

DANANG UNIVERSITY OF SCIENCE AND TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING



GRADUATION THESIS
CAPSTONE PROJECT

MAJOR: MECHANICAL ENGINEERING
AEROSPACE MECHANICAL ENGINEERING

TOPIC

DESIGN OF FIXTURE, ASSEMBLY PROCESS AND
INSPECTION FOR THE BOEING 757 FUSELAGE
FRAME ASSEMBLY

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GRADUATION PROJECT TASKS

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Chapter 2: Analysis of function and working conditions of the boeing757 fuselage

Chapter 3: Design and assembly of components using catia software

Chapter 4: Design of fixtures and assembly process

Chapter 5: Measurement process for fuselage frame assembly

Chapter 6: Stress and strain analysis of the fuselage frame assembly

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- | | | | |
|---|------|-------------------------------|------|
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8. *Task Completion Date:*/...../20.....

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Advising Instructor
 (Signature and Full Name)

PREFACE

The aerospace industry is constantly evolving with increasingly stringent requirements for precision, quality, and production efficiency. Among the critical tasks, the design, manufacturing, and inspection of aircraft structural assemblies play a decisive role in determining the durability, safety, and operational capability of the aircraft.

Fixtures are one of the key factors in the assembly and inspection processes of structural components, especially for the Boeing 757 fuselage frame- a widely used mid-range commercial aircraft. The jig design must ensure high accuracy, flexibility, and the ability to meet strict technical standards. Moreover, the assembly and inspection process must be scientifically structured to optimize time and cost while adhering to international aerospace standards.

The project titled “*Design of fixture, Assembly Process, and Inspection Procedure for the Boeing 757 Fuselage Frame Assembly*” aims to research and propose optimal solutions for the production and inspection of the aircraft fuselage frame assembly. The results of this project will contribute to enhancing product quality, minimizing assembly errors, and improving manufacturing efficiency in the aerospace industry.

Finally, I would like to express my sincere gratitude to my advisor, Dr. Vo Tran Anh, for his dedicated guidance throughout the course of this capstone project. Despite my best efforts, errors and shortcomings may still exist, and I respectfully welcome all feedback and suggestions from my advisor for further improvement.

Da Nang, 23/05/2025

Student

LÊ THANH HUY

DECLARATION

1. Project Title: Design of fixture, Assembly Process, and Inspection Procedure for the Boeing 757 Fuselage Frame Assembly
2. Supervisor: Dr. Vo Tran Anh
3. Student Name: Le Thanh Huy
4. Statement of Integrity: “I hereby declare that this capstone project has been carried out under the guidance of Dr. Vo Tran Anh. I affirm that this project is my original work and has not been copied from any existing sources. All referenced materials have been appropriately cited to ensure academic integrity.”

I also commit to fully complying with academic integrity policies throughout this capstone project:

- No cheating, fabrication, plagiarism, or aiding others in misconduct.
- Full honesty in presenting academic activities and results.
- Proper citation of all academic sources.
- All data and research results presented in this project are authentic and have not been used to earn any previous academic degree.

I hereby affirm that all data and research results presented in this thesis are truthful and have not been previously used to obtain any academic degree. All assistance received during the preparation of this thesis has been duly acknowledged, and all cited information has been clearly sourced and is authorized for publication.

Da Nang, 23/05/2024

Student

LÊ THANH HUY

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INTRODUCTION

1. Motivation for the Topic

The aerospace industry is undergoing rapid development, accompanied by increasingly stringent requirements for precision, quality, and safety in manufacturing. Among the critical components of an aircraft, the fuselage structure plays a vital role in ensuring structural integrity, aerodynamic performance, and safe operation. The production and assembly of the fuselage frame requires absolute accuracy to guarantee uniformity and load-bearing capacity throughout the entire structure. Therefore, the design and fabrication of specialized assembly fixtures, along with the development of an efficient assembly and inspection process, are essential factors for improving product quality and optimizing production workflows.

The Boeing 757 is a widely used mid-range commercial aircraft, known for its high operational efficiency, fuel economy, and suitable passenger capacity. The manufacturing process of the Boeing 757 fuselage demands a modern fixture system to accurately position each component, reduce assembly errors, and optimize production time. A well-designed fixture system enhances assembly precision, ensures component alignment, and supports quality inspection before the aircraft is commissioned into service.

However, in practice, many existing fixture systems still exhibit limitations, such as insufficient accuracy or non-optimized designs, which lead to increased production time and costs. Additionally, quality control during the assembly process is not always optimized, negatively impacting overall production efficiency. Thus, researching, designing, and fabricating an effective fixture system in conjunction with a well-structured assembly and inspection procedure is critical to meet the ever-increasing technical demands of the aerospace sector.

Moreover, this topic is not only of academic interest but also has significant practical applications in the aircraft manufacturing and assembly industry. Developing an advanced fixturing system will help enterprises improve labor productivity, minimize assembly errors, and enhance the quality of final products. Furthermore, establishing a robust

inspection procedure enables early detection of technical defects, thereby ensuring the absolute safety of the product before it enters operation.

The design of jigs and fixtures, along with the development of assembly and inspection procedures, contributes not only to production process optimization but also to improved product quality and service life. Recognizing the importance of this matter, I chose the topic: “Design of Fixtures, Assembly Process and Inspection for the Boeing 757 Fuselage Frame Assembly”, under the supervision of Dr. Vo Tran Anh.

2. Objectives of the Project

To design, analyze, and present the structural configuration of the aircraft fuselage.

- To research and analyze the fundamental principles of jig design and its function in the fuselage assembly process. This includes understanding the critical role of jigs in ensuring assembly accuracy, thereby improving product quality and enhancing manufacturing efficiency.

- To develop a standardized assembly and inspection procedure that ensures product quality in compliance with aviation standards.

- To investigate the load-bearing capacity of aluminum alloys and composite materials used in the fuselage frame, thereby determining suitable material selections for structural applications.

3. Scope of the Thesis

- Research subject: The Boeing 757 fuselage. Due to confidentiality constraints in the manufacturing process, this thesis is based on reference data available in published research papers and technical documents.

- Design of assembly fixtures for fuselage frame components.

- Development of the assembly procedure for the Boeing 757 fuselage frame.

- Analysis of the structure and shape of the aircraft fuselage, comparing the load-bearing capacity of aluminum alloys and composites.

- The capstone project is carried out based on academic knowledge acquired at university, internship experience at UACV Co, Ltd, and additional reference materials from the internet and published sources.

4. Graduation project structure

Includes 6 Chapters:

Chapter 1: Overview of the aviation industry

Chapter 2: Analysis of function and working conditions of the boeing757 fuselage

Chapter 3: Design and assembly of components using catia software

Chapter 4: Design of fixtures and assembly process

Chapter 5: Measurement process for fuselage frame assembly

Chapter 6: Stress and strain analysis of the fuselage frame assembly

CHAPTER 1: OVERVIEW OF THE AVIATION INDUSTRY

1.1 History of aviation

1.1.1 The Early Age and the Dream of Flight (Before the 20th Century)

Since ancient times, humans have longed to soar into the sky. Mythological tales such as the wings of Icarus and the flying machine designs of Leonardo da Vinci in the 15th century reflected this aspiration. However, it was not until the 18th century that a significant breakthrough with the invention of the hot air balloon by the Montgolfier brothers in 1783.

1.1.2 The Birth of Aviation (Early 20th Century)

A turning point in aviation history came in 1903, when the Wright brothers successfully completed the first powered flight with their aircraft, the Flyer I. This event marked the beginning of modern aviation.



Figure 1. 1 Flyer I aircraft

(Source: https://en.wikipedia.org/wiki/Wright_Flyer)

1.1.3 Aviation in Wartime (World War I & II)

World War I (1914–1918): Aircraft were used extensively in warfare for the first time, primarily for reconnaissance and aerial combat.



Figure 1. 2 German Halberstadt CL.II aircraft

(Source: https://en.wikipedia.org/wiki/Halberstadt_CL.II)

World War II (1939–1945): The aviation industry experienced significant advancements with the introduction of bombers, modern fighter jets, and notably, jet-powered aircraft.



Figure 1. 3 German Messerschmitt Me 262 aircraft

(Source: https://en.wikipedia.org/wiki/Messerschmitt_Me_262)

1.1.4 The Era of Commercial Aviation (Post-1945)

After the war, civil aviation grew rapidly with the emergence of commercial airlines. Aircraft like the Boeing 707 (1958) and Concorde (1976) revolutionized long-distance travel, making it faster and more convenient.



Figure 1. 4 Boeing 707

(Source: https://en.wikipedia.org/wiki/Boeing_707)

1.1.5 Modern Aviation and Advanced Technologies (21st Century)

Today, the aviation industry continues to evolve with new technologies such as supersonic aircraft, unmanned aerial vehicles (UAVs), and eco-friendly airplanes. Leading companies like Boeing, Airbus, and SpaceX are researching next-generation commercial aircraft and even spaceflight innovations.



Figure 1. 5 SpaceX spacecraft

(Source: <https://www.spacex.com/mission/index.html>)



Figure 1. 6 Boeing 787

(Source: <https://simpleflying.com/boeing-787-technical-features-guide/>)

1.2 Overview of Aerospace Mechanical Components

Aerospace components are the structural and functional elements that make up aircraft systems, assemblies, and the entire airframe. They play a crucial role in ensuring flight performance, operational safety, and overall aircraft efficiency.

Aerospace components are classified by several criteria, including:

- Material: metals, alloys, composite materials, plastics, rubber, glass, etc.
- Manufacturing process: casting, forging, machining, welding, stamping, extrusion, molding, etc.
- Function: structural components, engine parts, control system components, hydraulic system components, electrical system components, fuel system components, interior and exterior fittings.

Due to the specific demands of the aerospace sector, these components must meet strict requirements:

- High strength and load-bearing capacity
 - + Aircraft must withstand various types of loads, including aerodynamic, dynamic, and impact forces.
 - + Common materials: aluminum alloys (e.g., Al7075, Al2024), titanium alloys (Ti-6Al-4V), and high-strength steels.

- Lightweight construction

+ Weight is a critical factor as it directly impacts flight performance, fuel consumption, and payload capacity.

+ Materials must have a high strength-to-weight ratio.

+ Common materials include aluminum alloys, carbon fiber composites, and titanium instead of heavier steels.

- High machining precision

+ Aerospace parts require extremely tight tolerance, often in the micrometer (μm) range, to ensure safe and accurate assembly.

+ Machining techniques include 5-axis CNC, EDM (Electrical Discharge Machining), and ultra-precision machining.

- Resistance to heat and harsh environments

+ Components such as jet engines, turbine blades, and fuel conduits must endure extreme temperatures up to 1500°C .

+ Heat-resistant materials include nickel-based alloys (e.g., Inconel), advanced ceramics, and high-temperature composites.

- Corrosion and fatigue resistance

+ Aircraft operate in high-humidity environments and are exposed to fuel, chemicals, and marine salt, requiring high corrosion resistance.

+ Key components like the fuselage and landing gear are often anodized, coated, or made from corrosion-resistant alloys.

+ Fatigue is particularly hazardous, as cyclic stresses can cause cracks over time especially at stress concentration zones.

1.3. Aviation Standards

ISO 9001:2015 [1], one of the most widely recognized quality standards in the world, provides a general framework for organizations to manage quality in all aspects of their

business operations. In the aviation industry, ISO 9001 plays a crucial role in ensuring the consistency and effectiveness of quality management processes from design production to after-sales service.

AS9100D [2] is an international standard specifically for the aerospace, space, and defense industries, setting stringent requirements for organizations to ensure that products and services meet the highest quality and safety standards. AS9100D not only requires compliance with the general processes of ISO 9001 but also adds specific and stringent requirements for the aerospace industry.

AS 9102C, revised on 06/28/2023 [3], is an important standard in the aerospace industry, particularly related to the inspection and quality control processes of first articles. It provides a comprehensive framework to ensure that new components introduced into production fully meet the requirements for quality, reliability, and safety.

1.4 The world's leading commercial aircraft manufacturer

1.4.1 Boeing

Boeing is one of the leading aerospace and defense corporations in the world, headquartered in Chicago, USA. With over a century of operation, Boeing has become a major name in the aircraft, satellite, and other aerospace equipment manufacturing industry, playing a significant role in both the civilian and military sectors.

Development history: Founded in 1916 by William Boeing, the company has undergone many phases of development and expansion, becoming one of the largest aircraft manufacturers in the world. Boeing has introduced many revolutionary aircraft such as the Boeing 707, 747, 757, and 787 Dreamliner, shaping the modern aviation industry. The standout products that Boeing has participated in producing include:

The 737 series: The 737 MAX (737X) is one of Boeing's most popular single-aisle (also known as narrow-body) aircraft, designed to operate efficiently and with low operating costs.



Figure 1. 7 Boeing 737 max

(Source: <https://www.vietjetair.com/vi/pages/vietjet-ky-ket-hop-dong-mua-100-tau-bay-b737-max-200-voi-tap-doan-boeing-1608219279363>)

The 747, 767, 777, and 787 Dreamliner series: These are wide-body jetliners used for long-haul flights, with the 787 Dreamliner focusing on fuel efficiency and passenger comfort.



Figure 1. 8 Boeing 787

(Source: <https://nld.com.vn/kinh-te/vietnam-airlines-khai-thac-boeing-787-9-tren-duong-bay-ha-noi-moscow-20180328145655021.htm>)

CST-100 Starliner: A spacecraft designed to transport crews to and from the ISS and other low Earth orbit destinations. Developed by Boeing under NASA's CCP, it includes a reusable crew module and a usable service module.



Figure 1. 9 The CST 100 spacecraft is manufactured by Boeing.

(Source: <https://www.digitaltrends.com/cool-tech/boeing-starliner-attached-rocket/>)

1.4.2. Airbus

As one of the leading aircraft manufacturing groups in the world, headquartered in Toulouse, France. Airbus specializes in manufacturing commercial, military, and aerospace aircraft.

The prominent product lines of Airbus include:

- Airbus A320: is a narrow-body, twin-engine jet airliner produced by Airbus. The A320 has become the top choice for many airlines around the world for short and medium-haul flights.



Figure 1. 10 Máy bay Airbus A320

(Source: <https://khoahoc.tv/tim-hieu-may-bay-airbus-a320-duoc-ua-chuong-nhat-nhi-the-gioi-61077>)

- Airbus A380: Introduced in 2007, the Airbus A380 is a super wide-body aircraft capable of carrying hundreds of passengers and has become a symbol of luxury in the aviation industry.



Figure 1. 11 Airbus A380

(Source: <https://znews.vn/may-bay-cho-khach-lon-nhat-the-gioi-tung-den-chao-hang-tai-ha-noi-post916755.html>)

- Military aircraft C295: a type of twin-engine tactical military transport aircraft, highly regarded for its versatility and efficiency. It is produced by Airbus Military, a leading global military aerospace company.



Figure 1. 12 Military aircraft C295 manufactured by Airbus
(Source: <https://dantri.com.vn/xa-hoi/airbus-gioi-thieu-may-bay-san-ngam-c295-tai-trien-lam-quoc-phong-viet-nam-20241218161402019.htm>)

CHAPTER 2: ANALYSIS OF FUNCTION AND WORKING CONDITIONS OF THE BOEING757 FUSELAGE

2.1. Functions and structure of the Boeing 757 fuselage

2.1.1. Functions and working conditions of the aircraft fuselage frame

The fuselage structure of the Boeing 757 plays a crucial role in ensuring structural integrity, load-bearing capacity, and optimizing flight performance. At the same time, the fuselage also serves as the space for passengers, crew, and cargo, designed to maintain stable cabin pressure to ensure comfort and safety for passengers. With an optimal aerodynamic design, fuselage helps reduce air resistance, enhancing fuel efficiency. Additionally, this component is also integrated with electrical, hydraulic, air conditioning, and pressure control systems, and withstands unwanted impacts in the flight environment. Thanks to being made from aluminum alloys and composite materials, the fuselage assembly ensures both lightweight and high durability, meeting the stringent safety standards of the aviation industry.

The fuselage of the Boeing 757 must endure many harsh working conditions throughout its operation, including mechanical loads, cabin pressure, aerodynamic forces, and external environmental impacts:

- Mechanical load: During takeoff, flight, and landing, the fuselage must withstand tensile, compressive, bending, and torsional forces due to the load of passengers, cargo, and fuel distributed along the aircraft. High-load areas such as the wing attachment region, landing gear bay, and doors are specially reinforced.

- Cabin pressure: When flying at high altitudes, the cabin must maintain appropriate pressure to ensure passenger safety. This creates a pressure differential between the inside and outside, causing the fuselage to continuously undergo tensile stress, especially at joints and window areas.

- Aerodynamic impact: Throughout the journey, the aircraft fuselage must face air resistance and continuously changing pressure, causing vibrations and structural oscillations. This requires design to ensure rigidity while still being flexible to reduce material fatigue.

- Environmental impact: The fuselage is directly exposed to extremely low temperatures at high altitudes (which can drop below -50°C) and high temperatures when flying through hot climate regions. Additionally, it must withstand the effects of UV rays, high humidity, sea salt (when flying over ocean areas), and corrosion from chemical agents in fuel or cleaning fluids.

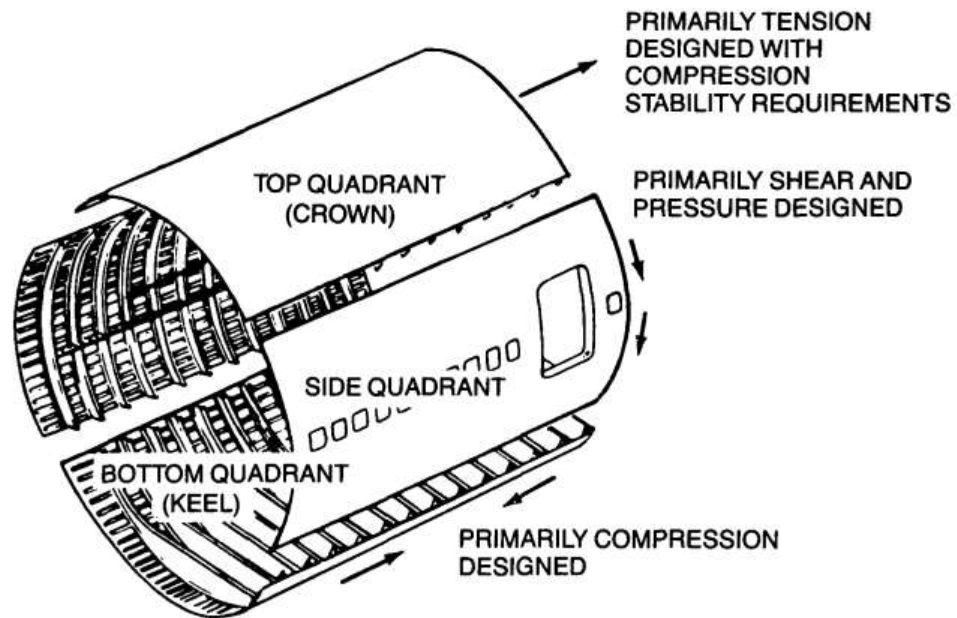


Figure 2. 1 Fuselage frame assembly

2.1.2. Overview of the Boeing 757 and the structure of the fuselage

The Boeing 757 is a mid-range, narrow-body commercial jet airliner developed and produced by Boeing since 1981. Designed to replace the Boeing 727, the 757 has a capacity to carry between 200 and 295 passengers, with a range of up to 7,222 km (4,488 miles), suitable for medium-haul domestic and international flights.

