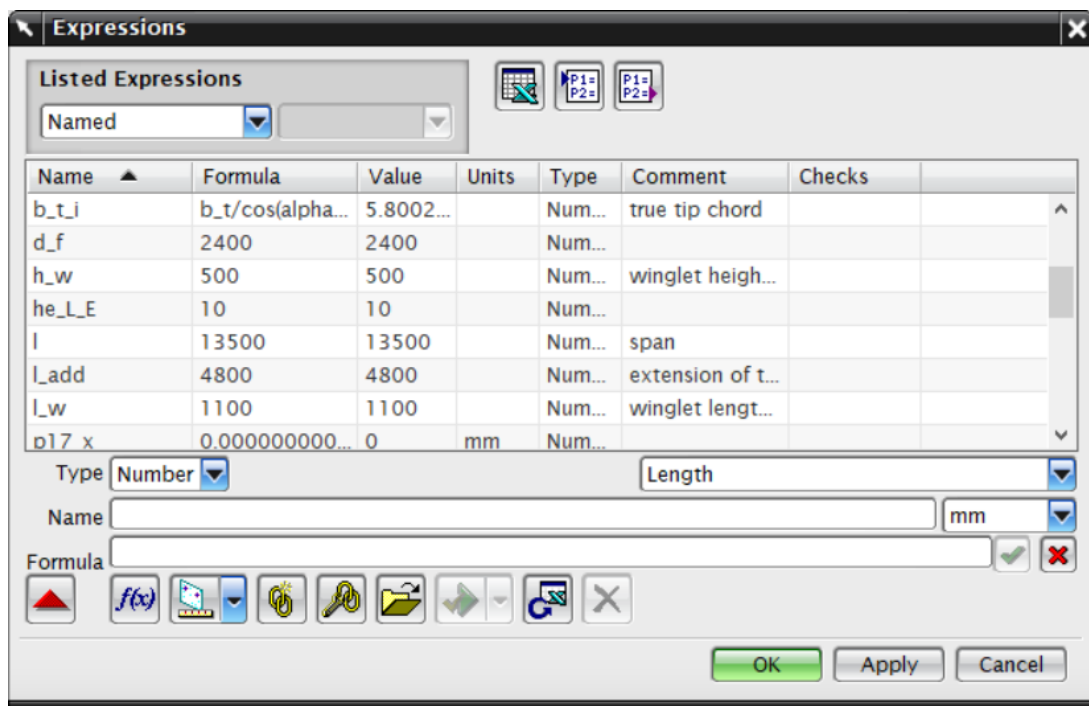Figure 1.25 – Expressions parameters of wing

Figure 1.26 – Additional expressions parameters of wing

Next step is to create sketches of wing tip and wing root. In a word, is to determine the position of points on the wing tip and wing root. In this step, some parameters such as root chord, tip chord and so on should be used to give the sketches constrains, as show at figure 1.27. and 1.28. There NACA-2212 type of airfoil is used.
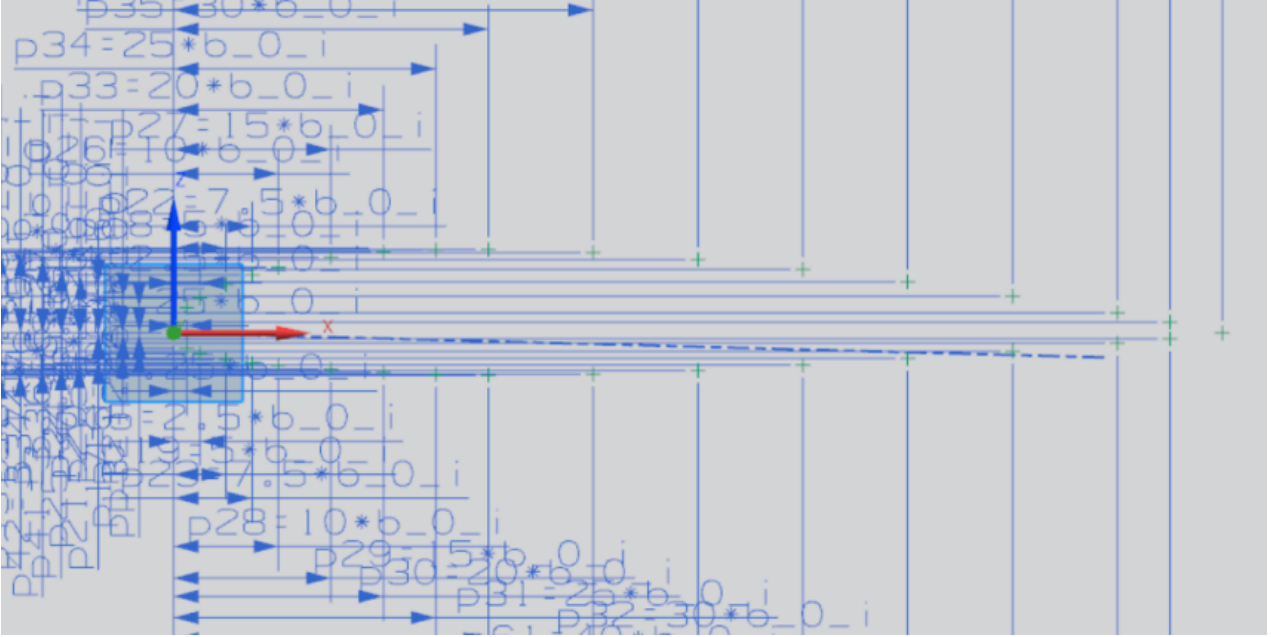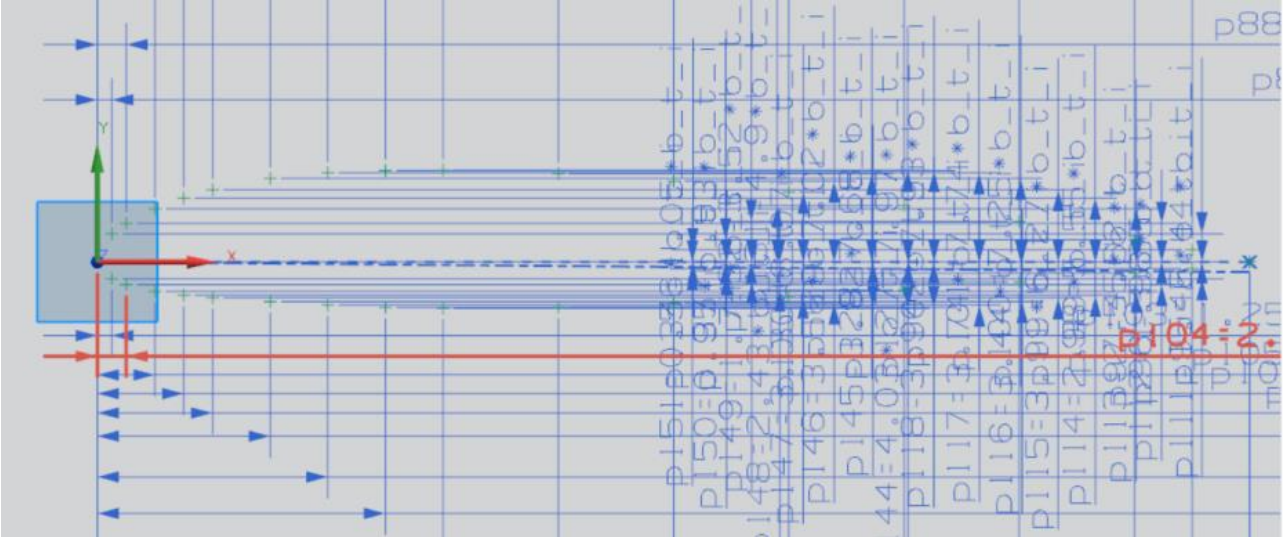
Figure 1.27 - Sketch of wing root

Figure 1.28 - Sketch of wing tip

After that goes to created splines. There the vector of some points should be defined to ensure the shape of the wing. For example, the upper curve should be tangent with lower curve at the leading edge point, as shown at figure 1.29.
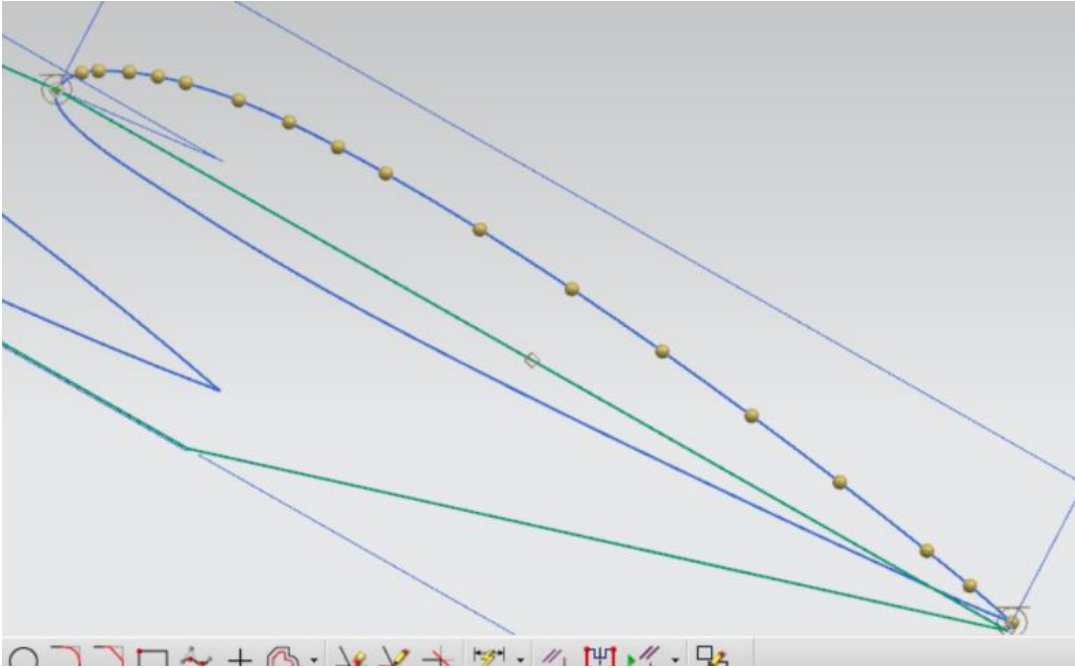
Figure 1.29 - Curve from points