This aircraft uses modern turbofan engines, primarily the Rolls-Royce RB211 or Pratt & Whitney PW2000, which help optimize fuel efficiency and reduce emissions. With its advanced aerodynamic design and lighter weight due to the use of aluminum alloys and composite materials, the Boeing 757 has lower fuel consumption compared to previous generations.

The Boeing 757 has two main variants: the 757-200, the most popular version, and the 757-300, a stretched version with a larger passenger capacity. Additionally, this aircraft series also includes a freighter version (757F) and a military version (C-32) used by the United States Air Force.



Figure 2. 2 Boeing 757

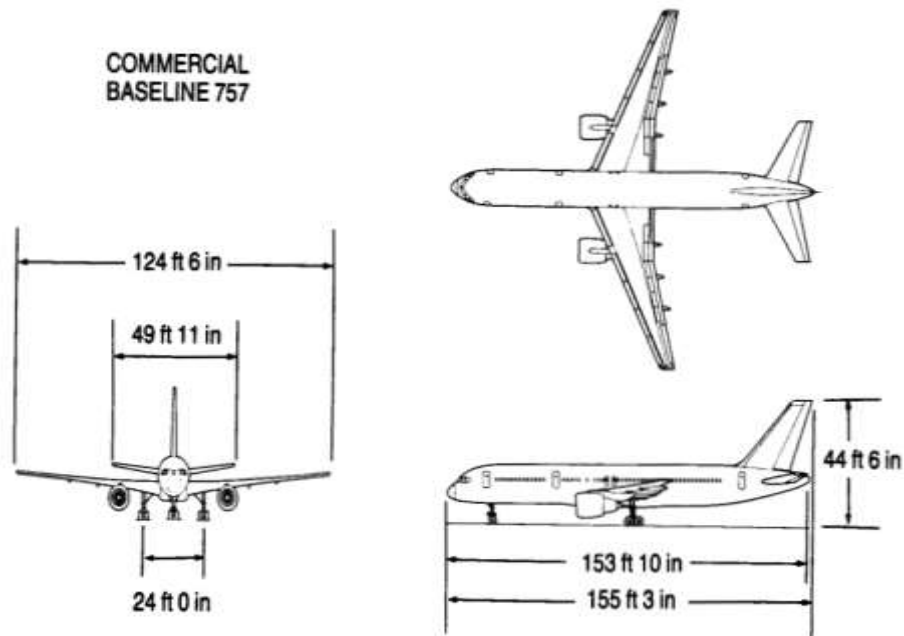


Figure 2. 3 Overall dimensions of the Boeing 757

The fuselage frame of the Boeing 757 is designed in a cylindrical shape and includes the following main components:

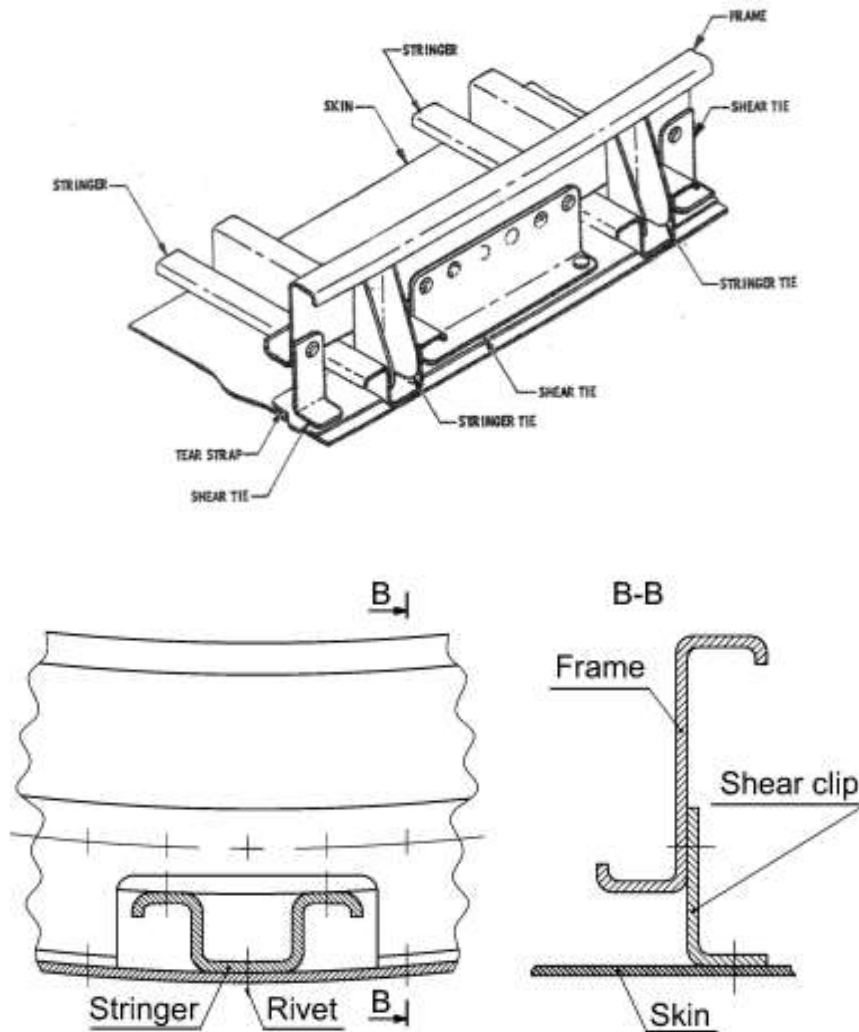


Figure 2. 4 Structure of the fuselage frame assembly

a/ Frame

An important structural component that helps maintain rigidity and distribute loads within the aircraft fuselage. These frames are circular or elliptical in shape, made from high-strength aluminum alloys and composites to ensure durability while maintaining a lightweight. They are arranged at specific intervals, linked with stringers and skin to form a sturdy frame. On the Boeing 757, the main frames are specially reinforced in critical areas such as wing connections, passenger cabins, doors, and landing gear, enhancing load-bearing capacity and ensuring flight safety. Thanks to its advanced design, the frame system

not only helps the aircraft fuselage withstand aerodynamic pressure and cabin pressure differentials but also optimizes the aircraft's operational performance.

b/ Stringer

They are reinforcement bars running along the length of the fuselage, tasked with increasing rigidity, distributing loads, and supporting the connection of other components. Made from high-strength aluminum alloys and some areas using composite materials, stringers help reduce weight while still ensuring load-bearing capacity. They often have Z, T, or Ω (Omega) cross-sections to optimize load-bearing capacity and easily connect with the frame and skin. On the Boeing 757, stringers are spaced appropriately to withstand cabin pressure, aerodynamic forces, and loads from the wings as well as the landing gear. Thanks to this design, the stringers help maintain the shape of the fuselage, prevent deformation due to pressure during flight, and optimize weight and fuel efficiency. This is an important factor that helps the Boeing 757 achieve high durability.

c/ Shear clips

An important component in the aircraft fuselage frame structure, playing a key role in framing with stringers and the outer skin, helping to enhance the strength and load-bearing capacity of the aircraft fuselage.

The main function of the shear clip:

- Transmitting loads between components: The shear clip helps distribute and transmit forces between the frame, stringer, and skin, ensuring the fuselage structure operates synchronously under the influence of mechanical and aerodynamic loads.

- Increase the rigidity of the fuselage: Thanks to its shear load capacity, the shear clip helps the fuselage frame resist deformation caused by cabin pressure, aerodynamic forces, and vibrations during flight.

- Reducing stress concentration: The shear clip helps distribute forces more evenly, reducing the risk of stress concentration at the joints between the frame and stringer, thereby extending the lifespan of the aircraft fuselage.

- Supports the assembly process: It serves as a fixed connection point between components, making the assembly process more precise and quicker.

d/ Skin

It is the outer layer of the aircraft fuselage, serving to protect the internal structure, maintain aerodynamics, and withstand loads during flight. Made from aluminum alloy and some areas using composite materials, the aircraft fuselage helps reduce weight while still ensuring strength and load-bearing capacity. The Boeing 757 fuselage is constructed from large panels, connected by rivets and high-strength bolts, with additional reinforcement in areas such as doors, cargo holds, and landing gear to enhance durability. Additionally, the outer coating helps prevent corrosion and protects against environmental impacts. Thanks to its sturdy design and advanced materials, the Boeing 757 aircraft fuselage ensures high flight performance and fuel efficiency.



Figure 2. 5 Fuselage B757

2.2. Materials that make up the fuselage frame assembly of the Boeing 757

Based on the working conditions of the component, the material for the frame and stringer components is selected as aluminum alloy AA7050.

- Mechanical properties of the AA7050 aluminum alloy:

- + Yield Strength: 469 Mpa
- + Ultimate Tensile Strength: 524 Mpa
- + Hardness: 140 HB
- + Modulus of Elasticity: 71.7 Gpa
- + Poisson's ratio: 0.33

- Thermal Properties:

- + Coefficient of thermal expansion: 25.6 (10⁻⁶/°C)
- + Thermal conductivity: 157 W/(m. K)
- + Melting temperature: 488 ÷ 629 °C

- Chemical composition (unit: % by weight)

Table 2. 1 chemical composition of Aluminum alloy 7050

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.4	0.5	2	0.3	2.9	0.28	6.1	0.2	Còn lại

Additionally, certain components in the fuselage structure may use composite materials to reduce weight and improve fuel efficiency. However, the use of composite materials on the Boeing 757 is not as common as on more modern aircraft like the Boeing 787.

Overall, the combination of these materials helps the Boeing 757 achieve a balance between lightweight and high durability, meeting safety and performance standards in the aviation industry.

The 7050 Aluminum alloy, also known as AA7050, belongs to the 7xxx series of aluminum alloys containing zinc, magnesium, copper, zirconium, and other alloying elements, providing superior strength compared to conventional alloys like 6061. It also has excellent stress corrosion cracking resistance compared to other 7xxx alloys.

- Some key characteristics of 7050 aluminum include:

- + High strength-to-weight ratio.
- + Good fracture toughness.

- + Excellent fatigue resistance.
- + Good corrosion resistance.
- + High thermal conductivity.

The strength of 7050 aluminum alloy approaches that of many types of steel while still retaining the lightweight properties of aluminum. This makes it an ideal choice for structural applications in the aerospace industry aimed at weight savings. To further enhance the properties of the aluminum alloy, the T7451 heat treatment process is often applied to ensure the alloy achieves optimal performance for its applications in the aerospace industry in particular and other industries in general.

- The skin is made from 2024 aluminum alloy, which has the following properties:

- + Very light, low density.
- + High tensile strength, good fatigue resistance.
- + Easy to machine and weld.
- + Poor corrosion resistance, often requiring protective coating.

Table 2. 2 chemical composition of aluminum alloy 2024

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.5	0.5	3.8-4.9	0.3-0.9	1.2-1.8	0.1	0.25	0.15	Còn lại

Table 2. 3 Reason the aircraft fuselage frame uses two different types of materials

Component	Function	Type of load
Skin	Shielding, withstanding aerodynamic pressure and cabin pressure	High cycle tensile and bending stress
Frame, stringer	Maintain the shell shape, bear the main load during bending and compression.	High load, concentrated, withstand compression and fatigue

Aluminum alloy 7050 has much higher tensile and compressive strength, making it suitable for structural components that bear significant loads, such as frames and stringers. The stress corrosion resistance of 7050 alloy is very good, making it suitable for frames and stringers located inside the aircraft fuselage, where humidity, water leaks, and salt can easily accumulate.

Aluminum Alloy 7050 is produced at a high cost, so it is not necessary for large panels.

With low stress and high cycles, aluminum alloy 2024 has better performance and higher toughness, ensuring it can withstand light impacts during flight.

CHAPTER 3: DESIGN AND ASSEMBLY OF COMPONENTS USING CATIA SOFTWARE

3.1. Introduction to the software and design of the parts

CATIA V5 (Computer Aided Three-dimensional Interactive Application) is a powerful CAD/CAM/CAE software developed by the French company Dassault Systèmes. Launched in 1998, CATIA V5 supports design on the Windows platform, providing comprehensive solutions for product design and manufacturing in various fields such as mechanics, automotive, aerospace, and architecture.

The ability to design in 2D and 3D in CATIA V5:

- 2D Design:

+ Module Sketcher: Allows the creation and editing of 2D sketch drawings, which serve as the basis for building 3D models. Users can define basic shapes, geometric constraints, and dimensions to ensure accuracy and consistency in the design.

+ Drafting Module: Supports creating 2D technical drawings from 3D models, including projections, sections, and details, adhering to international technical standards.

- 3D Design:

+ Module Part Design: Allows the creation and editing of 3D parts using features such as solid blocks, holes, ribs, and other geometric elements.

+ Module Assembly Design: Supports the assembly of multiple parts into an assembly or complete product, checking interactions and detecting collisions between components.

+ Module Generative Shape Design: Provides tools for designing complex surfaces and freeform shapes, commonly used in the aerospace and automotive industries to create aerodynamic shapes.

With over 170 specialized modules, CATIA V5 meets diverse design and simulation needs across various industries. The integration capability between 2D and 3D design

allows users to easily transition between different stages of product development, from the initial idea to production.

3.1.1 Design the frame

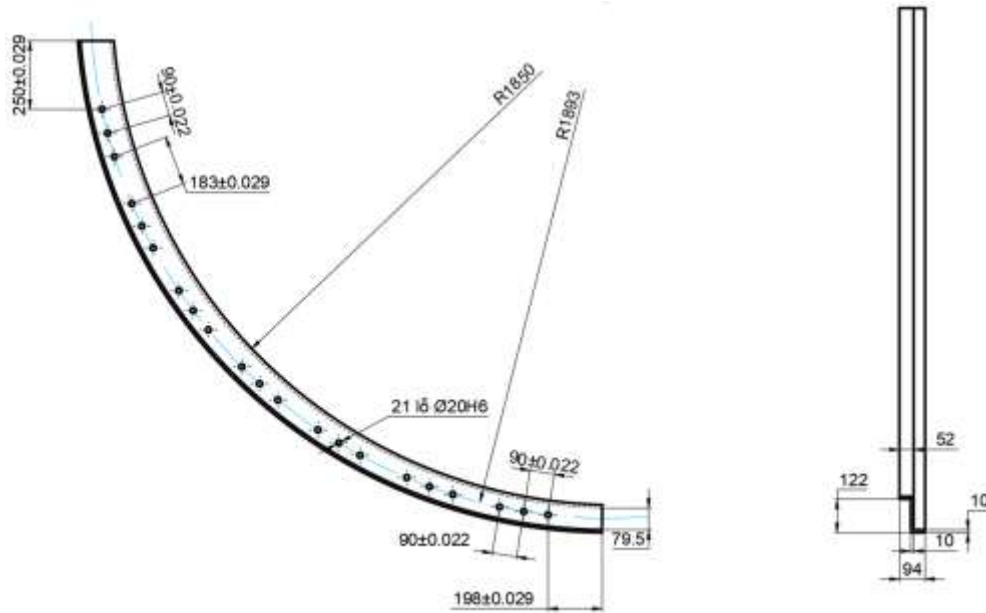


Figure 3. 1 2D frame drawing

Use Sketch to draw the 2D profile of the Frame, then use the Pad command to create the 3D shape and finally use the Pocket command to create holes for the part.

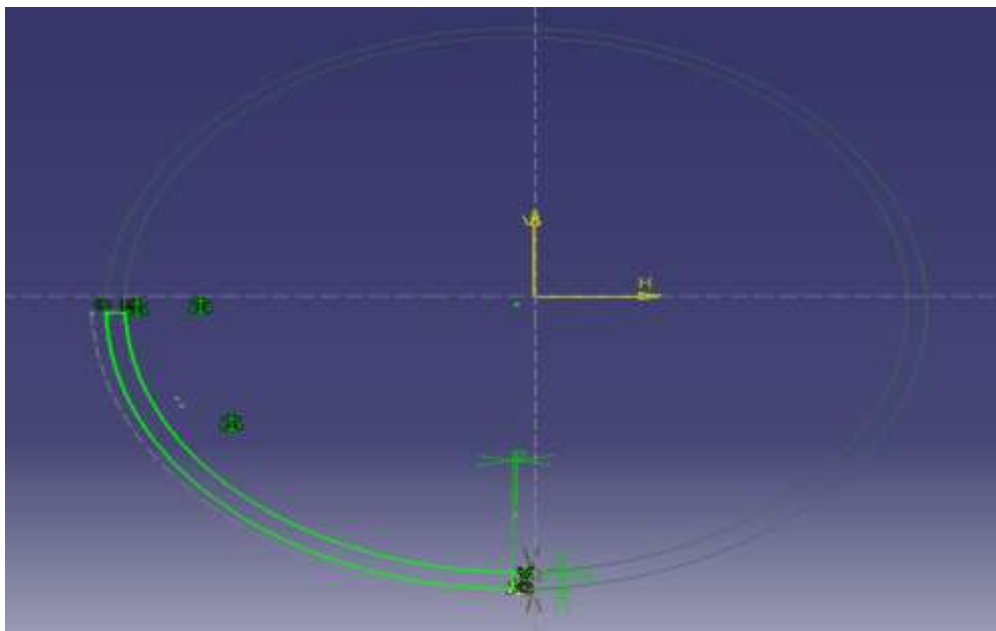


Figure 3. 2 Draw Frame profile

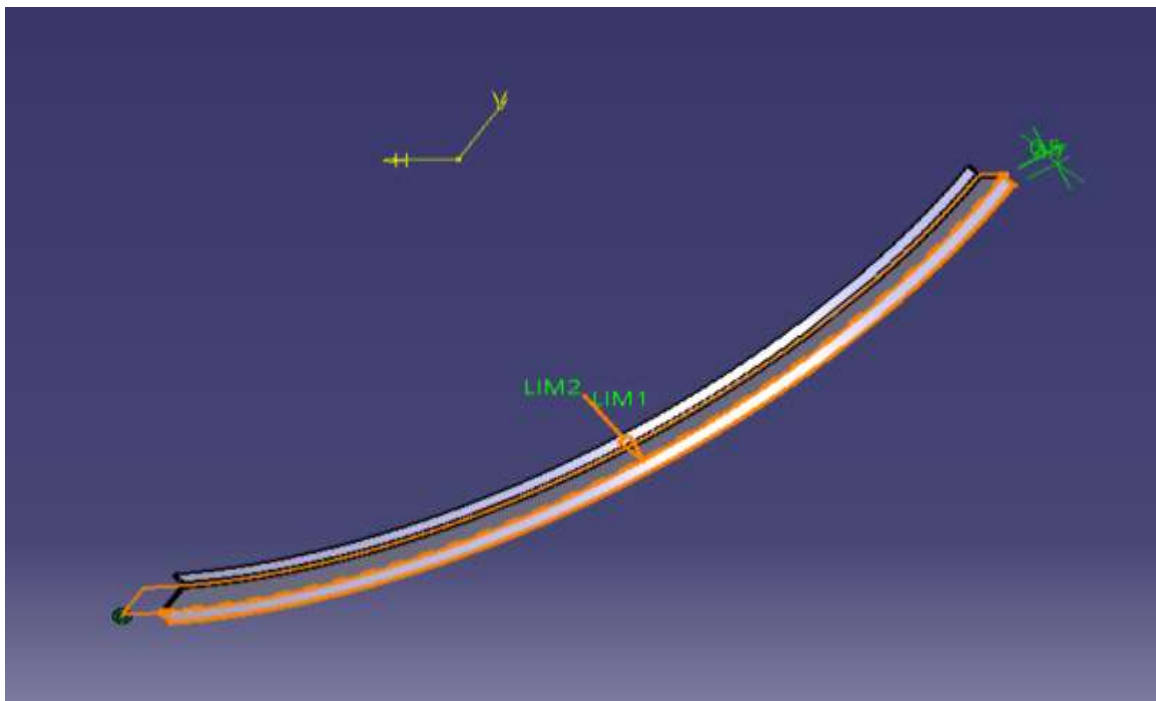


Figure 3. 3 Create 3d shape of frame

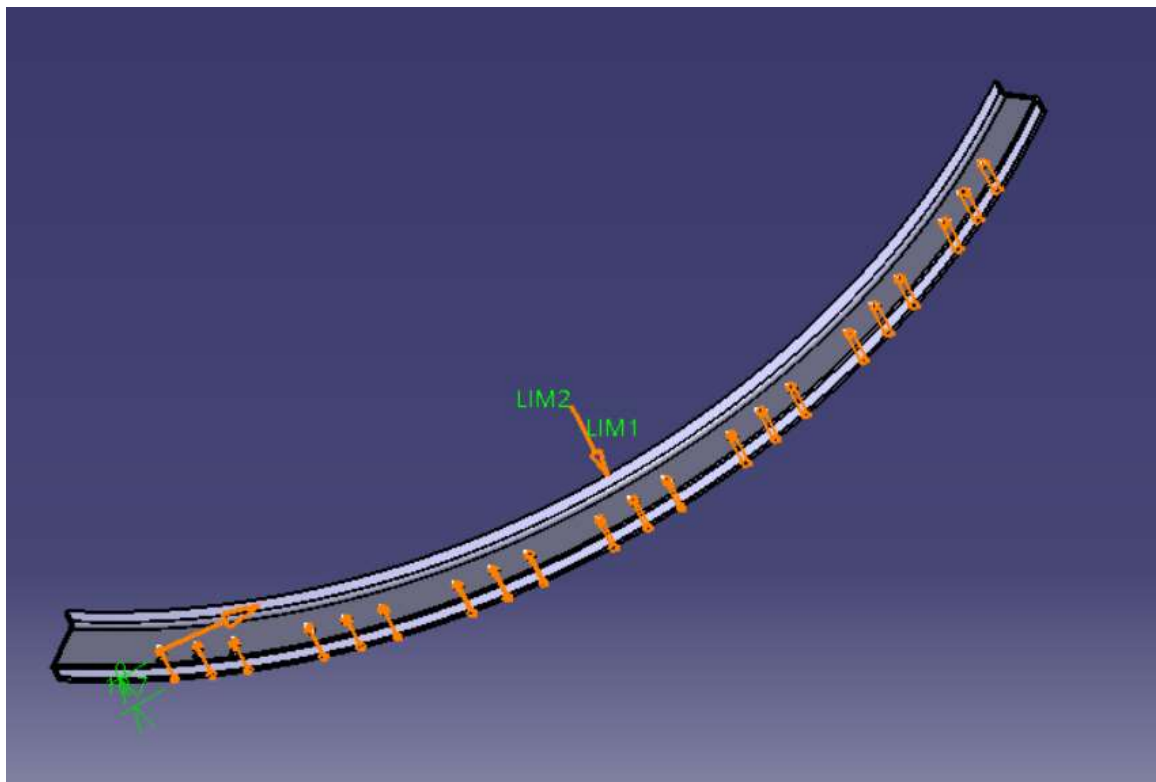


Figure 3. 4 Make the necessary holes

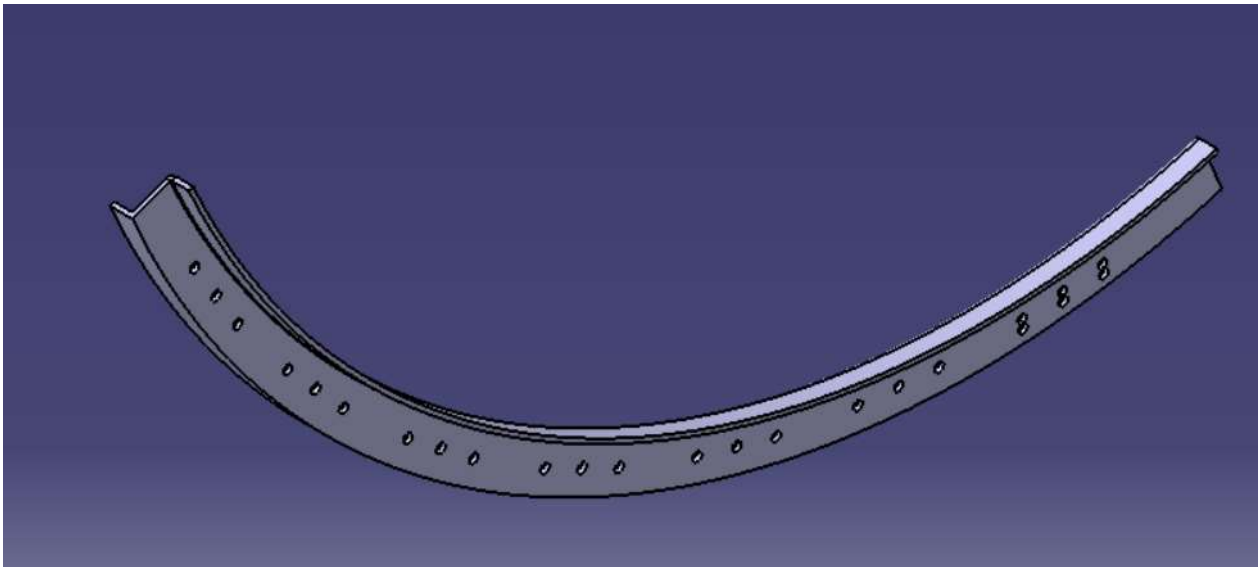


Figure 3. 5 Shape of the finished frame

3.1.2 Design the stringer

Based on reference document [1], use AutoCAD software to draw a 2D detail of the stringer with dimensions as shown in the figure.

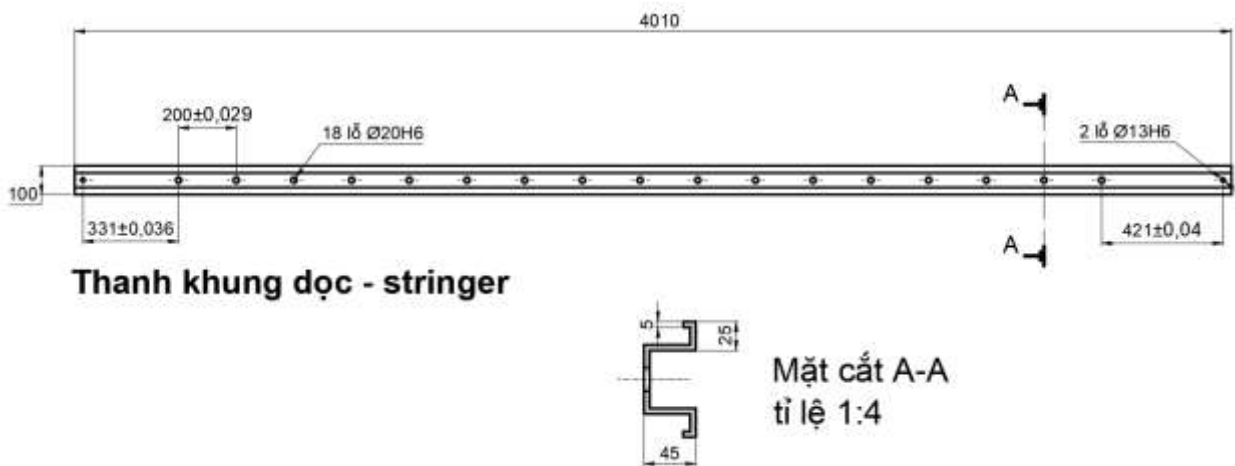


Figure 3. 6 2D stringer drawing

Use Catia V5 software in the Part design environment to create a 3D model of the detail. Use the Sketch command to draw the 2D profile of the stringer, then use the Pad command to create the 3D shape and finally use the Pocket command to create holes.