Next step is to use the wing tip curve, wing root curve, leading edge curve and trailing edge curve to do mesh through curves. By using such methods I can build the upper surface, which is shown at figure 1.30.
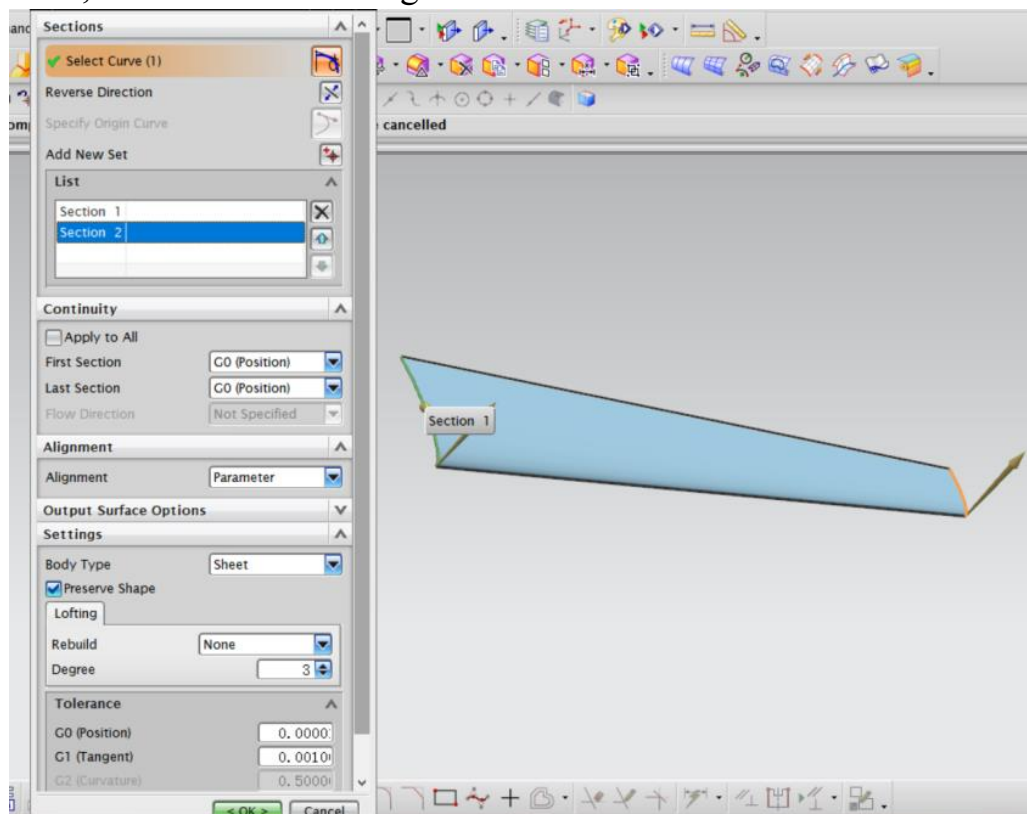

Figure 1.30 - Upper surface of wing

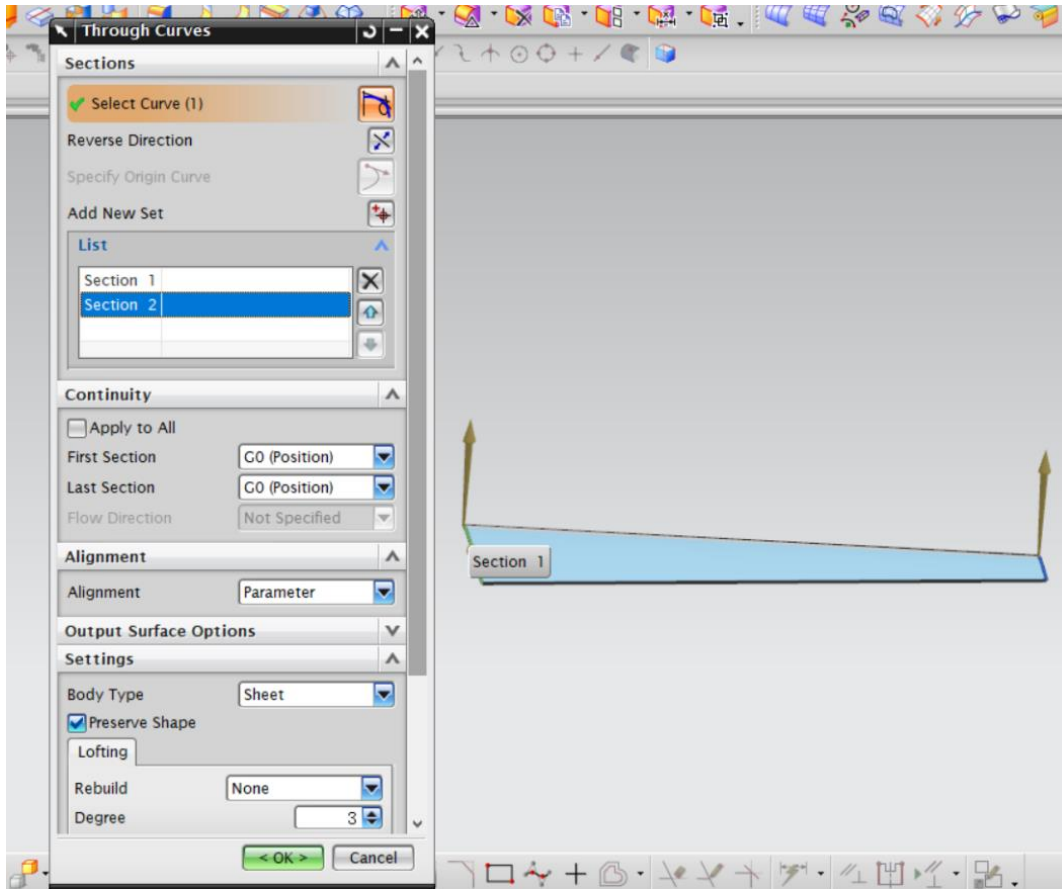There same method is used to build the wing lower surface, as shown at figure 1.31.

Figure 1.31 - Lower surface of wing

At next step, upper and lower surfaces of wing central section were built by Extrude method). The result is shown at figure 1.32.
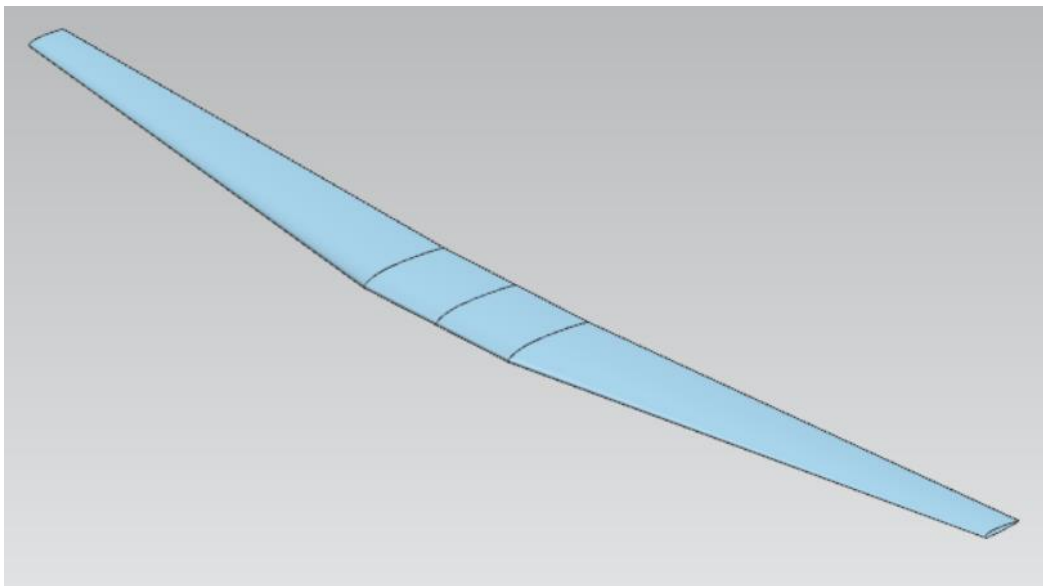

Figure 1.32 - Sheet of wing

1.4.3 Creating tail part

The steps that creating horizontal tail is similar to the wing, the steps to create the vertical tail are shown in detailed.

The define of the parameters in Expression, as shown at figure 1.33.

Figure 1.33 - Define parameters of vertical tail
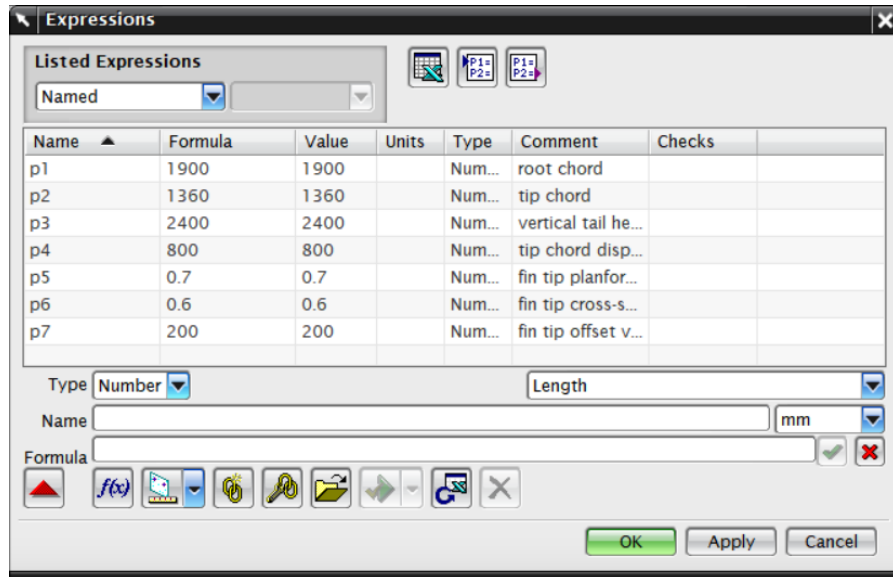
After defining parameters, it goes to create sketch of vertical tail planform, as shown at figure 1.34. The parameters above should be used, as well as some constrains.
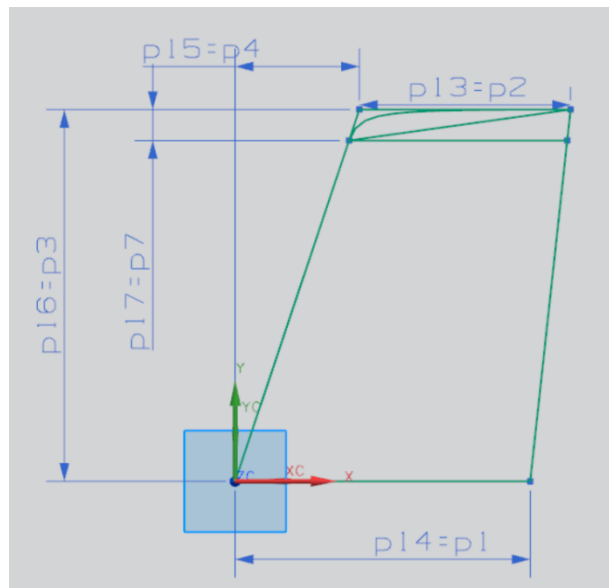

Figure 1.34 - Sketch of vertical tail planform

Then goes to create sketch of vertical tail tip airfoil. There the NACA 0012 type airfoil is used. The points coordinates are shown at following table 1.4.