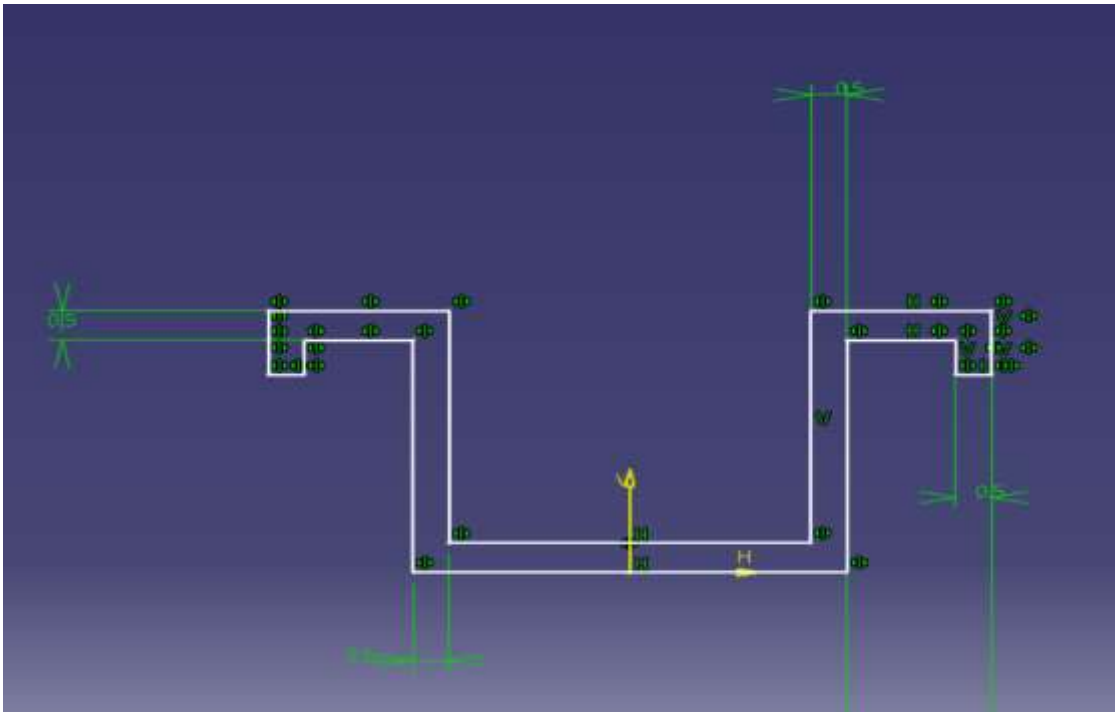


Figure 3. 7 Draw 2d profile of Stringer

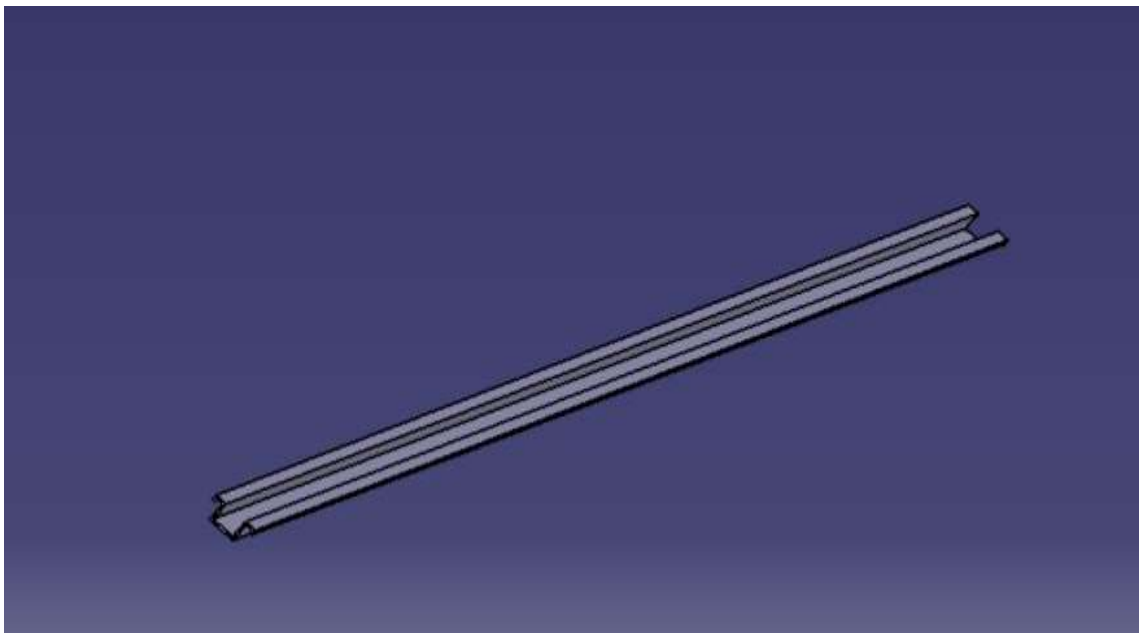


Figure 3. 8 Create 3d shape of Stringer

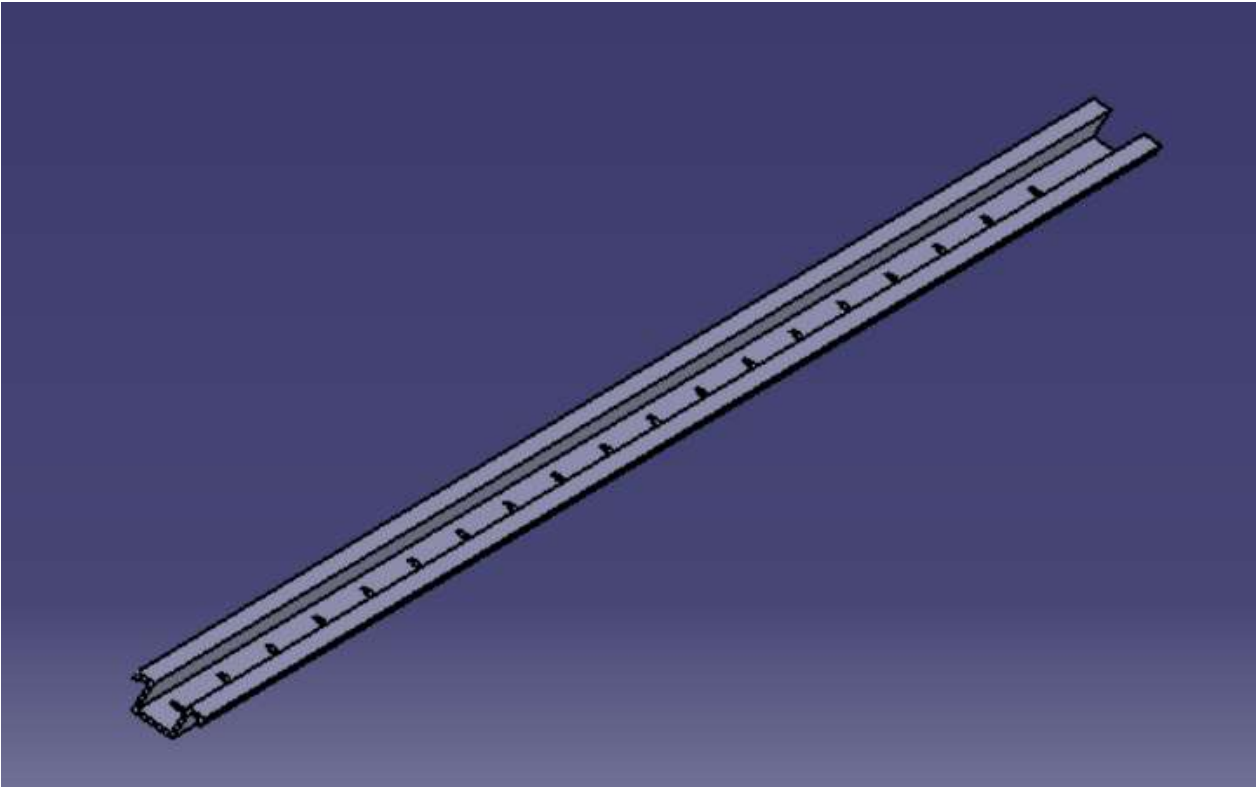


Figure 3. 9 Finished Stringer Shape

3.1.3 Design Shear clip and skin

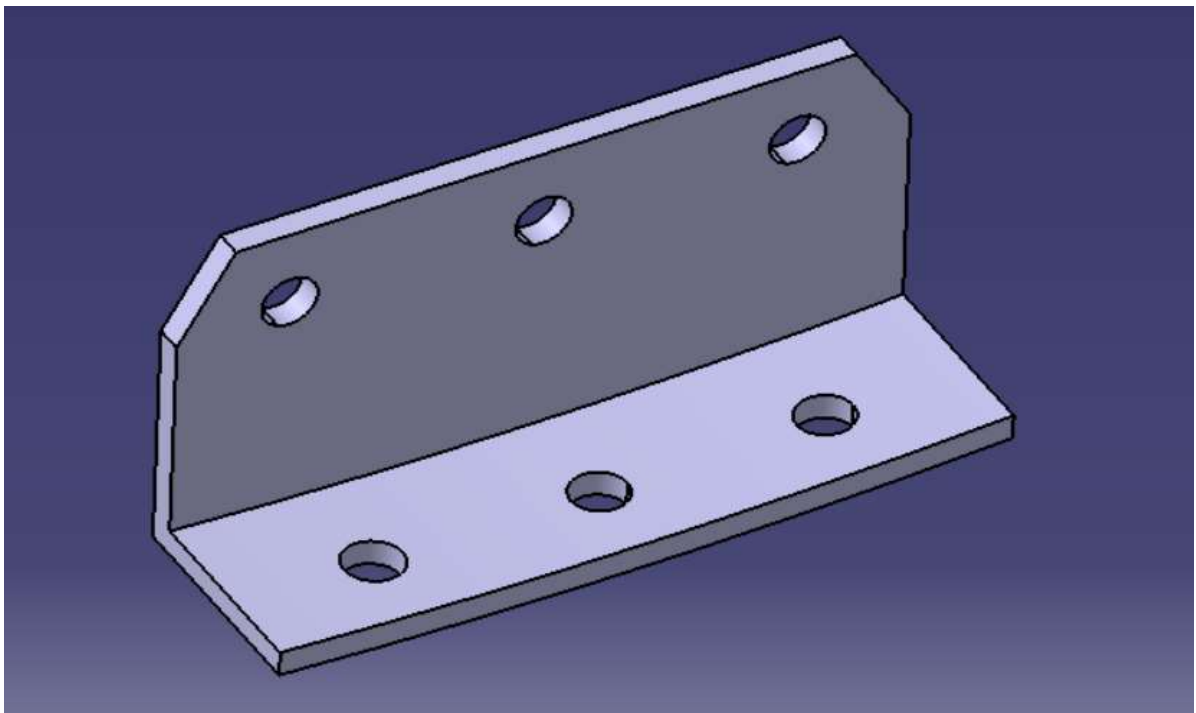


Figure 3. 10 Shear Clip

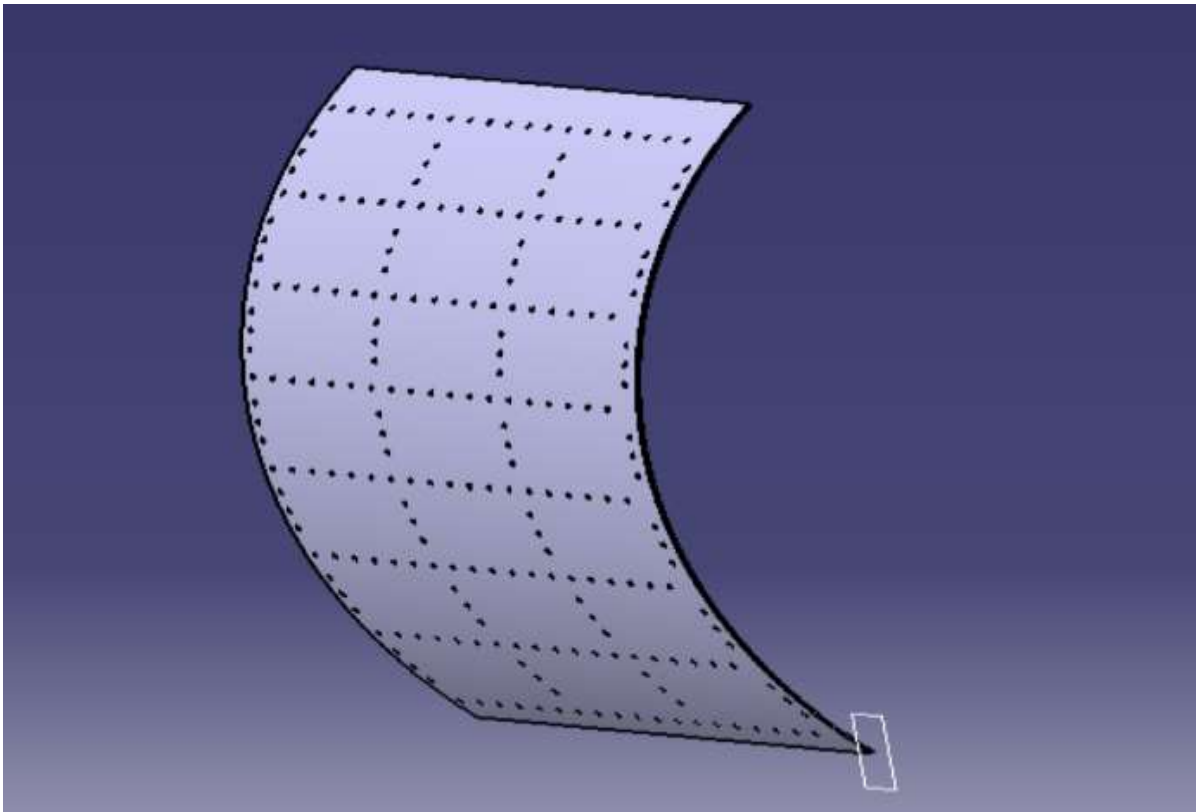


Figure 3. 11 Skin

Similar to the design of the Frame and Stringer parts, we can design the Shear Clip and Skin parts as shown above.

3.2. Assembling the components into an aircraft frame assembly

The steps to assemble components in CATIA V5:

- Start the Assembly Module
 - + Open CATIA V5 → Select Product to create a new file for the assembly.
- Insert the parts into the assembly.
 - + On the toolbar, select Insert Existing Component to insert the pre-designed parts.
- Position the original component
 - + Select a main detail as a reference and fix its position using the Fix Component command.

- Create constraints between the components
- + Coincidence Constraint: Align two planes or axes to coincide.
- + Contact Constraint: Place two surfaces in contact with each other.
- + Offset Constraint: Positioning the distance between two planes or parts.
- + Angle Constraint: Defines the angle between two faces.

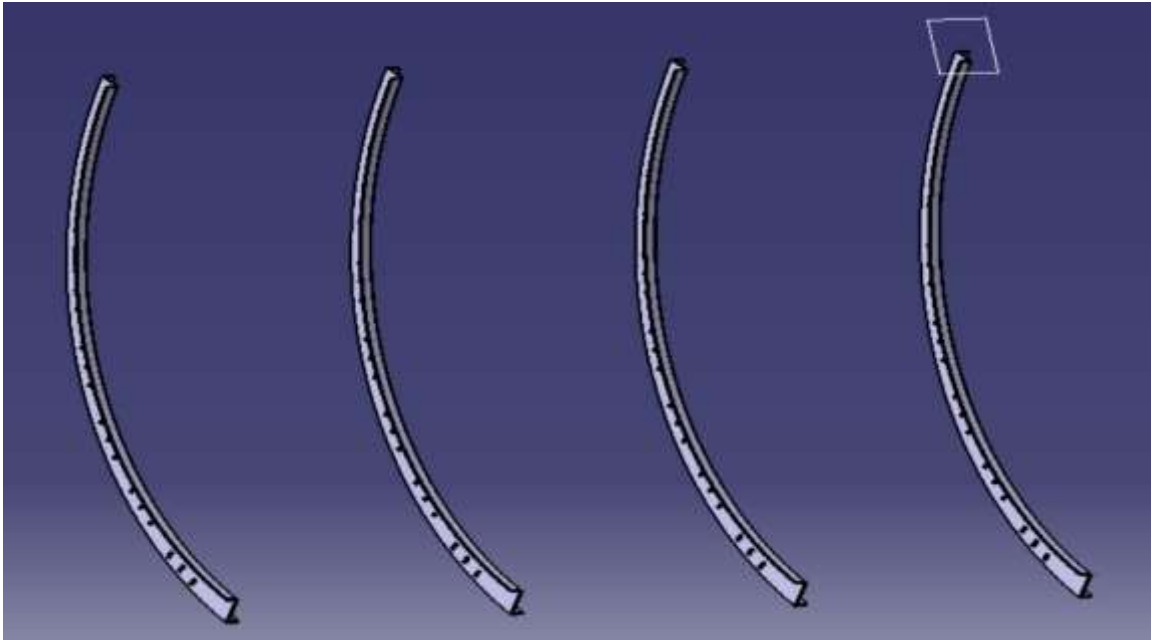


Figure 3. 12 Import Frame parts into assembly environment

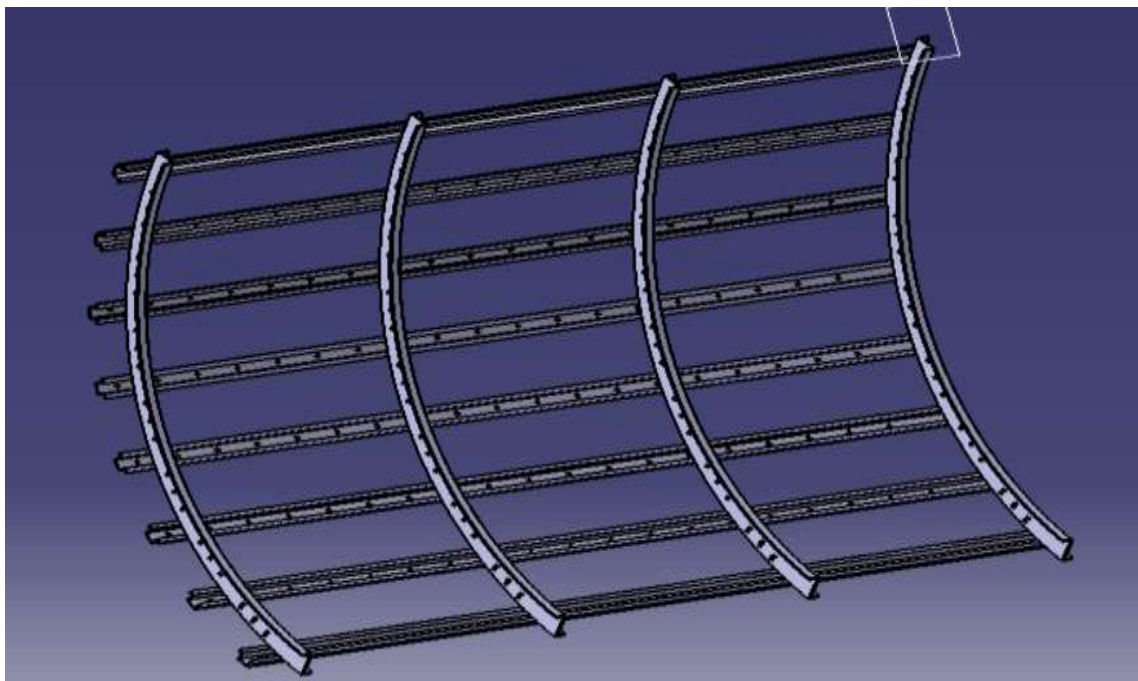


Figure 3. 13 Assemble Stringer Parts with Frame

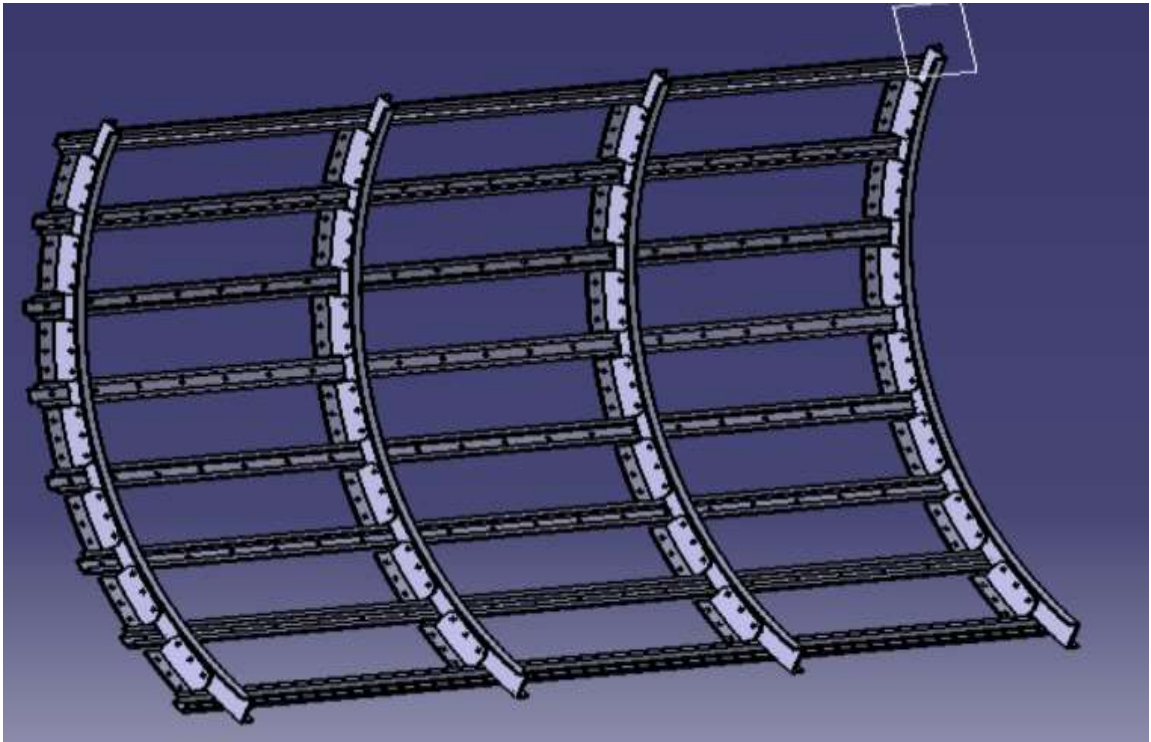


Figure 3. 14 Mount Shear Clip parts with Frame

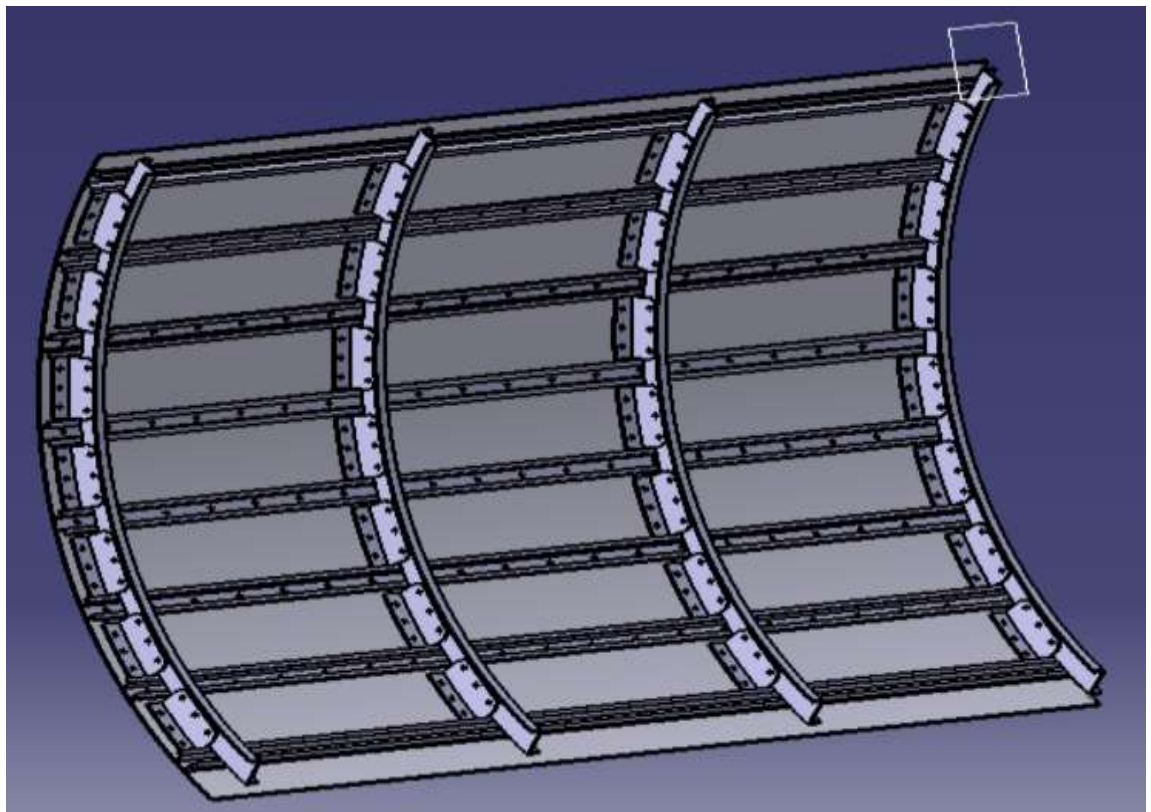


Figure 3. 15 Assemble the case with Stringer and Shear Clip

CHAPTER 4: DESIGN OF FIXTURES AND ASSEMBLY PROCESS

4.1. Overview of Assembly Technology

To have a complete product, after the machining stage, all the product components must be assembled together according to the requirements of the motion principle and the precision of the technical specifications. Assembly is the final stage in the production process, which determines the quality of the product.

In assembly technology, the first issue of concern is joints. The joints are divided into two main types: fixed joints and movable joints.

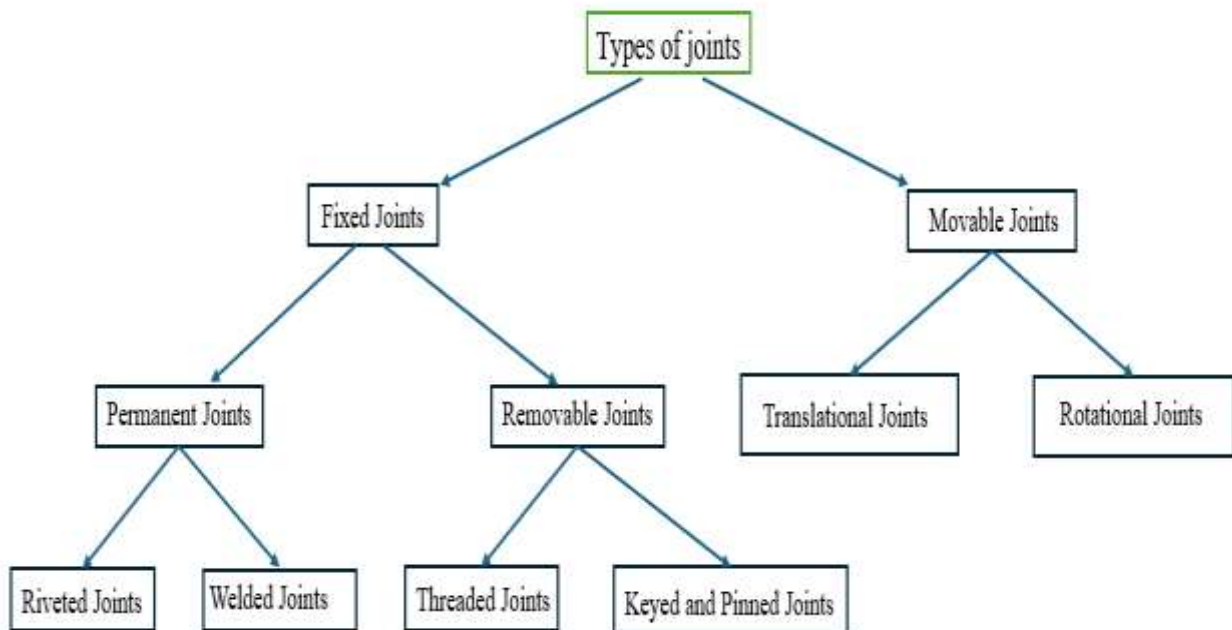


Figure 4. 1 Classification of joints

The assembly accuracy has the following characteristics:

- Deviation in the relative positions of the components in the assembly
- Deviation due to the appearance of stress during assembly causing deformation and resulting in positional displacement between the components in the assembly.
- The assembly process and inspection process are not carried out accurately.

4.1.1 Assembly methods

a/ Complete Interchangeability Method

The machine parts or components are manufactured independently of each other but still ensure assembly without the need for fine-tuning or repairs during assembly. This method is simple, has high assembly productivity, does not require highly skilled workers, allows for mechanization, automation of the assembly process, and is convenient for repair and replacement.

The disadvantages of this method:

- Requires high precision in manufacturing, leading to production costs
- Only used in large-scale production (mass production, bulk production) and standardized products.

b/ Non-Interchangeable Assembly Method

The components are manufactured without ensuring high precision like the complete interchangeability method.

The manufactured parts do not ensure high precision like the completely interchangeable method.

During assembly, the worker must test, measure, or fine-tune the parts to meet the technical requirements. When assembling, the worker must test, measure, or fine-tune the components to ensure they fit the technical requirements.

This is an assembly method that allows for the expansion of tolerances of the component parts to facilitate manufacturing, but when assembling, it must meet the requirements of the closed-loop section as specified by the design. Therefore, after assembly, a certain number of components will not fit together to meet the design requirements and will become scrap.

This method is implemented when:

$$P < C_{T'} - C_{T''}$$

Where:

P is the total cost of scrap parts.

C_T , is the total manufacturing cost when the tolerance has not been expanded.

$C_{T''}$, is the total manufacturing cost after tolerance expansion.

c/ Selective Assembly

It is a variant of the partial interchange assembly method, in which the components are classified by size or tolerance groups and then assembled in corresponding pairs to ensure accuracy without reworking.

- Advantages:

+ Reduces processing costs because high precision is not required during manufacturing.

+ No need for trial assembly or rework, just select the correct pair of components by group.

+ Ensures better assembly quality compared to partially manual assembly.

- Disadvantages:

+ Must check and classify in detail, which is time-consuming and labor-intensive.

+ Warehouse management is more complicated because it requires storing many different size groups.

+ Not suitable for extremely large-scale production because the manual sorting process causes delays.

Table 4. 1 Comparison of assembly methods

Method	Precision machining	Trial assembly	Part classification	Interchangeability
Completely interchangeable	High	No	No	Yes
Select assembly	Average	No	Yes	With limitations
Non-Interchangeable Assembly	Low	Yes	No	No

4.1.2 Types of Assembly Organization

The choice of assembly organization depends on the following factors:

- Production type
- Product complexity
- Achievable precision of assembled components
- Nature of joints and assembly methods
- Product weight

Based on the position and condition of the assembled object, they are divided into two types of assembly organization:

a/ Fixed assembly

It is a form of assembly organization carried out at one or several locations. The assembly parts, components, or units are transported to the assembly location. Fixed assembly is further divided into centralized assembly and decentralized assembly:

- Centralized fixed assembly is a type of assembly organization where the assembly object is completed at a specific location by one or a group of workers.

- Distributed fixed assembly is suitable for complex products, which can be divided into multiple assembly parts and carried out in various independent locations. Then proceed to assemble the parts into the product at a different location.

b/ Mobile assembly

It is a form of assembly line organization where the assembly objects are moved from one position to another according to the assembly technology process. Based on the mobility characteristics of the assembly object, they are divided into: Free mobile assembly and forced mobile assembly:

- Free mobile assembly is a type of assembly organization where at each assembly position, a complete assembly operation is performed, after which the assembly object is moved to the next assembly position in the assembly technology process.

- Forced mobile assembly is a type of assembly organization where the movement process of the assembly object is uniformly controlled to match the rhythm of the assembly cycle. According to the form of mobility, it can be continuous forced mobility or intermittent forced mobility.

4.1.3. Overview of the assembly fixture components

Assembly fixtures are classified into two types:

- Universal assembly fixtures
- Specialized assembly fixtures

The structure of an assembly fixture consists of the following components:

- Positioning mechanism: The positioning elements of the jig serve the same function as those in machining and inspection jigs.

- Clamping mechanism: It is required not to cause deformation and not to damage the surface of the assembled object. Note that the assembly object should not be clamped directly with magnetic force because it may become magnetized. In cases where a small clamping force is required, it is best to use vacuum clamping.

- When designing the clamping mechanism of an assembly fixture, it is necessary to determine the required clamping force. The method for determining the necessary clamping force and the clamping mechanism of the assembly fixture is similar to that of the

machining fixture. However, the K factor (safety factor) is calculated differently compared to the machining fixture.

$$K = K_0 \cdot K_4 \cdot K_5 \cdot K_6$$

Where:

K_0 - General safety factor for all cases, $K_0 = 1,5$

K_4 - Stability factor of the clamping force (Manual clamping $K_4 = 1,3$;
Automatic clamping $K_4 = 1$)

K_5 - Convenience factor for manual clamping (Easy clamping $K_5 = 1$,
Difficult clamping $K_5 = 1,2$)

K_6 - The coefficient accounting for the moment causing the assembly object to rotate (If the contact area between the assembly object's surface and the fixture is small, $K_6 = 1$, if large $K_6 = 1,5$)

- Guiding mechanism: It has the function of placing a component of the assembly object into its correct position.

- Auxiliary mechanism: These are mechanism aimed at improving working conditions for assembly workers while simultaneously reducing auxiliary time and increasing assembly productivity.

4.2 Tools and Joints Used

4.2.1 Tools Used for Assembly

a/ Pneumatic Drill

- Most commonly used in aircraft manufacturing.
- Lightweight, high-speed, and easy to control.
- Used with cobalt or carbide drill bits.



Figure 4. 2 Pneumatic Drill

b/ Cleco and cleco tools (Cleco Pliers)

Cleco (also known as Cleco fastener) is a very popular temporary tool in the aircraft fuselage assembly process, especially in the aerospace industry and the production of thin metal structures such as aluminum. This is a device that temporarily clamps metal sheets together before proceeding with riveting.

- Function:

- + Temporarily attach the aircraft skin panels to the stringers and frames.
- + Precisely align the drilled holes before fastening the rivets.

- The structure of Cleco:

- + Cleco: insert into the drilled hole on the part
- + Body: An alloy used to hold the internal structure
- + Spring: Located within the body to create clamping force
- + Clamp head: The place where the cleco pliers are used to expand or contract the clamp tip

The cleco gun, also known as a cleco pliers, is used to press and remove clecos from holes. When you squeeze the pliers, the Cleco tip contracts => insert it into the hole => release your hand => Cleco expands, holding the two sheets of material tightly.



Figure 4. 3 Cleco Pliers and Cleco

4.2.2 Riveted Joint

A rivet is a type of mechanical component used to permanently join two or more sheets of material (usually metal) together by creating a permanent bond. When installing rivets, the rivet head is forged, pressed, or rolled to deform and create a secure joint that cannot be removed without destroying the rivet. This is one of the main connecting methods in the aviation industry, especially in the assembly of aircraft fuselage panels like the Boeing 757 (B757).

Common types of rivets in aviation:

- Solid rivets: the most common type, especially aluminum alloy
- Blind rivets: used in positions that can only be accessed from one side.
- Hi-Lok and Jo-Bolt: high-precision rivets used in positions subjected to heavy loads.

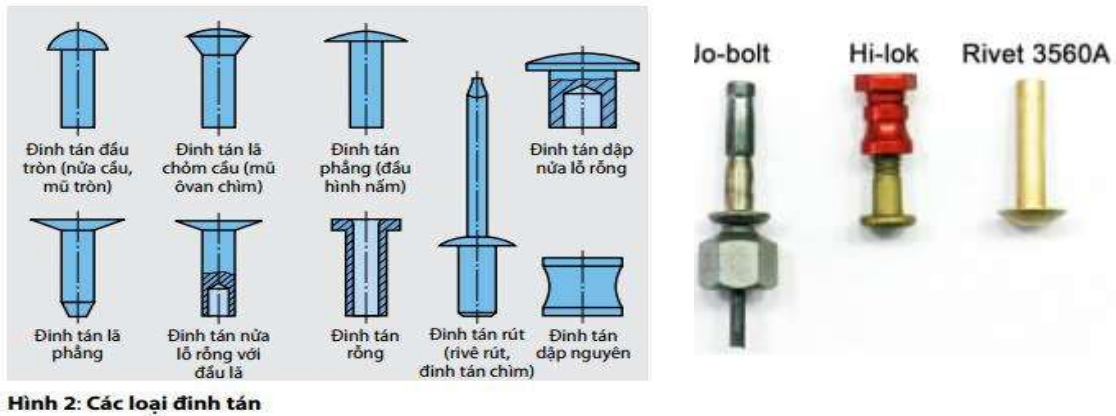


Figure 4. 4 Types of rivets

A riveted joint is a method of permanent connection between components, performed by punching holes in the parts to be joined, placing the rivet in the hole, and forming a head on the other side using mechanical methods (hammering, pressing, or shooting). The principle of connection for a riveted joint: The body of the rivet contacts the holes of the joined plates, the holes of the cushion plates, and the rivet acts like a pin that prevents relative sliding between the joined plates and between the joined plates and the cushion plates.

Classification of riveted joints:

- According to the structure of the joint:

+ Lap Joint:

- Two or more sheets of material are stacked on top of each other and joined with rivets.
- Easy to construct, commonly used in aircraft fuselages.
- Easy to construct, commonly used in aircraft fuselage.
- Disadvantage: can create gaps, prone to galvanic corrosion.
- Used extensively in fuselage panels where the aircraft skin sheets are overlapped.

+ Butt Joint

- Two plates are placed edge to edge, usually with a splice plate inside or outside to connect them.
- There can be one or two splice plates (one side or both sides).
- Used extensively in areas requiring flat, seamless surfaces, such as aircraft wings or fuselage.

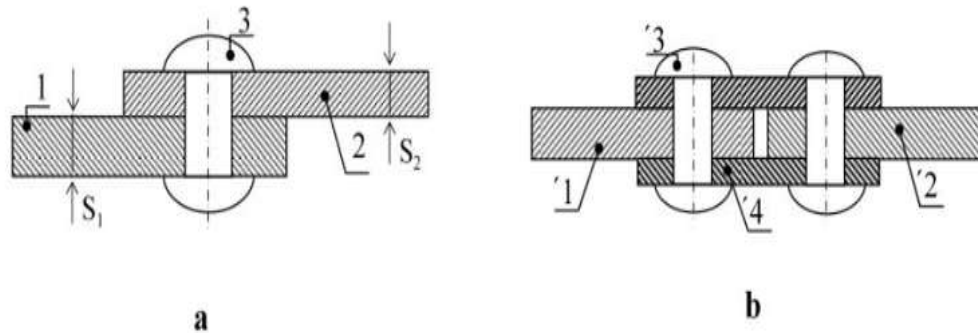


Figure 4. 5 Lap Joint and Butt joint

- According to the construction method

+ Solid Rivet Joint

- Must be accessible from both sides, using a hammer or pressing device to form the head.
- Used mostly in aviation (AN470, AN426...).

+ Hollow or semi-hollow rivet joint

- Used less in aviation due to lower strength.

+ Blind Rivet Joint

- Used when only one side is accessible.
- Includes types like CherryMAX, Avdel, Olympic-Lok.
- Used in narrow areas such as the cabin compartment, substructure.

- According to the number of rivet rows

+ Single - row riveted joint

- Each joint has only one row of rivets.
- Used for light load connections.

+ Multi-row joints (Double-row, Triple-row, etc.)

- Two or more rows of rivets in parallel or zig - zag.
- Increase strength and load-bearing capacity.
- Very common in structures that bear heavy loads, such as wings and fuselage.

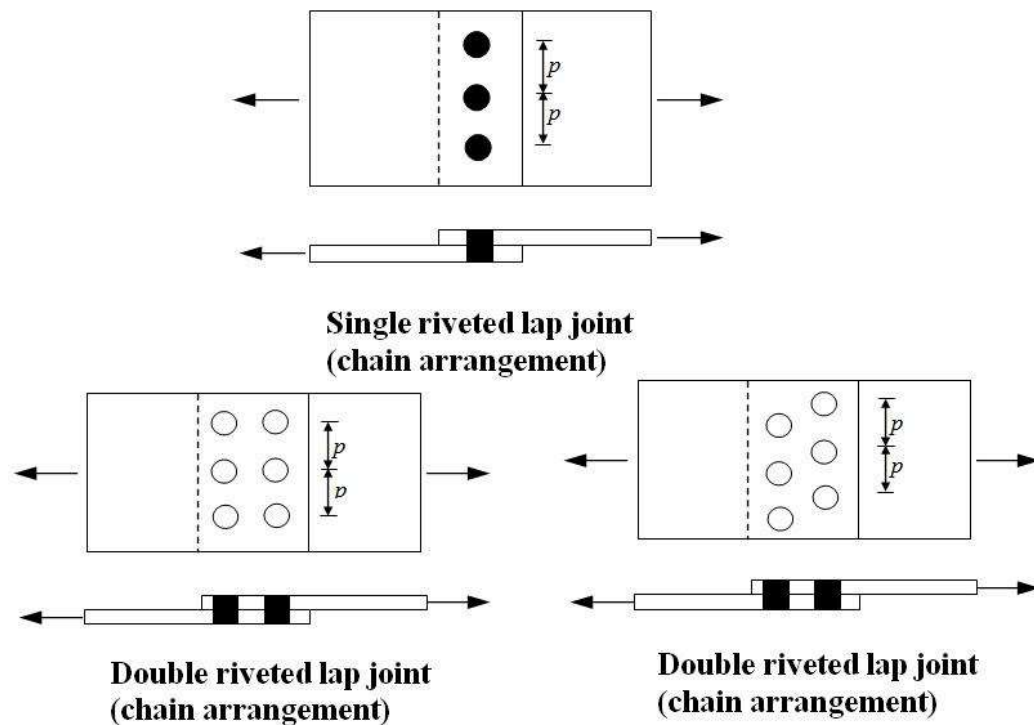


Figure 4. 6 Classification of rivet joints by number of rows

- Classification by the arrangement of rivets

+ Chain Type Riveted Joint: The rivet lines are arranged in a straight line on the same horizontal plane.

+ Zig-Zag Type Riveted Joint: The rivet lines are arranged in a zig-zag pattern, which helps distribute the load better and reduces fatigue cracking.

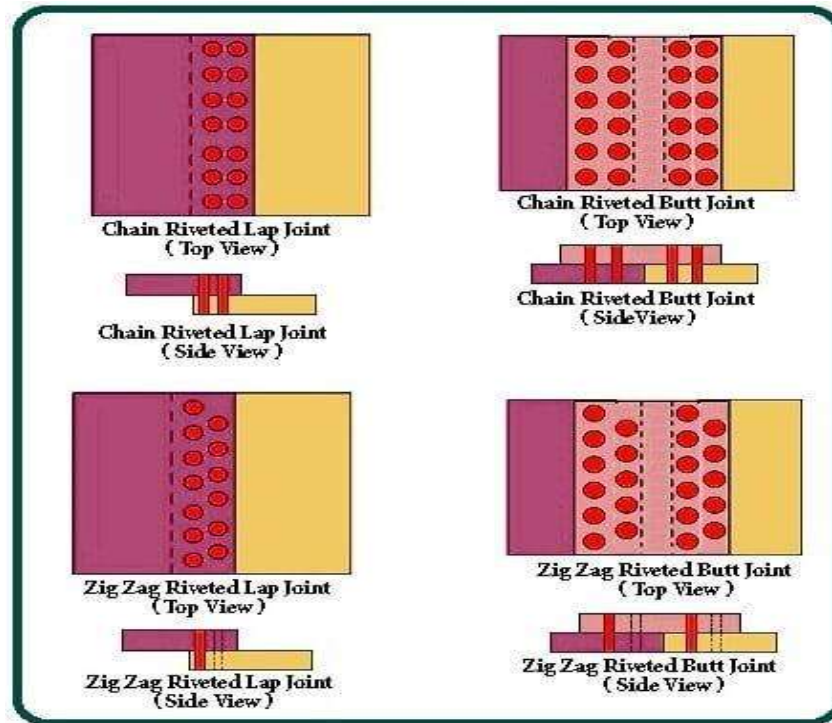


Figure 4. 7 Classification of rivet joints by arrangement

- We choose the single-row staggered riveted joint because the surface area of the Stringer and Frame is small.

Table 4. 2 Differences between assembly joints

Type of Joint	Application	Advantages
Lap joint	Fuselage	Easy to assemble, quick
Butt Joint	Main structure, load-bearing frame	Continuous surface, good load-bearing capacity
Staggered rows	Assemble the main frame, wings	Even load distribution, fatigue resistance
Blind rivet	Area inaccessible from the back	Easy construction

4.3. Assembly fixtures for the aircraft fuselage assembly

The assembly jigs for the aircraft fuselage are specialized devices and tools used to support the assembly process of the fuselage components. They play a crucial role in

ensuring accuracy, safety, and efficiency during the production and assembly process.

The function of assembly fixtures:

- Precise positioning: The fixture helps to secure the aircraft fuselage components in the correct position throughout the assembly process. This ensures that the components are assembled according to the technical design.

- Clamp the parts tightly: The fixtures hold the parts tightly so that they do not move or shake during assembly, welding, or machining.

- Support for inspection and measurement: Many types of jigs are equipped with measuring devices to check the accuracy and quality of assembled parts.

- Increase productivity: Using assembly jigs helps boost productivity and production efficiency, reducing assembly time and the number of tasks required.

- Ensure safety: Assembly jigs are designed to ensure worker safety by minimizing the risk of accidents and protecting sensitive aircraft components.

The typical structure of an aircraft fuselage assembly jig:

- Main Jig Bed: A large steel frame system that is fixed in place on the factory floor.

- Locators & Supports: Used to support the frames (hoops or frame) according to the contour of the aircraft fuselage.

- Adjustable Fixtures: Allow for flexible adjustments according to each design version.

- Integration of measurement systems (Laser Tracker/Photogrammetry): Ensure the 3D accuracy of the assembly.