Table 1.4 - NACA 0012 type airfoil points coordinates

Type of curve	Points coordinates		
	X_{upper}, %; X_{lower}, %	Y_{upper}, %	Y_{lower}, %
Spline	0	0	0
	1.25	1.89	1.89
	2.5	2.62	2.62
	5	3.56	3.56
	7.5	4.20	4.20
	10	4.68	4.68
	15	5.34	5.34
	20	5.74	5.74
	25	5.94	5.94
	30	6.00	6.00
	40	5.80	5.80
	50	5.29	5.29
	60	4.56	4.56
Line	60	4.56	4.56
	1	0	0

Several arbitrary points are drawn, then use constrains to give them specific location, next is to use Spline Through Points and insert Straight line to create the curves. The result is shown at figure 1.35.
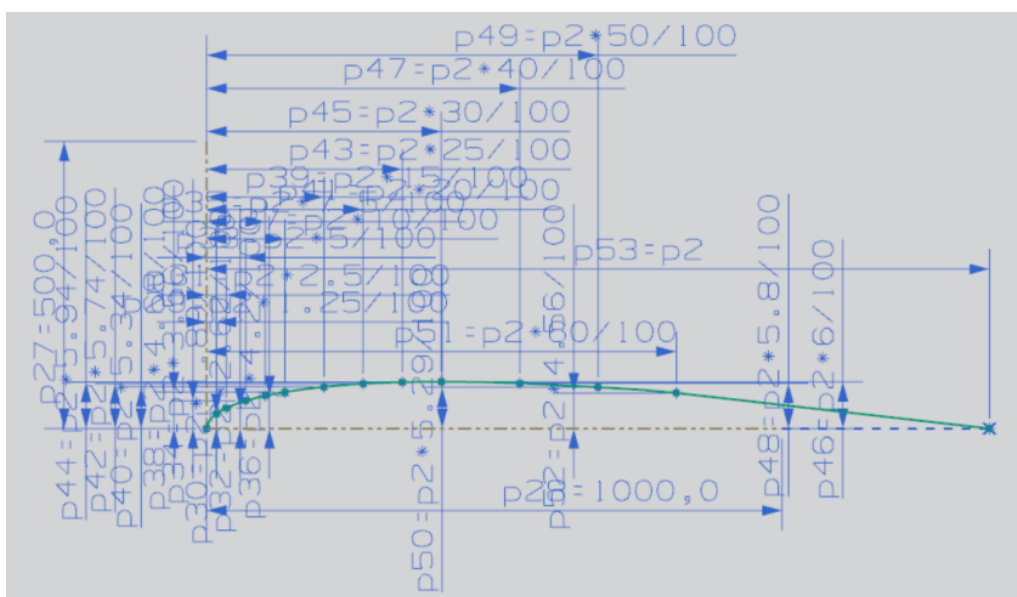

Figure 1.35 - Stretch of vertical tail tip airfoil

Next step is to create vertical tail surface, the result is shown at figure 1.36.
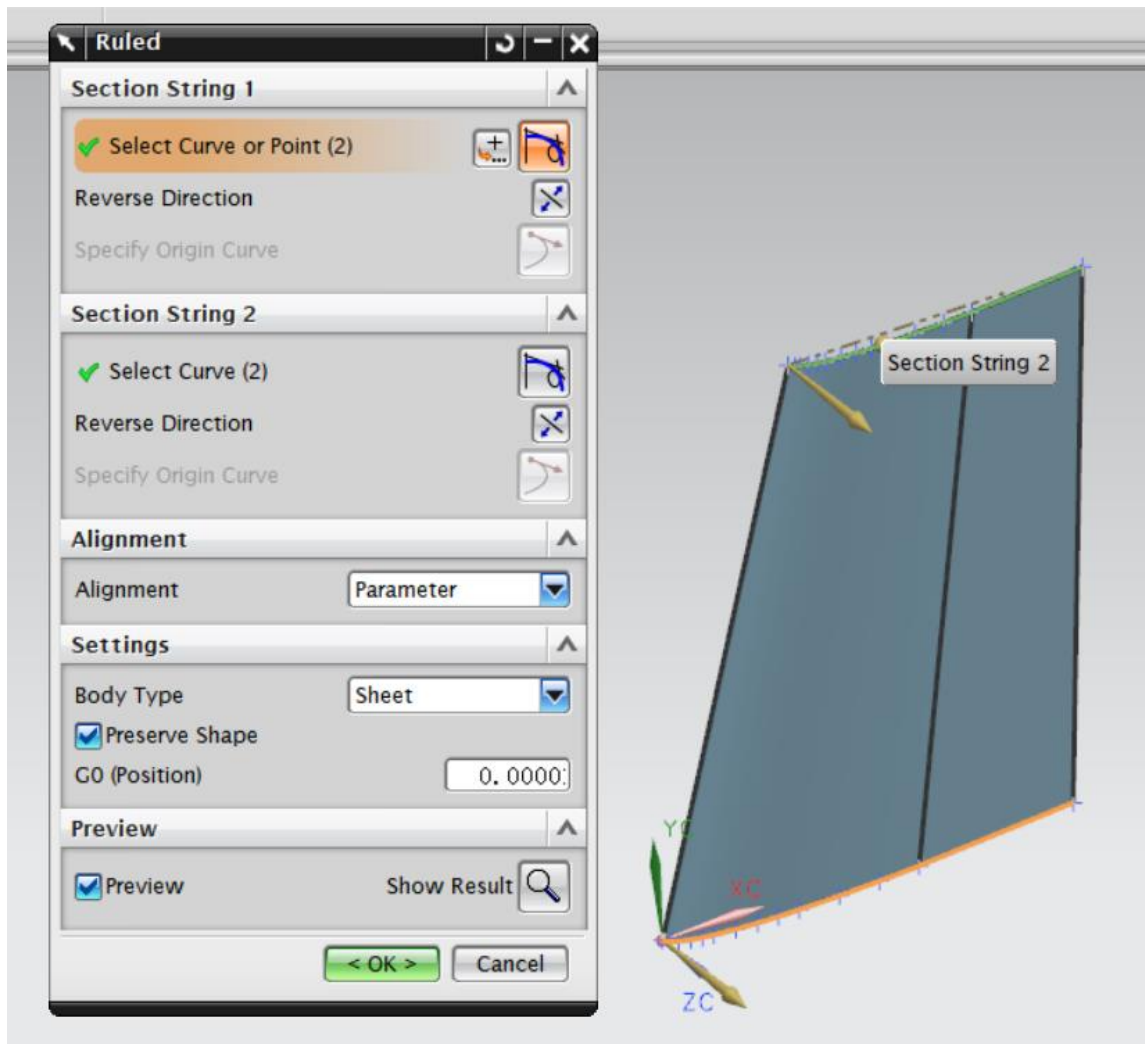

Figure 1.36 - Vertical tail surface creating

Create surface by which vertical tail surface will be cut for creating fin tip, Cut the vertical tail surface, Create spine curve for creating fin tip surface, Create additional surface for creating fin tip and the last step Mirror body, I can get the finial drawing of vertical tail, as shown at figure 1.37.

Some instructs should be used, for example:

◆ Insert → Design Features → Extrude. At this instruct, I should know the limited distance, and the section is fin tip planform.

◆ Insert → Trim → Trim Body. At this instruct, I should know which section I should trim and which section I should retain.

◆ Insert → Associative Copy → Mirror Body. About this instruct, I should know where is the mirror plane, if it not exist, I should create the plane first.
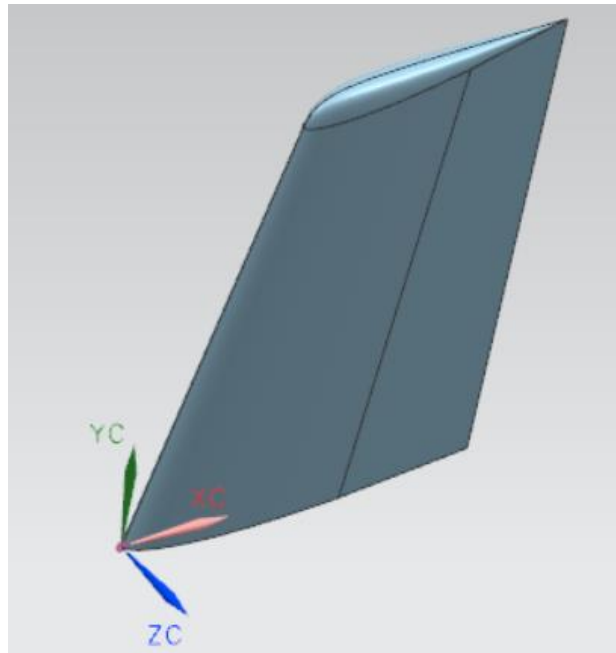
Figure 1.37 – Master-geometry of vertical tail

1.4.4 Assembly of modeling

The airplane has a classical aerodynamic scheme with lower wing and single vertical tail and horizontal tail located in the end part of the fuselage. The aircraft is equipped by control surfaces (aileron and spoilers on the wing, rudder on the vertical tail, and elevator on horizontal stabilizer) and mechanization (lift devices) – double slotted flap and retractable slats.

To create parametric model of master-geometry of designed aircraft the three-dimensional software Siemens NN 7.5 were used.