The fixture has the following overall dimensions: Length 6400 mm; Width 6148 mm; Height 6562 mm

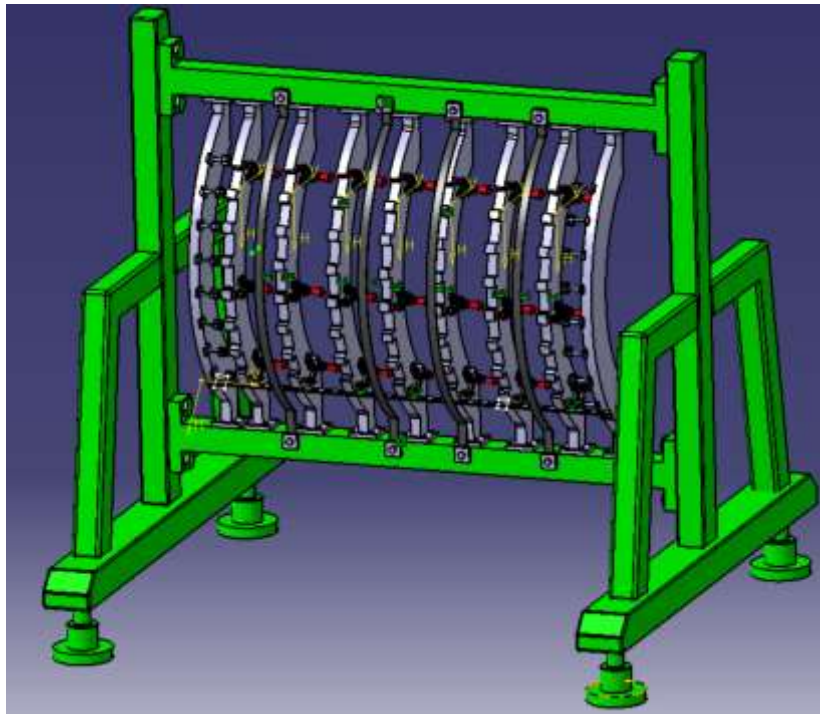


Figure 4. 8 3D model of assembly fixture

4.3.1 Frame and frame support components of the jig

The jig frame is the main structural component of a jig/fixture system – where it bears loads, shapes, and holds the parts of the product during assembly or machining. In the field of precision mechanics, the jig frame plays a crucial role in the rigidity, accuracy, and repeatability of the production process.

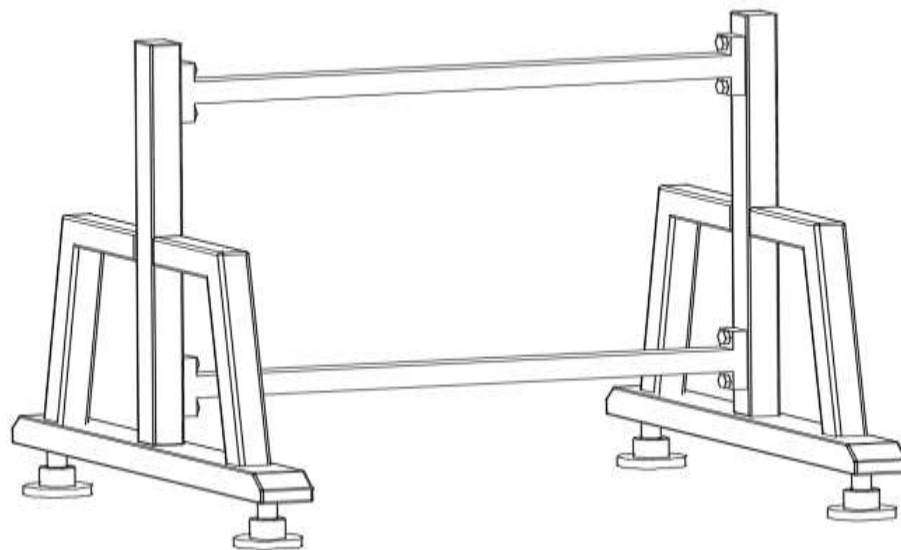


Figure 4. 9 Assembly fixture frame

The frame positioning component plays a crucial role in accurately holding each frame in the correct spatial position, ensuring that the aircraft fuselage is assembled with the correct contour, coaxially, and without geometric errors. This component also functions to house the clamping mechanism to securely hold the frame and the stringer positioning mechanism.

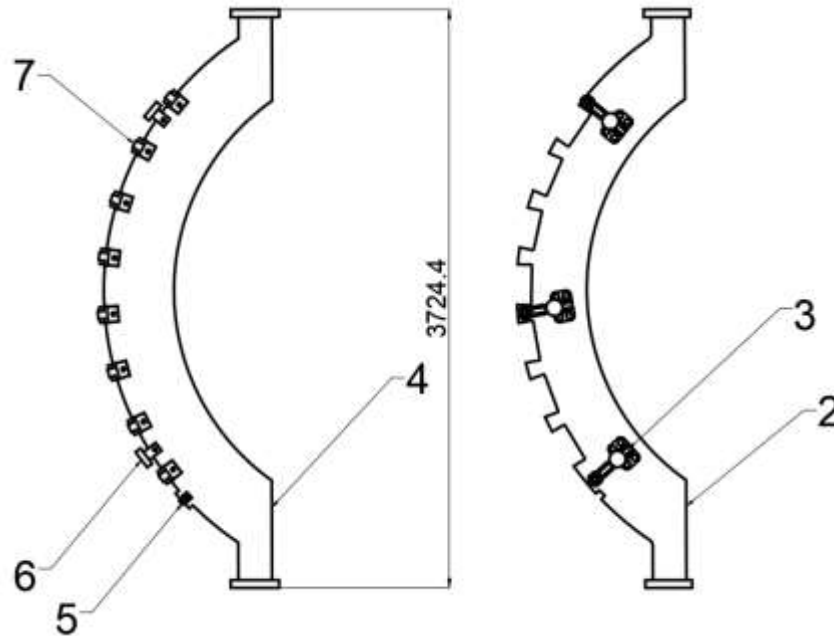


Figure 4. 10 Location parts

4.3.2 Clamping mechanism and clamping force calculation

a/ Vertical toggle clamp mechanism

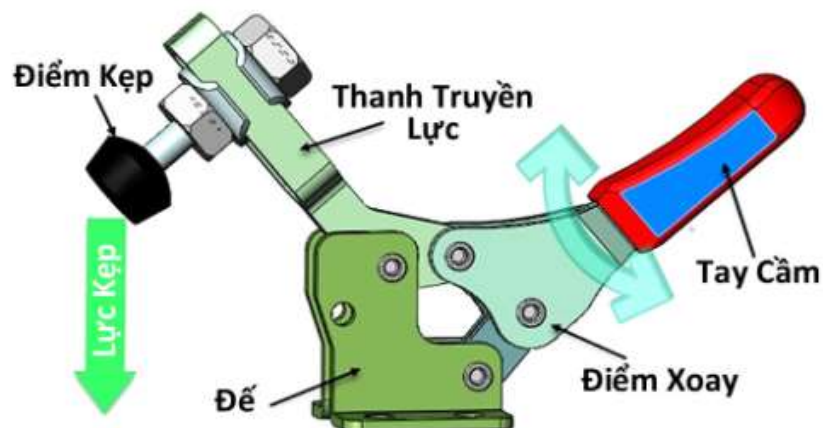


Figure 4. 11 Toggle Clamp Structure

- Base: This is the base part of the clamp and is usually made of cast iron or steel.
- Force transmission bar: this is a part of the clamp that holds the workpiece in place. It is connected to the base and is usually made of steel or aluminum.
- Pivot point: this is the mechanism that generates clamping force. It is connected to the clamp handle and base and usually consists of two or more links that move in a toggle-like manner.
- Handle: is the part used to convert hand force into clamping force and also the part that opens or closes the clamping mechanism.
- Clamping point: is the part that directly contacts the detail and receives the force from other parts to hold the detail in place. Usually made from rubber or steel depending on the usage requirements.

b/ Calculate the clamping force

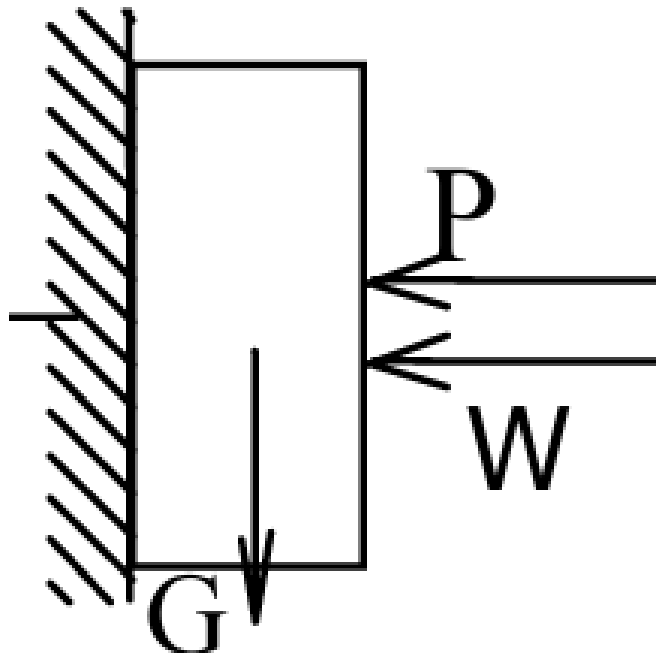


Figure 4. 12 Clamping force diagram

The clamping diagram on the fixture is as shown above, where:

+ G is the weight of the detail

+ W is the clamping force

+ P is the cutting force

Based on the Catia V5 software, the mass of the frame is calculated to be 1.6 kg.

$$\Rightarrow G = m \cdot g = 1,6 \cdot 10 = 16 \text{ N}$$

The cutting force P is the cutting force when drilling or shooting rivets on a thin surface, the force is very small so it can be neglected.

There is $F_{ms} = G = W \cdot \mu$ (where μ is the coefficient of sliding friction equal to 0.6)

$$\Rightarrow W = \frac{16}{0,6} = 26,7 \text{ N}$$

From that, we can calculate the actual clamping force needed

$$W_{tt} = K \cdot W = 1,5 \cdot 1,3 \cdot 1,1 \cdot 1,5 \cdot 26,7 = 78 \text{ N} \text{ (K is safety factor)}$$

4.4 Assembly process design

The goal of assembly process design in the aerospace industry – especially with structural components like the aircraft fuselage – is to ensure that the production process is carried out efficiently, accurately, safely, and with high repeatability. Specifically, the main objectives include:

- Ensure quality and accuracy:

+ Ensure that the details are assembled according to the technical drawings.

+ Ensure that assembly tolerances meet strict aviation standards.

+ Prevent errors that affect flight safety.

- Optimizing performance and productivity:

+ Shorten assembly time.

+ Minimize waiting time and waste.

+ Maximize resource utilization (human resources, materials, equipment).

- Increase synchronization and repeatability:
 - + Create a unified process that can be applied to multiple aircraft units.
 - + Reduce dependence on individual skills.
- Ensure the safety of workers:
 - + Design assembly steps that align with optimal working postures.
 - + Reduce the risk of workplace accidents when handling large and heavy materials.

4.4.1. Sequence of designing the assembly technology process

The sequence of designing the assembly technology process is a well-organized technical process aimed at ensuring the product is assembled correctly, on schedule, and with high economic efficiency.

- Study the overall assembly drawing of the product, check the technological aspects of the assembly:

First, the designer needs to carefully study the overall assembly drawing of the product to understand the structure and the relative positions of the details and subassemblies. This process helps identify early any factors that could cause difficulties in assembly, thereby assessing feasibility and technological viability. If unreasonable assembly dimension chains are detected, the designer needs to resolve the dimension chains to ensure allowable tolerances or adjust the design structure to enhance convenience and efficiency during the assembly process.

- Choose an appropriate assembly method:

Depending on the nature of the product, materials, technical requirements, and production conditions, it is necessary to choose an appropriate assembly method such as mechanical assembly (tightening, pressing, threading...), welding, gluing, screwing, or combined methods. This choice must ensure accuracy, durability, stability, and cost-effectiveness in production.

- Analyze the product to divide it into assembly clusters and reasonable components:

The product needs to be thoroughly analyzed to break it down into assembly parts, assembly units, and detail groups. This division helps to easily organize the assembly process step by step and by sub-assemblies, thereby enhancing the flexibility of production organization, allowing for the simultaneous assembly of different sub-assemblies before proceeding with the overall assembly.

- Build a diagram of the assembly sequence for parts and subassemblies:

After identifying the assemblies and details, the next step is to determine a reasonable assembly sequence, represented by an assembly diagram. This diagram helps to clearly visualize the assembly process from small components to the finished product, specifying the inspection points, adjustments, and the assembly relationships between the components.

- Choosing the method of organizing the assembly process:

The organization of assembly can be done in a sequential manner, parallel assembly, cluster assembly, or assembly line. Depending on the scale of production (single units, small batches, large batches, or mass production), the conditions of the workshop and equipment, it is necessary to choose an appropriate organizational form to optimize productivity and costs.

- Design the technological process for the assembly process:

Based on the assembly diagram and the chosen organizational form, proceed to develop a specific technological process. This process describes the sequence of assembly operations, the content of the tasks, the equipment used, the technical standards, and the inspection points throughout the assembly process.

- Determine the specific work content for each operation and technological step:

Each assembly operation must be clearly described, including the tasks to be performed, the tools used, the quality standards to be met, and the estimated time. This not only serves the production process but also serves as the basis for training workers and quality inspection.

- Establish technical requirements for joints, components, and assemblies:

It is necessary to clearly specify technical requirements such as sealing, rigidity, positional tolerances, dimensions, etc., for each joint, assembly, or component. This is a key factor that helps ensure the product meets quality requirements and operates stably.

- Selection of tools, fixtures, and equipment for the assembly and inspection process:

To ensure that assembly operations are performed accurately and quickly, it is necessary to identify the appropriate tools and fixtures. At the same time, testing equipment also needs to be equipped to assess quality immediately after each operation or critical stage.

- Determine technical specifications and time for each operation, while also analyzing economic efficiency:

Providing standard times for each operation helps in production planning, calculating productivity, and costs. Additionally, various assembly options can be developed, followed by analysis and selection of the optimal option in terms of technical and economic aspects.

- Develop a set of technical documents for production and inspection

The entire process above needs to be compiled into a complete technical documentation set including: product drawings, detailed drawings of assemblies and components, assembly diagrams, technology process charts, assembly operation instructions, and technical inspection guidelines. This is a mandatory document to be handed over to the production department, quality control, and workforce training.

4.2.1 Assembly process

Step 1: Attach the frame to the fixture, which has a contour similar to the positioning detail, and secure it tightly using a Toggle clamp mechanism.

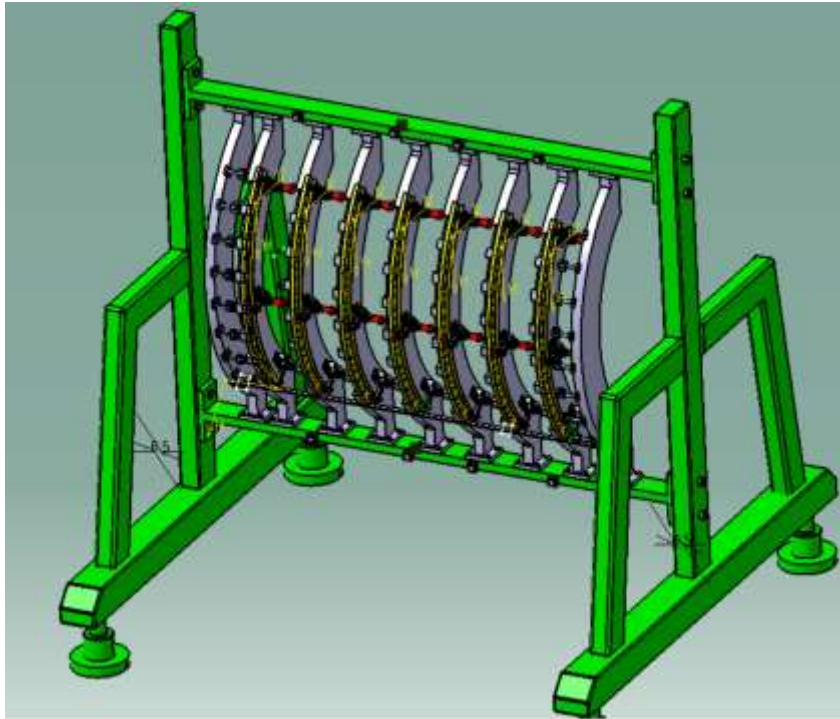


Figure 4. 13 Mount the frames onto the hoop frame locator

Step 2: Install the vertical frame members (stringer) onto the positioning mechanism on the fixture and clamp tightly with a clamping screw as shown in the drawing.

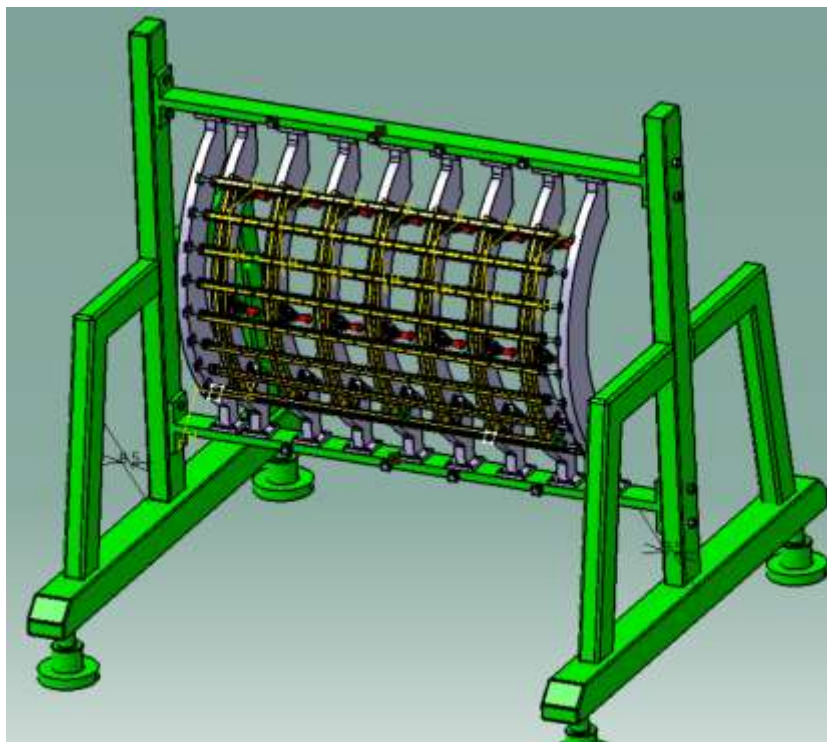


Figure 4. 14 Install stringer in pre-determined locations

Step 3: Install the skin onto the fixture and clamp it tightly as shown, then drill holes and use Cleco to temporarily hold the skin to the stringer and frame to ensure the parts are aligned with the drilled hole positions and then rivet.

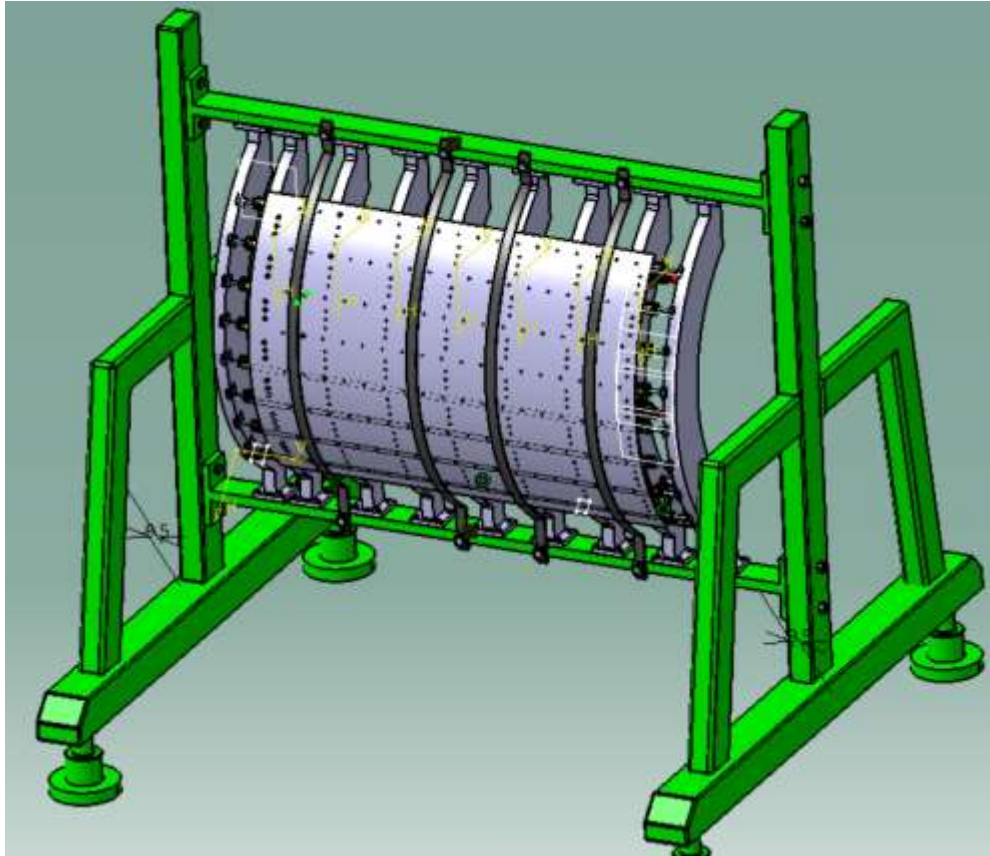


Figure 4. 15 Install the housing onto the stringer and clamp tightly.

4.3 The process of manufacturing composite aircraft fuselage frames

- Design and simulation:

+ Use CAD/CAE software to design the 3D aircraft fuselage.

+ Calculate stress, deformation, and perform FEA (Finite Element Analysis) to determine the optimal geometry and fiber layout.

- Material preparation:

+ Prepreg: It is carbon fiber that has been pre-impregnated with epoxy resin.

+ Prepreg is stored at low temperatures (-18°C) and cut automatically by CNC machines using blades or lasers according to the shape of each composite layer.

- Lay-up:

+ Prepreg layers are stacked manually or using Automated Fiber Placement or Automated Tape Laying machines onto the mold or mandrel.

+ The fibers are placed in different orientations (0° , $\pm 45^\circ$, 90°) to optimize load-bearing capacity. The fibers are placed in different orientations (0° , $\pm 45^\circ$, 90°) to optimize load-bearing capacity.

- Vacuum and cure in an autoclave:

+ After lay-up, the frame is vacuum bagged and placed in the autoclave.

+ The curing process (temperature $\sim 180^\circ\text{C}$, pressure ~ 7 bar) takes place over several hours to harden the resin and create a solid structure.

- Post-cure machining:

+ After being removed from the autoclave, the composite part is machined for holes and edge trimmed using CNC or waterjet.

+ Install metal pins, inserts, or reinforce high-load areas.

- Assemble frames and stringers:

+ The stringers and frames can be pultruded or molded composites.

+ Assembled with epoxy glue or rivets.

+ Some areas use co-curing techniques (common curing in an autoclave) to achieve a monolithic connection.

- Quality inspection:

+ Use ultrasonic inspection (NDT) to check for internal defects such as lamination.

+ Measure dimensions using CMM or 3D scan.



Figure 4. 16 Production of composite fuselage frame assemblies

CHAPTER 5: MEASUREMENT PROCESS FOR FUSELAGE FRAME ASSEMBLY

5.1. Introduction to the CMM Coordinate Measuring Machine

The three-dimensional coordinate measuring machine (CMM) is an important device in the manufacturing industry, helping to accurately measure the dimensions, shape, and position of mechanical, electronic, automotive, aerospace, medical, and many other components. CMM operates by using a probe to capture the coordinates of points on the surface of the object to be measured and then comparing them with the technical specifications or design drawings.



Figure 5. 1 Mitutoyo CMM machine

5.1.1. Basic structure of the CMM machine

- Machine frame (Machine Body)

+ Structure: CMM machines typically have a bridge, column, arm, or gantry structure, depending on the specific design and application.

+ Material: The machine body is usually made from high-stiffness materials such as aluminum alloy, steel, or ceramics to minimize deformation and vibration during the measurement process.

+ Material: The machine body is usually made from high-hardness materials such as aluminum alloy, steel, or ceramics to minimize deformation and vibration during measurement.

+ Axis system: The CMM operates on three main axes: X, Y, and Z, allowing the probe to move to any point on the surface of the part to be measured. Axis system: The CMM machine operates on three main axes: X, Y, and Z, allowing the probe to move to any point on the surface of the part to be measured.

- Probe System

+ Function: The probe, either tactile or non-contact (optical, laser), makes contact with the surface of the detail to determine the coordinates of the measurement points.

+ Probe material: Probes are usually made from hard and thermally stable materials such as ruby or zirconia to ensure accuracy under all temperature conditions.

There are 3 main types of probes used in CMM:

Table 5. 1 Comparison of type of probe

Type of probe	Main features
Touch	the measurement point, common, high accuracy
Non-contact	Use laser beams, light, etc., for soft/thin materials.
Scanning probe	Surface scanning to collect data, using curved surfaces

- Measuring Table

+ Material: The measuring table is usually made of granite, as granite has high thermal stability and is less prone to deformation over time, helping to maintain accuracy throughout the usage period.

+ Size: The size of the measuring table varies depending on the size of the part to be measured, ensuring enough space to place and secure the part.

- Control system (Controller and Software)

+ Control system: Includes components such as the microprocessor, control board, and user interface, which help control the machine's movement and collect measurement data.

+ Software: Specialized software such as PC-DMIS, Calypso, or Quindos is used to analyze measurement data, compare it with design drawings, and generate quality inspection reports.

- Other supporting equipment

+ Fixtures: Includes jigs, clamps, and magnets used to secure components during measurement, preventing errors due to component movement.

+ Air Compressors and Dryers: Used in bridge or gantry-type CMMs to provide compressed air, reduce friction, and ensure smooth machine movement.

5.1.2 Classification of CMM Machines

Based on the coordinate system used

- Based on the coordinate system, 3D measuring devices are divided into 2 types:

+ Non-contact measuring devices

Non-contact measuring devices are often optical CMM coordinate measuring machines such as laser trackers, photogrammetry systems, etc.



Figure 5. 2 Laser Tracker

+ Contact measurement devices

There are a total of 11 different types of CMM machines. But the 4 most commonly used types are: Bridge; Column; Gantry; Horizontal arm

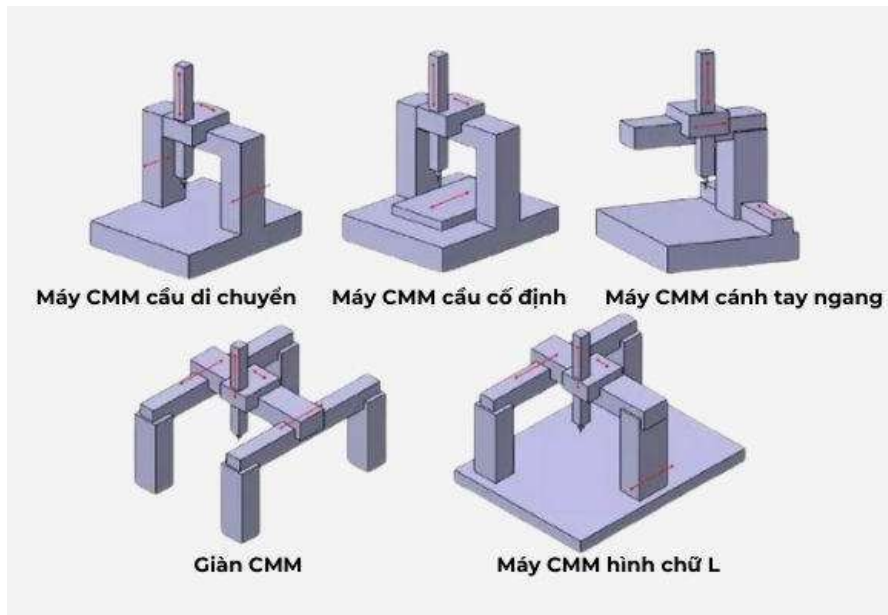


Figure 5. 3 Common types of CMM machines

5.1.3 Operating principle

- Moving the probe: The probe moves along the X, Y, and Z axes to contact different points on the surface of the part.

- Collecting coordinate data: When the probe touches the surface, the system will record the coordinates of that point.

- Data analysis: The coordinate points are processed and analyzed by the software to create a digital model of the part. From there, it can be compared with the CAD design or technical specifications.

Coordinate Measuring Machine(CMM)

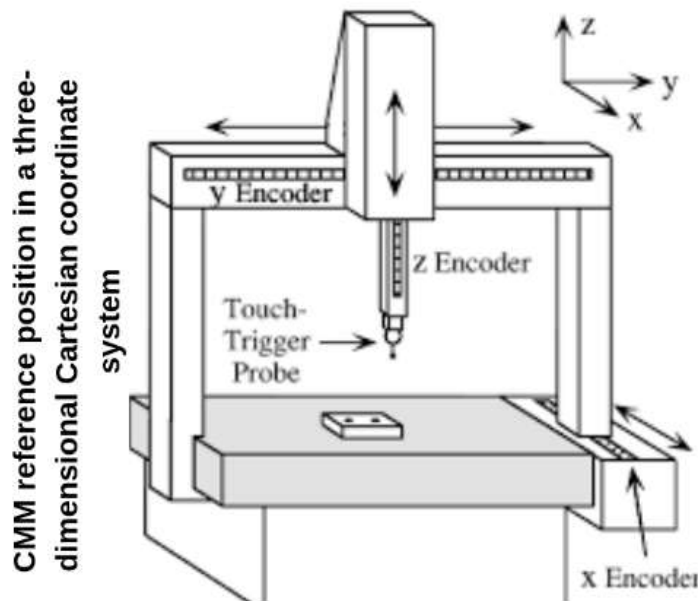


Figure 5. 4 The operating principle of the CMM machine

5.1.4 Benefits of CMM Coordinate Measuring Machines

The CMM, or three-dimensional coordinate measuring machine, is an important tool in the process of product quality control and dimensional measurement. The applications of CMM machines are very diverse and important in the industry, helping to improve the accuracy and consistency of products. Here are some important uses of the CMM machine:

- Measuring dimensions: CMM machines are primarily used to measure the dimensions of product components. With the ability to measure 3D coordinates (X, Y, Z) and high precision, it helps determine the length, width, and height of manufactured parts.

- Sample inspection: CMM machines are used to inspect and ensure the quality of product samples. This ensures that the product meets the established standards and technical requirements.

- Angle, direction, and depth schematics: The CMM machine has the capability to measure parameters such as angles, directions, and depths of product details, ensuring that they are processed and assembled correctly.

- Template measurement or modeling: The CMM has the capability to measure and store information about the shape and size of samples, aiding in the production and quality control processes.

- Measuring objects with easily changeable properties: The probe of the CMM has the ability to detect coordinates with high precision, allowing for accurate measurement of details with easily changeable dimensions such as rubber and soft plastic, while also reducing measurement errors.

- Software control system: The CMM control software helps to move the coordinates accurately, preventing machine vibrations during manual measurements, ensuring precision and consistency in the measurement process.

- 3D measurement and high resolution: The CMM machine not only measures length but also has the capability to measure the roundness and concentricity of drilled holes on manufactured parts. This enhances quality control and ensures product accuracy.

- Create 3D dimension drawings: The CMM machine can use a 3D laser scanning head to create dimension drawings of the actual product, assisting in design and production.

5.1.5 Measurement capabilities of the CMM

- Basic geometric measurements:

+ Circle: 3 points are needed for measurement; if measuring 4 (up to 50) points or more, the shape deviation is determined.

+ Plane: Plane measurements require 4 or more points to determine the shape. These measurement points help the computer accurately calculate the position and tilt of

the plane in three-dimensional space. If you need to check the flatness or shape deviation, you can measure more points to get more accurate results.

+ Cylinder: To determine a cylinder, at least 5 points are needed. These measurements help determine the axis and diameter of the cylinder.

+ Cone: A cone (or conical shape) requires at least 6 points to be defined. The calculations determining the angles include those of the cone and its axis in space.

+ Sphere: The position of the sphere is found by measuring 4 points that are also calculated.

- Distance measurements such as:

+ Distance between two points.

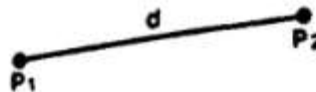


Figure 5. 5 Distance between two points

+ The distance from a point to a line.

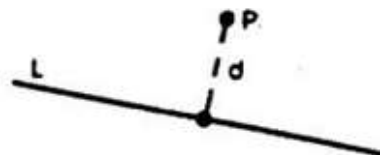


Figure 5. 6 The distance from a point to a line.

+ The distance between two lines.

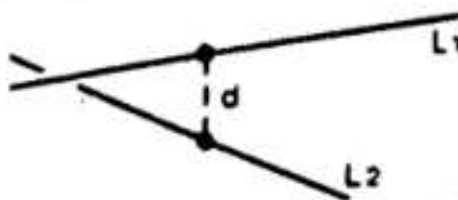


Figure 5. 7 The distance between two lines.

+ The distance between a point and a plane.



Figure 5. 8 The distance between a point and a plane

+The distance between a point and a circle.



Figure 5. 9 The distance between a point and a circle

+ The distance between a line and a circle.

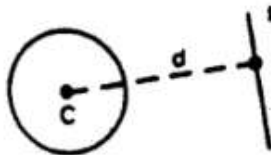


Figure 5. 10 The distance between a line and a circle

+ The distance between two circles.

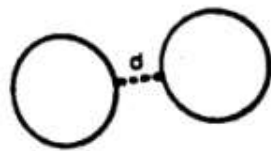


Figure 5. 11 The distance between two circles

- Angle measurements:

+ Angle between two lines

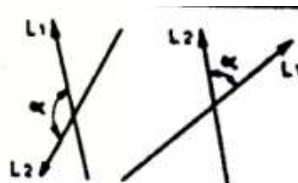


Figure 5. 12 Angle between two lines

+ Angle between a line and a plane

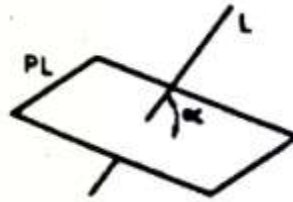


Figure 5. 13 Angle between a line and a plane

+ Angle between two planes

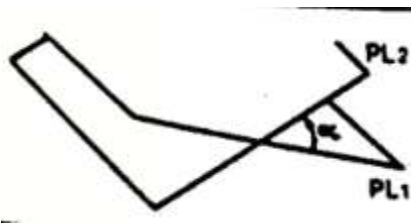


Figure 5. 14 Angle between two planes

5.2 Choosing the type of measuring equipment

Compare the differences between traditional CMM machines and laser trackers

Table 5. 2 Comparison of CMM and laser tracker

Criteria	Traditional CMM	Laser Tracker
Measurement size	Limited (usually within a few meters)	Very large (several dozen meters)
Mobility	Bulky, fixed Mobile	easy to install in the factory
Accuracy	$\pm 1 - 5 \mu m$	$\pm 10 - 20 \mu m$
Measurement time	Slower	Fast (minimal setup, flexible measurement)
Application in aviation	Suitable for small details	Common in measuring large details such as the body, wings, ...

Conclusion:

Laser tracker is a more suitable choice for inspecting the B757 fuselage panel because:

- The fuselage panel of the B757 is very large (length in meters).
- Need measuring equipment that can be moved flexibly.
- Laser tracker allows for quick and accurate measurements in a production environment.



Figure 5. 15 Using a Laser Tracker to measure the aircraft fuselage

The operating principle of the Laser tracker:

The laser tracker emits a laser beam towards a spherically mounted retroreflector (SMR) placed at the point to be measured on the object. The laser beam reflects back and is received by the device. The two pan/tilt motors of the laser tracker will adjust to follow the direction of the SMR, thereby measuring two angles: azimuth (horizontal angle) and elevation (vertical angle). Combined with the distance measured from the laser to the SMR, the device calculates the 3D coordinates of the measurement point.

Laser tracker uses two main distance measurement methods:

- IFM – Interferometer (laser interferometer):
 - + Measure the phase shift of the reflected light wave to calculate the distance.
 - + Very accurate, suitable for measuring small displacements.

- ADM – Absolute Distance Measurement:

+ Based on continuous multi-frequency waves (multi-frequency laser) to measure the absolute distance to the reflective mirror.

+ Allows for quick measurements, works well in non-continuous 3D measurements or when the beam is lost.