The assembly navigator is shown at figure 1.38. The thing to note here is that the all Model files and Assembly file should be located at a common file without special character. There the method up to down is used to assign the assembly. Settled the location of tail units at first, then use constrains and Dynamic to locate the wing and fuselage.
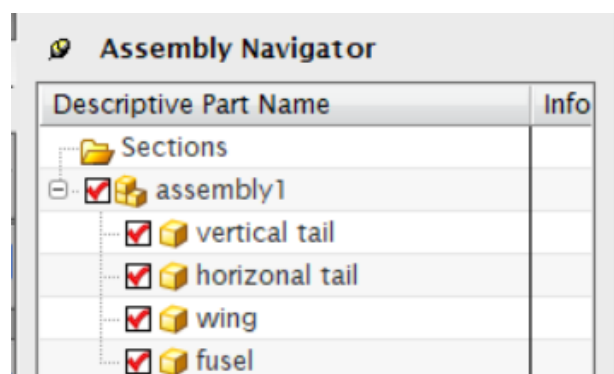
Figure 1.38 - Assembly navigator

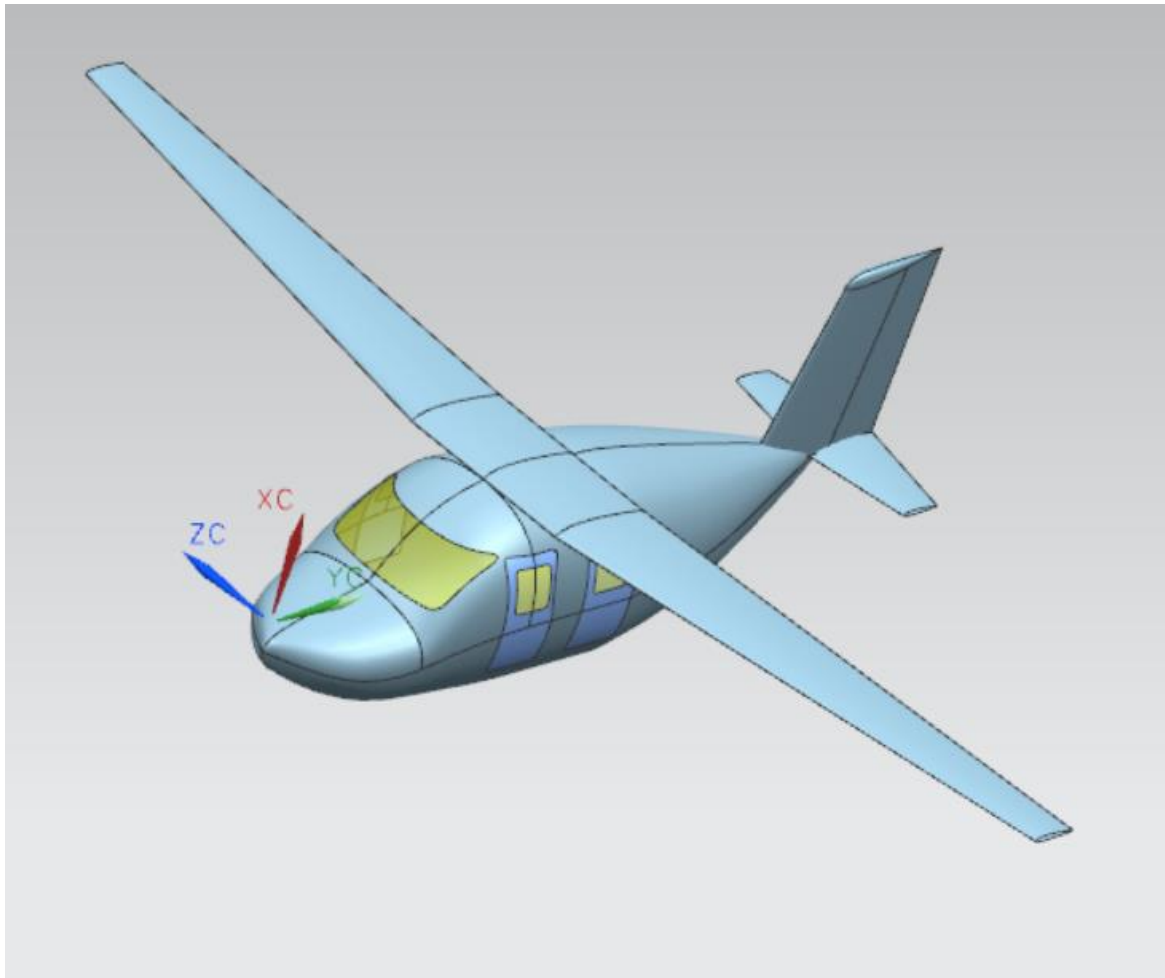The assembly model of fuselage master-geometry is shown at figure 1.39.

Figure 1.39 – Master-geometry of designed light aircraft

1.5 Design Features of an Electric Light Aircraft Discussion

1.5.1 Low cost

For the traditional aviation industry, fuel prices have been a key factor in determining the cost of flying because of the burn of jet fuel. The figure below shows how jet fuel prices are moving these years.
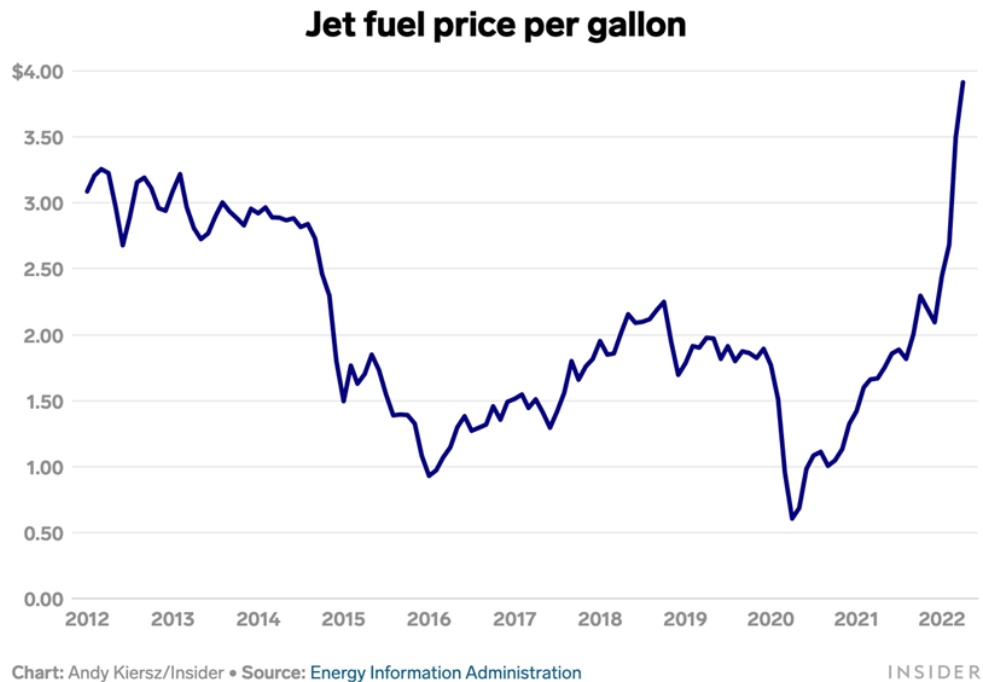
Jet fuel price per gallon

Figure 1.40 - Jet fuel price trends

As we can see from the chart, although jet fuel prices will sometimes fall, this seems to make it cheaper for airlines to operate. But when fuel prices fall, it also means that the world economy is in a slump, and people don't have much spare money to take plane, it also means that the airline industry is in a slump. So we have to consider the price of fuel when think about the cost of flying

Since the types of electrical aircraft the decision to design a kind of all-electrical aircraft has been made. Because it is powered by electric but not fuel, and electrical energy is much cheaper fuel assumption, because of electricity can also be obtained from nuclear power plants, wind power and other sources, so AEA has the feature with low cost [9].

1.5.2 Zero emission

Because of the carbon in jet fuel, when the fuel is burned, it inevitably produces carbon dioxide, a greenhouse gas. The excessive emission of carbon dioxide will cause the intensification of the greenhouse effect and seriously damage the earth's environment. The chart below shows how much carbon dioxide emission caused by aviation industry.

Figure 1.41 - Carbon dioxide emissions from aviation

As can be seen from the trend chart, carbon dioxide emissions from the aviation industry are rising sharply every year, due to the rapid development of the aviation industry and the increase in the number of airplanes.

When we use new energy such as electric to carry out aircraft propulsion, it could lead to zero emission without emitting carbon dioxide, which is also the feature of all-electrical aircraft.

1.5.3 Low noise

Aircraft engine noise has always been an important factor that interferes with passengers' comfort experience during flight. Many people check in away from the engine, and airlines provide headphones to silence noise on long flights.

The two main sources of jet engine noise are fan noise and exhaust noise, as shown at figure 1.42. Jet engines are widely used in fuel - powered aircraft, so this noise is inevitable.

Figure 1.42 - Noise of exhaust duct

Because of using electrical engine as power generator instead of jet engine, the AEA also the feature with low noise.

The purpose of such kind of electrical aircraft is to open sightseeing routs above the cities, so the comfort of passengers on the plane needs the utmost attention. There the confirmation appeared of choosing reduce the noise as feature.
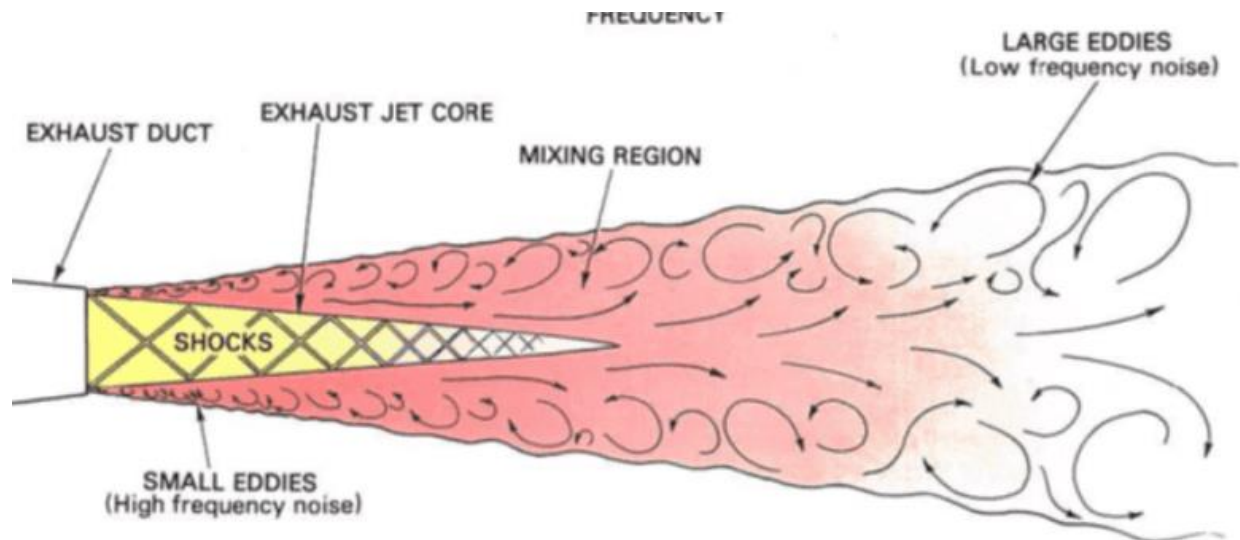
1.6 Change the fuselage material to reduce the noise

There are three ways to control noise:

1. Controlled from the source.
2. From the human ear.
3. From the transmission process.

The first way is about electric engine, not about aircraft design. The second way will give passengers a bad experience. So the third way - control noise from the transmission process is concerned [10].

Aircraft noise is the sum of various noise sources in flight, including propulsion system noise and aerodynamic noise. Among them, air body noise is also called aircraft body noise, which is caused by airflow pressure caused by airflow flowing through the fuselage [11].

The all electrical aircraft uses electric engine as propulsive power, which is low noise. Here considering about changing the material of fuselage to reduce noise.

Metamaterials refer to a class of artificial composites that do not exist in nature and have special properties. In periodic composites, there are ranges of frequencies capable of prohibiting a certain propagation of classical waves, known as band gaps. A

material or structure with an elastic wave band gap, known as a phonon crystal, is a novel functional metamaterial. In 1995, Martinez-Sala et al [12] conducted acoustic tests on "Flowing Melody", a sculpture with a history of more than 200 years in Madrid, and experimentally confirmed the existence of elastic bandgap for the first time. The coefficient of thermal expansion is the physical quantity that measures the degree of thermal expansion of a solid material. We can design a metamaterial with a specific thermal expansion coefficient which has good stiffness and an elastic wave band gap. When the temperature changes, the configuration of the material changes, thus in the band gap properties.

Based on finite element and using COMSOL Multiphysics finite element simulation software, studying its band gap properties by constructing a newly proposed high stiffness arbitrary tunable bimaterial triangular lattice material (JTCLM) [13], which is shown at figure 1.43.
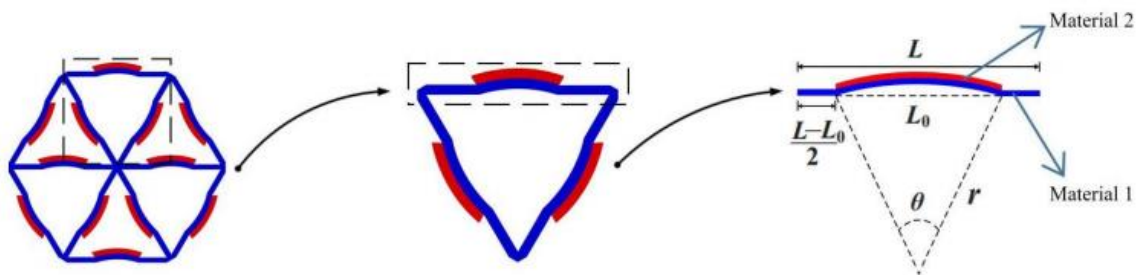

Figure 1.43 - JTCLM composite materials

When the two materials constituting the composite are determined, the total thermal expansion coefficient of the triangular monas is only related to the three geometric parameters: the curvature of the bending part, the material thickness ratio and the bending part. We design these three geometric parameters to achieve a certain thermal coefficient of expansion. When the temperature changes, the configuration becomes curved and deformed due to the different thermal expansion coefficient of the two materials, thus changing the band gap properties.

1.6.1 Some properties of metamaterials

Metamaterials refer to a class of artificial materials with special properties. These artificial media are not found in the natural world. They all have some special physical properties, such as light and electromagnetic wave can change some of their general physical properties, and this effect is often unable to achieve other traditional building materials.

With the continuous progress and development of modern engineering science and technology, the range of composite metamaterials is becoming more and more

extensive. Through material design, the properties of materials that cannot be realized in nature are designed, which has a very broad prospect.
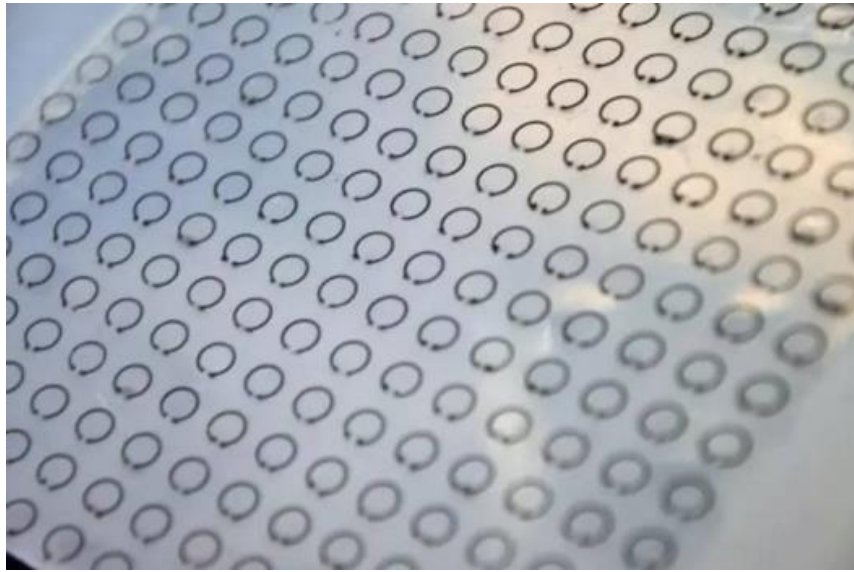

Figure 1.44 - A novel flexible, scalable and adjustable frequency stealthy metamaterial

Metamaterials has some important characteristics which we should now here, as following:

➢ Band gap property

The electron bandgap, or the range of frequencies between electron bands, is caused by the interaction between electrons travelling within a semiconductor and periodic atomic potential fields. By designing the band gap of the composite material, we can control the flow of electrons. The semiconductor technology based on silicon crystals has greatly improved our social production and life, making us a step closer to the exploration of the future and the unknown.

In recent years, guided by the theory of electron band in natural crystals, the problem of classical wave propagation in periodic composites or structures has been studied deeply. In this kind of material and structure, there exists a band gap, that is, it can prohibit the propagation of a certain classical wave in a certain range. We can see at figure 1.45. in a range of frequency, the wave can be stopped spreading.
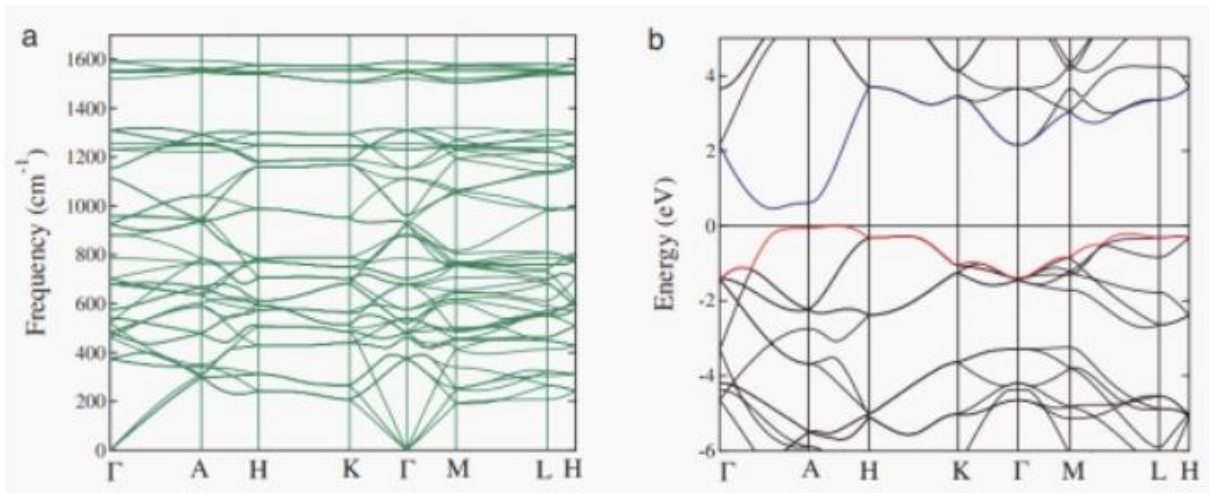
Figure 1.45 - Diagram of band gap properties

According to the different types of band gap, it can be divided into electron band gap, photon band gap and elastic wave band gap, which exist in electron crystal, photonic crystal and phonon crystal respectively.

Here we study phononic crystals, because we should use its characteristic - band gap to decrease the noise. The detailed information will be given.

➤ Phononic crystals

At the end of last century, the research of photonic crystal has been developed rapidly and attracted wide attention. In 1998 and 1999, the American journal Science listed the research results on photonic crystals as one of the top ten research advances of the year. A new concept of phonon crystal is proposed based on the analogy of photonic crystal. It has been found that the propagation of elastic waves in periodic elastic composite media also generates similar elastic wave band gaps, which leads to the analogy of photonic crystals and the concept of phononic crystals.

When the elastic wave propagates in the phononic crystal, due to the effect of the internal periodic structure, the band structure will be formed, that is, a special dispersion relationship. We call the region (frequency range) between the dispersion curves as the band gap. In theory, elastic waves in the band gap frequency range are suppressed, while elastic waves in the other frequency ranges, which we call the passband, will propagate lossless due to the effect of the dispersion relationship. If there are defects in the periodic structure of phononic crystals, then elastic waves in the band gap frequency range will be localized at or along the defects of these structures. Therefore, phononic crystals can be used to control the propagation of elastic waves.

Phononic crystals can be divided into one, two and three dimensional phononic crystals according to their periodic dimension.
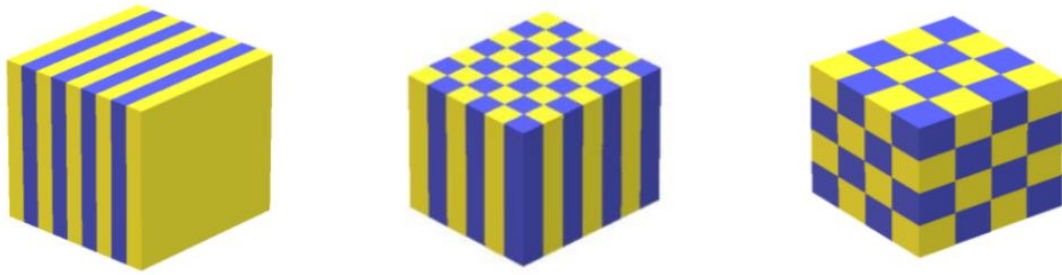
Figure 1.46 - Schematic diagram of phonon crystal structure in different dimensions. From left to right are one, two and three dimensional phonon crystals

➢ Thermal expansion

With constant external pressure, most substances increase in volume as the temperature increases and decrease in volume as the temperature decreases. Literally, the expansion of an object when its temperature changes is called thermal expansion. And the physical quantity that measures this phenomenon is called the coefficient of thermal expansion.

Through the composite of materials, we can design a positive or negative thermal expansion coefficient, or zero thermal expansion coefficient of the composite material. So that we can design and manufacture what we want, a class of materials with a specific coefficient of thermal expansion.

Thermal expansion coefficient is an important parameter to measure the thermal and physical properties of materials. In the service environment where the temperature changes rapidly, such as aerospace engineering satellites, hypersonic vehicles, precision instruments, microelectronics packaging, etc., the thermal deformation of a large number of structures needs to be accurately controlled. This shows that the development of materials with adjustable thermal expansion is not only of great scientific significance, but also very useful in practical engineering.

1.6.2 Triangular lattice material JTCLM and its characteristics

The configuration is a triangular structure composed of double ribs and can be prepared by additive manufacturing techniques such as 3D printing. The picture is shown at figure 1.47.
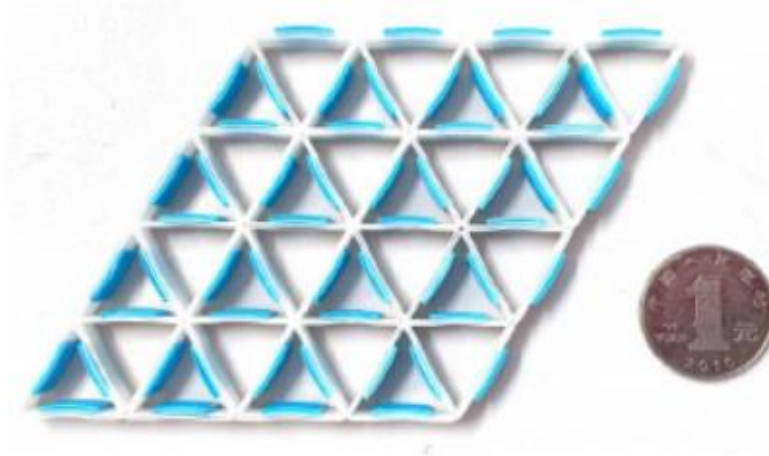
Figure 1.47 - Triangular monocell

The two materials we use here are Al and Invar alloys. The material parameters are shown in the following table.

Table 1.5 - Material parameters

Material	Young modulus （GPa）	Poisson's ratio	Density （kg/ m^3 ）	Coefficient of thermal expansion （10^{-6}/K）
Al	71	0.33	2810	23
Invar	144	0.25	8100	1.1

The dimensions of such monocell is shown at following figure 1.48.

Figure 1.48 - Dimension of rib a single cell

When the parameters of the double material and the geometrical parameters of the rib are known, the overall coefficient of thermal expansion (CTE) of the single cell can

be calculated as:

$$\overline{\alpha}_{sum} = \alpha_1 + q(\alpha_2 - \alpha_1)$$

$$\times \left\{ \begin{array}{c} \dfrac{4m^2 + 3m + \dfrac{1}{mn}}{m^3n + 4m^2 + 6m + \dfrac{1}{mn} + 4} - \dfrac{6(1+m)^2}{3(1+m)^2 + (1+mn)\left(m^2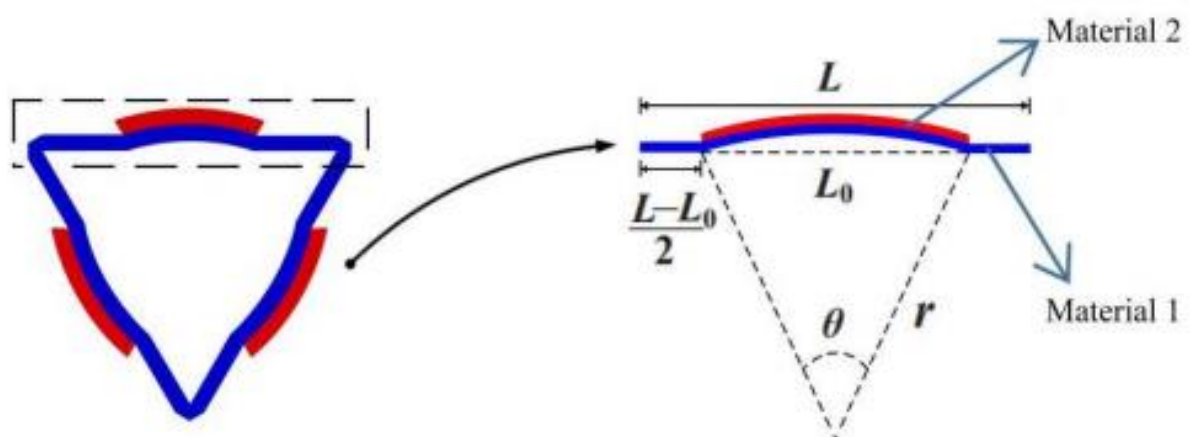 + \dfrac{1}{mn}\right)} \\[4mm] \times \dfrac{(1-q)(1+n)(1+m)^3}{2qnm^3 + (1-q)(1+n)(1+m)^3} \times \left[\dfrac{\theta qL}{12} + \dfrac{m}{2(m+1)} \right] \end{array} \right\} \qquad (1.2)$$

In this formula, the angle θ corresponding to the bending part, α_1, α_2 is the thermal expansion coefficient (CTE) of material 1 and material 2 respectively, q is the ratio of L_0 and L, where L is the overall length of the rib and L_0 is the length of the curved part of the rib, m is the ratio of the thickness of material one to material two, n is the ratio of elastic modulus of material one to material two, that is, n=E1/E2.

So when we identified two materials that make up JTCLM cells, the parameters that we mentioned before can be decided.

It means that when we change the geometric parameters of JTCLM cell, or when we change the material that made up JTCLM cells, the CTE can be changed, so the expansion characteristics will change, resulting in a change in the band gap properties.

Equation (1.1) was programmed with MATLAB software. Here, we fixed the total coefficient of thermal expansion (CTE) of JTCLM cell, that is, given a required CTE, a surface with m, q and n as coordinates could be drawn, and the coordinates of points on the surface were the geometric parameters of the JTCLM cell. We can use this to construct a triangular cell. The program is shown at figure 1.49.

```
1 -    clear all
2 -    alpha1=1.1e-6;
3 -    alpha2=2.3e-5;
4 -    CTE=0;
5 -    E1=1.44e11;
6 -    E2=7.1e10;
7 -    n=E1/E2;
8 -    L=50;
9 -    t=1;
10
11 -        syms m q
12 -    theta=(((alpha1-CTE)/(q*(alpha2-alpha1))+(4*m^2+3*m+(1/(m*n)))/(m^3*n+4*m^2+6*m+(1/(m*n)+4)))*((3*(1+m)^2)+...
13         (1+m*n)*(m^2+1/(m*n)))/(6*(1+m)^2)*(2*q*n*m^3+(1-q)*(1+n)*(1+m)^3)/((1-q)*(1+n)*(1+m)^3)-(m/(2*(m+1))))*(1
14
15
16 -    ezmesh(theta, [3/7, 4], [0.5, 0.9])
17 -    title('CTE=0, theta')
```

Figure 1.49 - MATLAB program to get geometric parameters

There we define, in the composite rib of this configuration, the outer enclosed rib material is Invar, and the inner rib material is Al, which are the materials with known physical parameters. We assign the thermal expansion coefficient, elastic modulus E1 and E2 of the corresponding material according to the related properties of the two materials, and assign the thermal expansion coefficient CTE of the triangular cell as 4. I can get a graph with m, q, θ, as following figure 1.50.
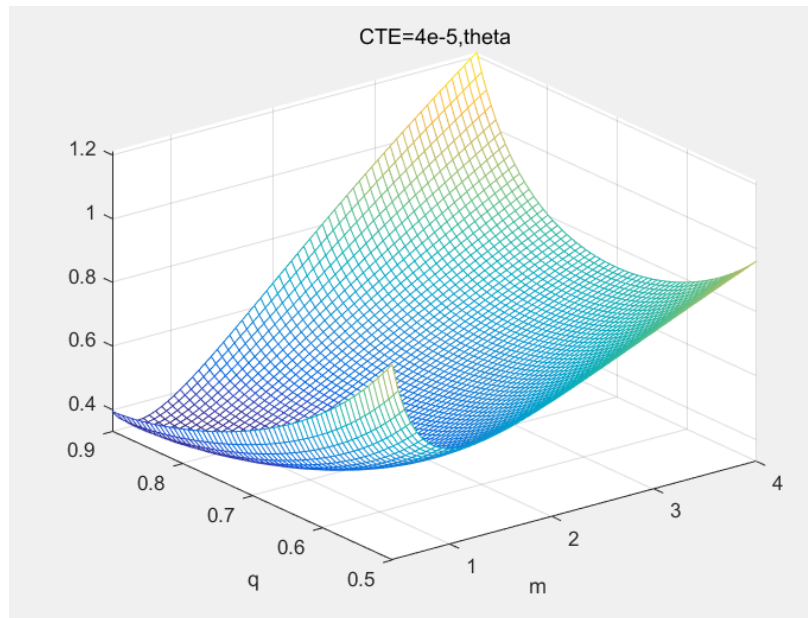
Figure 1.50 - Three-dimensional coordinate diagram with m, q, θ

Here we can randomly select the points on the graph, that is, we can randomly evaluate these three parameters. There set m=2.366; q=0.8932; θ=0.7365. And we can get the monocell diagram as following figure 1.51.

Figure 1.51 - Triangular monocell with defined parameters

In COMSOL software, the steps can be: add the physical field of solid mechanics to the physical field, set three pairs of corresponding periodic conditions, and then grid the geometric configuration. In the next step, parametric scanning is added in the study

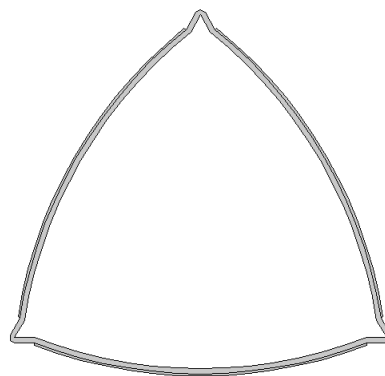to study the characteristic frequency, and the solution and parameter resolution are obtained. Finally, the band gap diagram of its configuration is obtained by plotting the parametric solution in the result. Then we use MATLAB software to process the obtained band gap diagram and get its band gap range, namely the shadow part, as shown at figure 1.52.
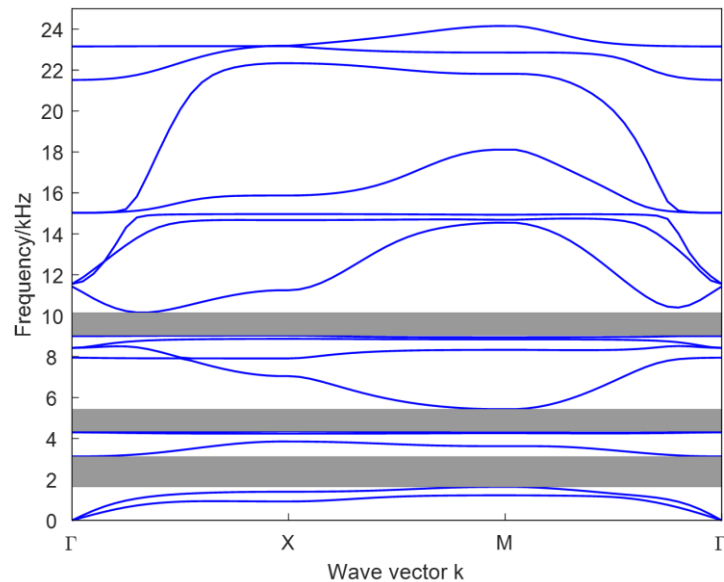
Figure 1.52 - Band gap in the above configuration

Then I derive this geometry and import it into thermal physics field for thermal deformation. Here, the thermal deformation at 300/400/500/600K can be obtained by taking 300K as the initial temperature. Taking 600K as an example, the deformed ones are shown in the following figure 1.53.
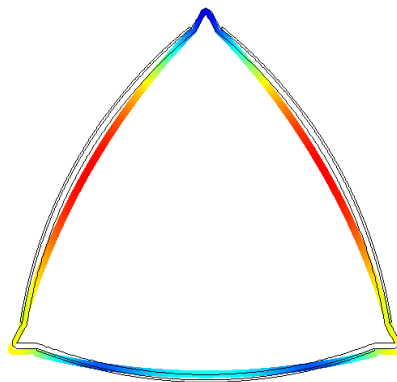
Figure 1.53 - Expanded configuration at 600K

The black line part of the figure is the geometry at 300K before thermal expansion, and the colored part is the geometry at 600K after thermal deformation. It can be seen that the whole is in a state of inward contraction. The so-called positive expansion means that the relative position of the three angles changes outward and the relative

distance becomes larger.

Then can use the same method to get the band gap figure at 600K, as shown at following figure 1.54.

Figure 1.54 - Band gap at 600K

By using the same step, the different configuration at 400K and 500K can be gotten, then the band gap figure at these two temperatures are shown at figure 1.55.

Figure 1.55 - Band gap with different temperature

It can be seen that when the temperature gradually rises from 300K, there will be a band gap in the high frequency band (20kHz), and the ba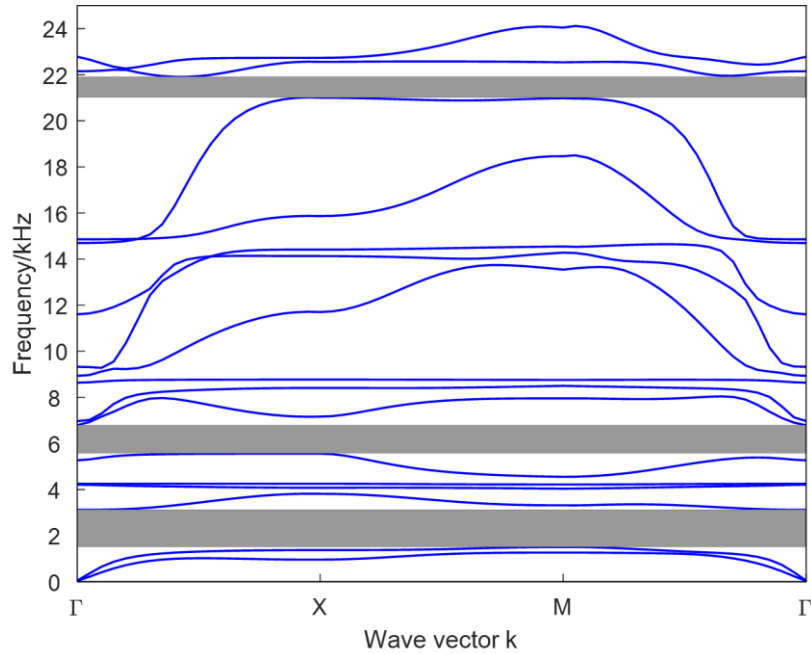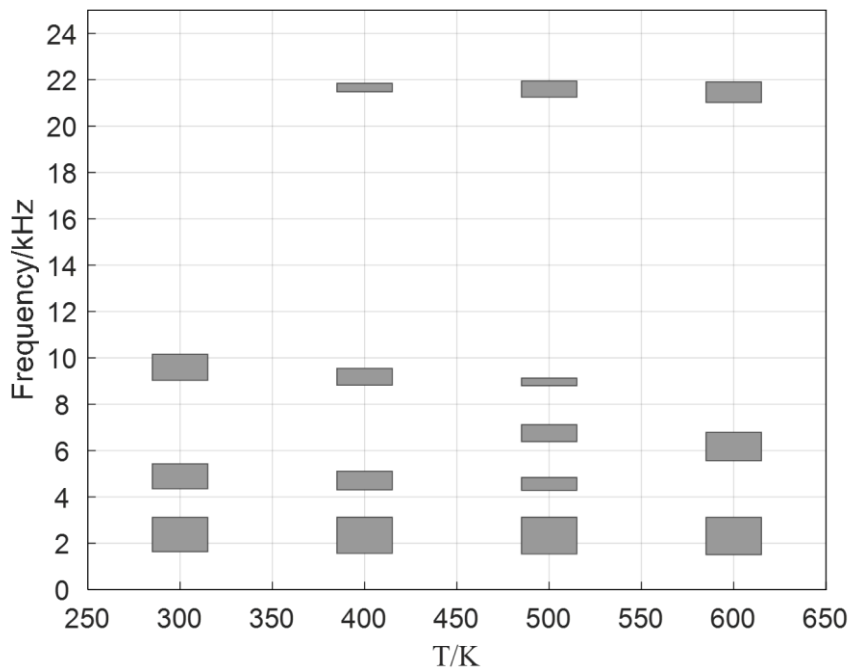nd gap range will become wider with the gradual increase of temperature. On the other hand, the width of the band gap of 9kHz will narrow with the increase of temperature, so as to gradually disappear. Therefore, we can make use of this property of the configuration to increase the band gap range of its high frequency band by increasing the temperature, or reduce the band gap of about 9kHz to regulate its band gap properties.

Using this property of JTCLM material, we can achieve the purpose of shock and noise reduction. In other words, the idea can be appeared to apply JTCLM materials to some parts of my electric aircraft to reduce noise in general, so that passengers can get a better environment and better experience when they are watching the scenery in the air.

1.6.3 Application of JTCLM to electric aircraft

When the temperature changes, various properties of the material, such as Young's modulus, elastic modulus and density, will change. Therefore, when the temperature changes greatly, it will become complicated to calculate the expansion coefficient of composite materials according to Formula 1.2 due to the change of parameters.

Therefore, in the last item 1.6.2, we only discussed the change of band gap properties of materials within the temperature range of 300K-600K, that is, the temperature variation range is small.

Another reason is that AEA don't need a gas engine to provide the power, so the temperature will not be very high in the power unit, as well as in other parts of aircraft.

There apply JTCLM materials to fuselage nose part segments of electric aircraft to reduce noise, as show at figure 1.56. and 1.57, the green surfaces are applied with JTCLM material. The material can be applied to the inside of the aircraft skin and fix it, so the skin can bear the load in flight because we need to ensure sufficient stiffness on the outside to ensure the reliability of the aircraft in normal flight. Materials can be painted in comfortable colors or even painted to ensure a comfortable experience for passengers.
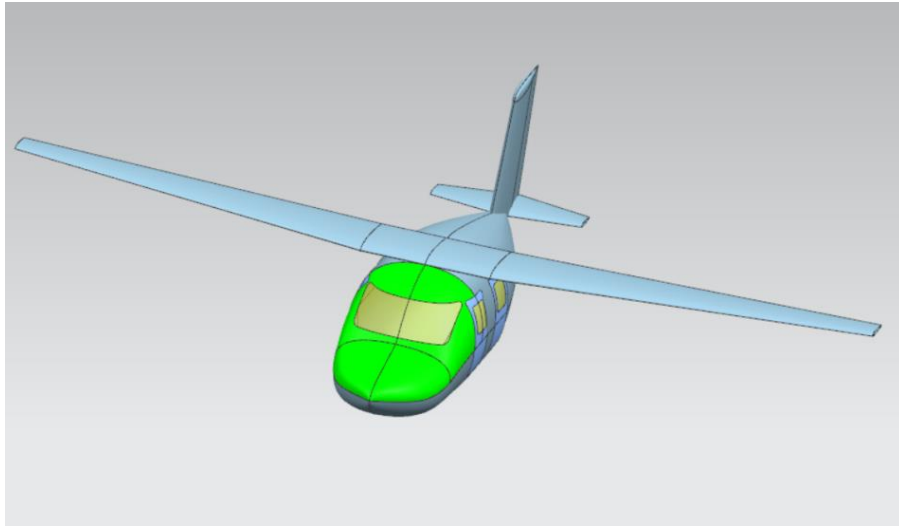
Figure 1.56 - Surfaces that applied with JTCLM material

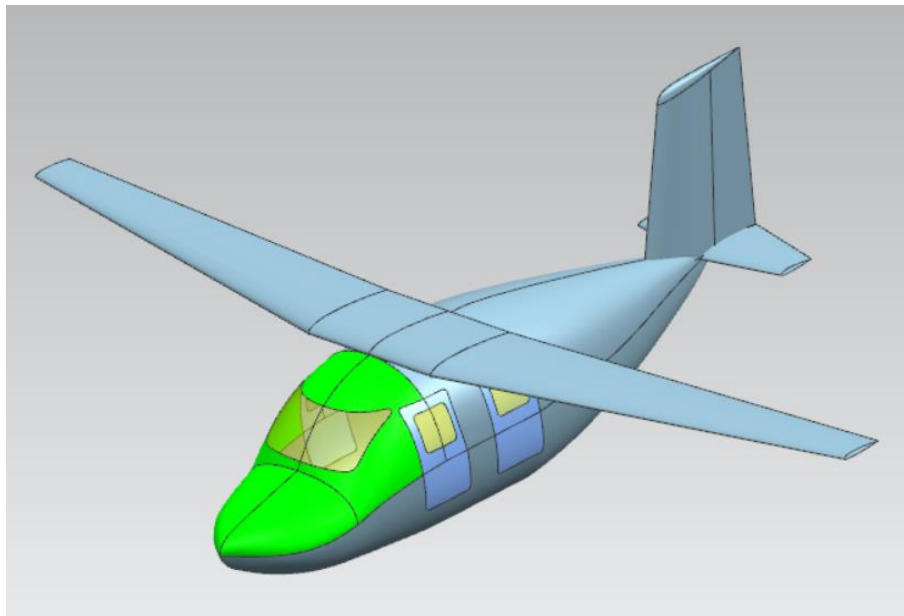
Figure 1.57 - Surfaces shown at another view

The coefficient of expansion CTE can be set as negative, positive and zero. There the CTE is set as -3×10^{-5}, using the same method of item 1.6.2, the Band gap with different temperature can get as shown at figure 1.58.
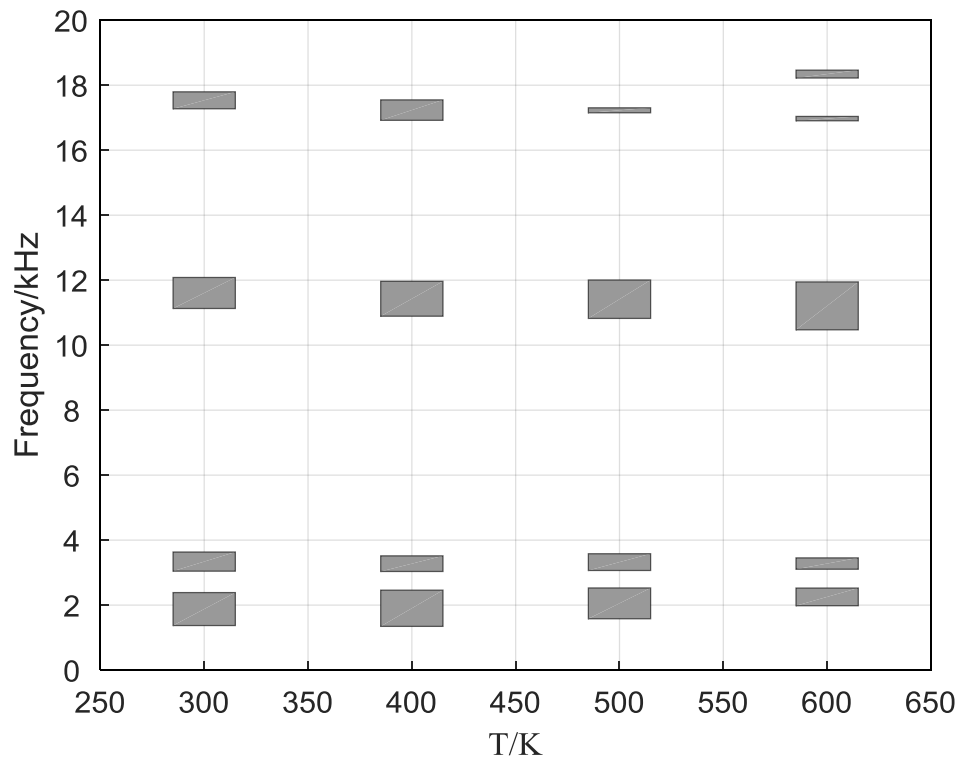
Figure 1.58 - Band gap at different temperature

It is shown at the figure that for the band gap located in the range of 10-12khz, the lower boundary gradually moves down and the band gap width gradually widens as the temperature gradually increases. Since Ukraine has a temperate continental climate, the maximum temperature of the year will be 20 higher than the minimum temperature, so we can use the characteristic of JTCLM - when temperature raises, the Anti-noise capability will be enhanced, to get a better anti-noise effect in summer, which is a suitable season for tourism.

Of course, even if the temperature does not change, because of JTCLM has a band gap property, it can still show a good anti-noise effect. That's why the material can be used in airplanes all years.

1.7 Conclusion of design section

The idea came up with to design a kind of all- electrical aircraft by analyzing the research of scientists and comparing the advantages of all-electric aircraft over conventional aircraft.

The flight assignment is to carry up to 1 pilot and 3 passengers to go sightseeing and also can used as training aircraft with range 600 km. By discussing features of all-electrical aircraft, the conclusion can be gotten that AEA has three main advantages:

zero emission, low cost and low noise. In Ukraine, three basic routes are designed: from Kyiv to Kharkiv, from Kyiv to Odessa and from Kharkiv to Odessa.

The take-off weight of the aircraft in the zero approximation is 1143 kg. Aircraft geometrical parameters were calculated which helps to create three-dimensional parametric model of project. The master-geometry of designed all-electrical aircraft is build using Siemens NX software. After collecting statistical data, it is possible to develop tactical and technical requirements. This stage is based on the analysis of the above statistical materials and Technical Requirements Specification.

JTCLM is kind of material that has the feature to prevent sound waves of a certain frequency to propagate, so it can be used to reduce noise as well as in this kind of AEA. By applying JTCLM material in fuselage segments,it can reduce noise of airplane, which will give passengers a better experience, which is the feature of the kind of electrical airplane.

2 ECONOMIC SECTION

2.1 Initial data

- No. of working days in a month (W_{days}) = 22 days/month
- Workers salary (W) = 44000 UAH/month
- Total number of days engineer works in this project (F) = 60 days

2.2 Calculations of expenses spent on research of the project

Expenses during the course of this project is shown in the table below

Table 2.1 - Total expenses on the project

No.	Names	Expense (UAH)	Number of item	Total expense (UAH)
1	Computer	15000	3	45000
2	Working place	10000	1	10000
3	Stationeries	500	1	500
4	Software (full package)	41000	1	41000
Total				96500

2.3 Regular wage for engineer

Regular wage ($W_{total.wage}$) is the total amount paid to an engineer to complete the project, UAH;

$$W_{total.wage} = F * L_{days}$$

Where, F – Total number of days engineer works in this project,
L_{days} – daily wages of engineer.

$$L_{days} = \frac{W}{N_{days}} = \frac{44000}{22} = 2000 \ UAH$$

So we obtain:

$$W_{total.wage} = 60 * 2000 = 120000 \ UAH$$

2.4 Extra (Bonus) wages for engineer

Bonus wage (W_{Bonus}) is an amount of money bonuses paid for certain qualitative or qualitative achievements, which is 20% of regular wage, UAH:

$$W_{Bonus} = \frac{W_{total.wage} * bonus\,\%}{100\%} = \frac{120000 * 20}{100} = 24000 \ \text{UAH}$$

Where bonus percentage = 20%.

2.5 Social Measure

Social wage ($S_{measures}$) is an amount of money spent on other social activities, UAH;

$$S_{measures} = (W_{total.wage} + W_{Bonus}) * \frac{S_N}{100} = (120000 + 24000) * \frac{22}{100}$$
$$= 31680 \ \text{UAH}$$

Where S_N is Normative percentage = 22%

2.6 Management costs

Administrative expenses (E_{ad}) is the amount of money we spent to buy and repair equipment we used in our projects, which is 15% of regular wage, UAH. It also includes the cost of utilities i.e electricity, internet, heating e.t.c:

$$E_{ad} = W_{total.wage} * (\frac{\alpha_d}{100}) = 120000 * (\frac{15}{100}) = 18000 \ UAH$$

Where α_d is administrative percentage = 15%

2.7 Depreciation of equipment

When calculating the expenses, it's necessary to know the values of the annual depreciation from the values of fixed assets of the organization.

$$D = D_b * R_d$$

$$D_{computers} = 44000 * (\frac{1}{5}) = 8800$$

$$D_{working\ palce} = 9000 * \left(\frac{1}{5}\right) = 1800$$

$$D_{software} = 40000 * \left(\frac{1}{5}\right) = 8000$$

Where, Depreciation rate $R_d = {}^1/_{useful\ life}$

Depreciation Base $D_b = W_{total\ cost\ of\ n} - V_{res}$

The Residual value $V_{res} = 1000$

$W_{total\ cost\ of\ n}$ = Total cost of each fixed asset from the table 2.1

Since the duration of the project research is 2 months, the value for depreciation will be approximately 3100 UAH.

2.8 Total cost of research

Total cost price of research (C_p) is the total amount of money spent on our research including all wages, UAH;

$$C_p = 500 + 120000 + 24000 + 31680 + 13200 + 3100 = 195480 \ UAH$$

2.9 Cost profit

Cost profit (P) is a financial gain for engineer, especially the difference between the amount earned and the amount spent in producing.

$$P = C_p(profit\,\%/100) = 195480 * (10/100) = 19548 \ UAH$$

Where, Percentage of profit = 10%.

2.10 Wholesale price

Wholesale piece (W_p) is the sum of total cost price and cost profit, UAH;

$$W_p = C_p + P = 195480 + 19548 = 215028 \ UAH$$

2.11 Results of calculations

The results of calculations are shown at following table 2.2.

Table 2.2 - Calculation items used to calculate production cost

No	Calculation items	Expenses, UAH	Commentary
1	Regular wage of engineer	120000	$W_{total.wage} = F * L_{days}$
2	Extra wage of engineer	24000	20□ of regular wage
3	Social measure	31680	22%of $(W_{total.wage} + W_{Bonus})$
4	Management costs	18000	15□ of regular wage
5	Depreciation	3100	-
6	Total cost price	195480	Sum of all above expenses
7	Cost profit	19548	10□ of total cost price
8	Wholesale price	215028	$W_p = C_p + P$
9	VAT	46005.6	20□ from wholesale price
10	Market price	365514.4	Sum of $(W_p + VAT)$

2.12 Conclusion of Economical Section

In this project on research and development of the cost required in the design stage of the kind of AEA (All - electrical aircraft), excluding the manufacturing stage, after a series of calculations, the required cost is 365514.4 UAH.

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