Combine 3 parameters: distance (L), horizontal angle (θ_H), vertical angle (θ_V) → calculate the 3D coordinates of the measurement point using the formula:

$$X = L \cdot \sin(\theta_V) \cdot \cos(\theta_H)$$

$$Y = L \cdot \sin(\theta_V) \cdot \sin(\theta_H)$$

$$Z = L \cdot \cos(\theta_V)$$

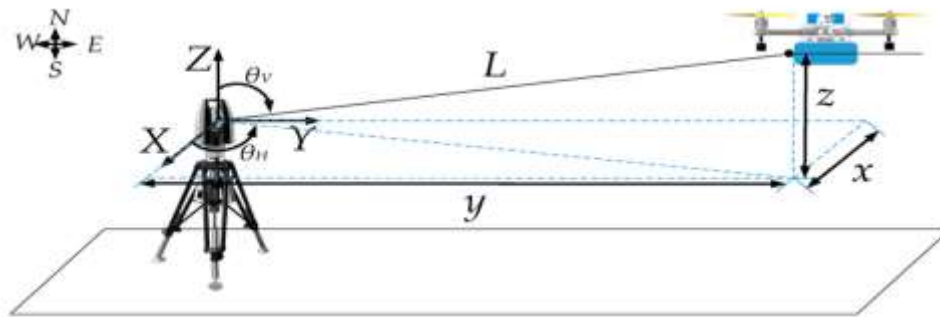


Figure 5. 16 The operating principle of a Laser tracker

The measurement data from the laser and angular encoders are transmitted to the processing software, where the 3D coordinates of the measurement point are calculated and displayed. The software also allows for comparing measurement data with the CAD model, checking tolerances, and generating measurement reports.

In cases where the measurement positions are obstructed or the space is limited, using T-probe or T-scan is extremely effective.

- T-Probe – Contact measurement in confined spaces

+ No direct line of sight required: T-Probe uses reflective mirrors and an infrared light system to determine the position and orientation of the probe, allowing measurements in areas where the laser beam cannot directly reach.

+ Wireless and lightweight design: With a wireless and lightweight design, T-Probe is easy to maneuver in tight or obstructed spaces.

+ Wireless and lightweight design: With a wireless design and lightweight construction, the T-Probe is easy to maneuver in tight or obstructed spaces.

+ Wide measurement range: When combined with the Leica Absolute Tracker AT960, the T-Probe can measure up to 60 meters, making it suitable for large measurement applications such as aircraft frames or car bodies. Wide measurement range: When combined with the Leica Absolute Tracker AT960, the T-Probe can measure within a range of up to 60 meters, suitable for large measurement applications such as aircraft frames or car bodies.



Figure 5. 17 T-probe

- T-Scan – Non-contact surface scanning

+ Fast and accurate scanning: T-Scan 5 can collect data at a rate of up to 210,000 points per second, allowing for quick scanning of complex or hard-to-reach surfaces.

+ Flexible in confined spaces: With its handheld design, T-Scan can easily operate in areas with limited space or obstructions.



Figure 5. 18 T-Scan

Prominent Laser Tracker manufacturers:

- Hexagon (Leica Geosystems)

+ Featured products: Leica Absolute Tracker AT960, AT402

+ Advantages:

- High accuracy
- Supports SMR, T-Probe, T-Scan (for 3D scanning)
- Used extensively in aerospace, automotive, and space industries



Figure 5. 19 Laser tracker leica AT402

- FARO Technologies

+ Featured products: FARO VantageS, VantageE Laser Tracker

+ Advantages:

- Compact, easy to carry
- More competitively priced than Leica

- Integrates well with FARO CAM2, PolyWorks software



Figure 5. 20 Laser tracker Faro vantages

- API Metrology (Automated Precision Inc.)

+ Featured products: API Radian Pro, API Radian Core

+ Advantages:

- Directly compete with Leica & FARO
- Stand out with wireless tracking technology
- API excels in technical support services



Figure 5. 21 Laser tracker API radian Pro

5.3 Laser tracker measurement process

Ensure that the frame assembly (skin, frame, stringer...) is assembled according to the design, meeting the geometric, positional, and deformation tolerance standards.

Equipment and software used

Table 5. 3 Equipment and software of measurement process

Device	Purpose
Laser Tracker (FARO, Leica, API)	Measure large dimensions with high precision
T-Probe / SMR / T-Scan	Measure hidden points, 3D surface scanning
Fixture	Fix the fuselage assembly while measuring
Software SpatialAnalyzer / PolyWorks / Verisurf	Communication with measuring devices, processing – analyzing results

Measurement procedure for the component

Step 1: Preparation

- Position the frame assembly on the fixture and clamp it tightly to ensure its position.
- Clean the surface before measuring (avoid dust and grease affecting the laser measurement)
- Install the Laser Tracker in a position that allows full observation of the measurement area, avoiding blind spots.

Step 2: Determine the reference coordinate system (Reference Coordinate System):

- This is an extremely important step to ensure that all measurements are referenced to a common system.
- Use pre-known reference points on the body frame or created reference points (e.g., precise positioning holes, reference surfaces) to establish the 3D coordinate system.

- Use pre-known reference points on the body frame or created reference points (e.g., precise locating holes, reference surfaces) to establish a 3D coordinate system.

- The three-point plane definition method, two-point axis definition method, one-point origin definition method, or other methods can be used depending on the measuring software.

- You can use the 3-point method to define a plane, the 2-point method to define an axis, the 1-point method to define an origin, or other methods depending on the measuring software.

Step 3: Measure the main geometric characteristics

Table 5. 4 Target of measurement and inspection

Position to measure	Target
Rivet holes	Check the center coordinates, roundness, relative position
Frames	Check for parallelism, distance
Stringers	Check the distance between the stringers.

Step 4: Process and export the report

- The measuring software will automatically record all coordinate data, perform calculations as required, and display results in real-time.

- Ensure that the measurement points are named clearly and systematically for easy tracking and analysis later.

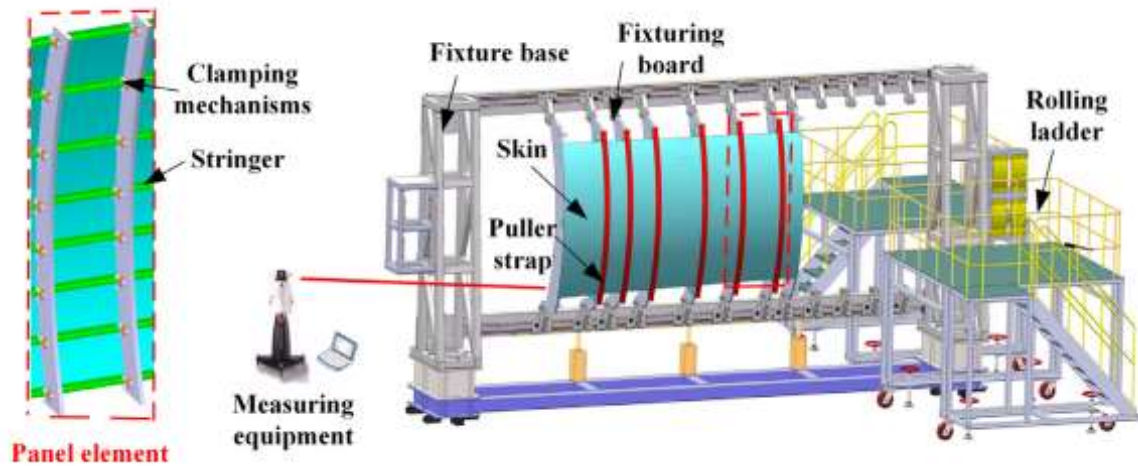


Figure 5. 22 Measuring the fuselage frame assembly with a Laser tracker

CHAPTER 6: STRESS AND STRAIN ANALYSIS OF THE FUSELAGE FRAME ASSEMBLY

6.1 Introduction to Abaqus software

Abaqus was first developed in 1978 by the company Hibbitt, Karlsson & Sorensen (HKS). The name ABAQUS is inspired by the word abacus – the ancient counting tool, a symbol of computation.

In 2005, HKS was acquired by Dassault Systèmes (France) – the owner of major industrial software such as CATIA, SolidWorks, and later integrated into the high-end simulation platform SIMULIA.

Abaqus is used for simulation:

- Stress – strain
- Collision, fatigue, material failure
- Heat, heat transfer
- Nonlinear mechanics
- Solid-fluid-thermal interaction

Table 6. 1 The main modules in Abaqus

Module	Description
Abaqus/CAE (Complete Abaqus Environment)	Main interface: model building, meshing, boundary condition assignment, simulation running, result processing.
Abaqus/Standard	Linear & nonlinear static analysis, quasistatic displacement, residual stress
Abaqus/Explicit	Fast dynamic analysis: collision, fall, impact, explosion, forming...
Abaqus/CFD	Fluid flow simulation (not as strong as ANSYS Fluent)
Abaqus/Viewer	Analyze results, export graphs, images

Outstanding features of Abaqus:

Table 6. 2 Feature of Abaqus software

Feature	Description
Nonlinear processing	Very strong: nonlinear material simulation, complex contact, large deformation
Dynamic analysis	Impact simulation, vibration, real-time
Advanced material models	Available models: metal, composite, rubber, bone, biological tissue
CAD/CAE integration	Import from SolidWorks, CATIA, NX, STEP, IGES easily
Programming capability	Can write Python scripts to automate model processing.

Practical applications of Abaqus:

- Aerospace

- + Simulation of fuselage panels, wing box, composite tail section
- + Bird strike impact durability test
- + Analysis of thin shell stability, panel stiffener

- Car

- + Full car crash test
- + Calculation of the energy absorption zone (crumple zone)
- + Forming the car body steel sheet

- Manufacturing engineering

- + Simulation of heavy load structures (cranes, presses)
- + Thermo-mechanical analysis in machining

- Bioengineering

- + Prosthetic limb simulation, dental grafting, soft tissue
- + Load testing of the implant area
- Oil and gas, energy
 - + Corrosion simulation, high-pressure resistance, composite materials in pipelines

Advantages and Disadvantages of Abaqus:

Table 6. 3 Advantages and disadvantages of Abaqus software

Advantages	Disadvantages
Extremely strong nonlinear simulation	Learning to use it initially is harder. ANSYS
Can simulate many fields	Need high machine configuration if the model is large.
Reliable results, industry-recognized	High licensing cost
Python programming support	No in-depth CFD

6.2 Applying the finite element method for calculations

FEM (Finite Element Method) is a numerical method used to solve complex physical problems in the form of partial differential equations (PDE), commonly encountered in:

- Structural mechanics (static/dynamic stress analysis)
- Heat transfer
- Hydraulics, electric fields, magnetic fields, etc.

The basic idea of FEM

- Discretization of the computational domain
 - + Continuous objects → are divided into small elements (finite elements): triangles, quadrilaterals, hexahedra, tetrahedra...
 - + The elements are connected at the nodes.

For example: A degree axis is divided into many small segments, each segment being an element.

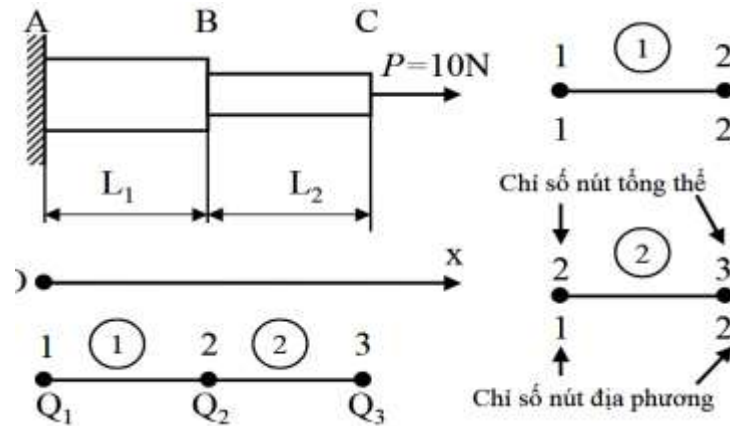


Figure 6. 1 Example of dividing the number of elements

- Establish the element equation

In linear static analysis, the equilibrium equation takes the form:

$$K \cdot u = F$$

K: Element stiffness matrix

u: Element node displacement

F: Element load vector

- Apply boundary conditions

+ Assign constraints such as constant displacement or force.

+ This ensures that the problem has a unique solution.

- Solve the system of equations

+ Use numerical methods such as:

+ LU Decomposition (Linear)

+ Newton–Raphson (Nonlinear)

+ Find the displacement values at the nodes.

- Analysis

+ From node displacements → calculate stress, strain using the derivative of the shape function.

+ Visualization: deformation, internal force diagrams, stress concentration, etc.

The main components in FEM:

Table 6. 4 The main components in finite element method

Components	Role
Element	Small block carrying the physical model
Node	Connecting point between elements – where the variable is contained
Stiffness matrix K	Relate load to displacement through mechanical properties
Boundary conditions	Necessary conditions for the problem to have a unique solution
Mesh	An assembly of all the elements and nodes constituting the numerical model

Advantages and Disadvantages:

- Advantages:

- + Capable of handling complex geometry and loads.
- + Suitable for all types of materials (elastic, plastic, nonlinear).
- + Expandability: thermal, kinetic, contact, fracture, etc.

- Limitations:

- + Need to correctly understand mesh division techniques and boundary conditions.

+ An incorrect model → an incorrect result.

+ Complex problems are very resource-intensive in terms of computation.

Applied in Abaqus

In Abaqus, there is no need to manually construct the entire system of equations, you only need to:

1. Geometric modeling
2. Assign materials
3. Assign loads and boundary conditions
4. Mesh generation
5. Run analysis (Static, Dynamic, Nonlinear, ...)

6.3 Theoretical basis for static problem analysis

The classical analytical method, in linear solid mechanics, for the thin shell problem according to reference [2], uniform stress distribution:

Assume: The airplane at an altitude of 8000m => Cabin pressure is approximately 80 kPa, shell thickness $t = 3$ mm, fuselage diameter $D = 4$ m, modulus of elasticity of 2024 aluminum alloy $E = 73$ GPa, Poisson's ratio $\gamma = 0.33$, modulus of elasticity of 7050 aluminum alloy $E = 72$ GPa.

Atmospheric pressure with altitude:

$$P = P_0 \cdot \left(1 - \frac{L \cdot h}{T_0}\right)^{\frac{g \cdot M}{R \cdot L}}$$

Where:

P: Pressure at height h (Pa)

P_0 : Pressure at sea level (101325 Pa)

L: The rate of temperature decrease with altitude (0.0065 K/m)

h: Height above sea level (m)

T_0 : Temperature at sea level (288.15 K)

g : Gravitational acceleration (9.80665 m/s²)

M : Molar mass of air (0.0289644 kg/mol)

R : Ideal gas constant (8.3144598 J/(mol·K))

Table C.2
Properties of the U.S. Standard Atmosphere (SI Units)^a

Altitude (m)	Temperature (°C)	Acceleration of Gravity, g (m/s ²)	Pressure, p [N/m ² (abs)]	Density, ρ (kg/m ³)	Dynamic Viscosity, μ (N · s/m ²)
-1,000	21.50	9.810	1.139 E + 5	1.347 E + 0	1.821 E - 5
0	15.00	9.807	1.013 E + 5	1.225 E + 0	1.789 E - 5
1,000	8.50	9.804	8.988 E + 4	1.112 E + 0	1.758 E - 5
2,000	2.00	9.801	7.950 E + 4	1.007 E + 0	1.726 E - 5
3,000	-4.49	9.797	7.012 E + 4	9.093 E - 1	1.694 E - 5
4,000	-10.98	9.794	6.166 E + 4	8.194 E - 1	1.661 E - 5
5,000	-17.47	9.791	5.405 E + 4	7.364 E - 1	1.628 E - 5
6,000	-23.96	9.788	4.722 E + 4	6.601 E - 1	1.595 E - 5
7,000	-30.45	9.785	4.111 E + 4	5.900 E - 1	1.561 E - 5
8,000	-36.94	9.782	3.565 E + 4	5.258 E - 1	1.527 E - 5
9,000	-43.42	9.779	3.080 E + 4	4.671 E - 1	1.493 E - 5
10,000	-49.90	9.776	2.650 E + 4	4.135 E - 1	1.458 E - 5
15,000	-56.50	9.761	1.211 E + 4	1.948 E - 1	1.422 E - 5
20,000	-56.50	9.745	5.529 E + 3	8.891 E - 2	1.422 E - 5
25,000	-51.60	9.730	2.549 E + 3	4.008 E - 2	1.448 E - 5
30,000	-46.64	9.715	1.197 E + 3	1.841 E - 2	1.475 E - 5
40,000	-22.80	9.684	2.871 E + 2	3.996 E - 3	1.601 E - 5
50,000	-2.50	9.654	7.978 E + 1	1.027 E - 3	1.704 E - 5
60,000	-26.13	9.624	2.196 E + 1	3.097 E - 4	1.584 E - 5
70,000	-53.57	9.594	5.221 E + 0	8.283 E - 5	1.438 E - 5
80,000	-74.51	9.564	1.052 E + 0	1.846 E - 5	1.321 E - 5

^aData abridged from *U.S. Standard Atmosphere*, 1976, U.S. Government Printing Office, Washington, D.C.

Figure 6. 2 International Standard Atmosphere

In reality, the cabin pressure acting on the aircraft fuselage creates two types of stress:

- Hoop stress:

+ Arises from internal pressure wanting to expand the body in the circumferential direction

+ Since the frame bears the entire load (a common assumption), the shell does not experience circumferential stress or it is very small.

+ In reality, a small portion will be transmitted to the shell, but assuming the frame is very rigid, it can be neglected.

- Longitudinal stress:

+ Arises from internal pressure wanting to elongate the hull

+ The shell and stringers share the load

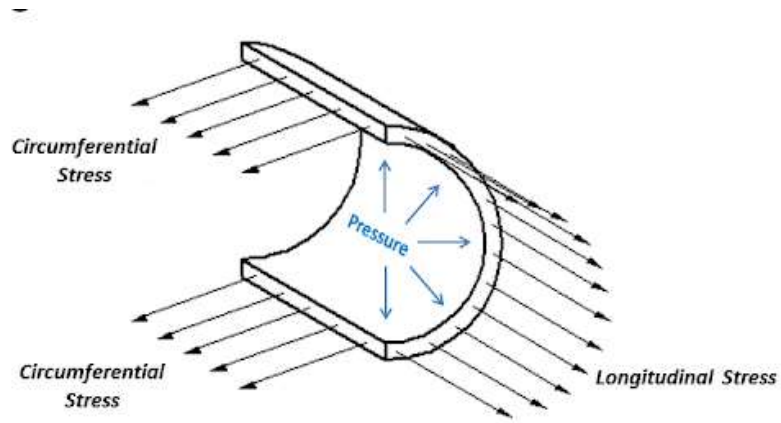


Figure 6. 3 The pressure acting on the fuselage

(Source: <https://trenchlesspedia.com/definition/2799/hoop-stress>)

- Hoop stress:

$$\sigma_{\theta} = \frac{p \cdot R}{t} = \frac{80000.2}{0,003} = 53 \text{ MPa}$$

- Longitudinal stress:

$$\sigma_x = \frac{p \cdot R}{2t} = \frac{80000.2}{2.0,003} = 27 \text{ MPa}$$

- Hoop strain:

$$\varepsilon_{\theta} = \frac{\sigma_{\theta}}{E} - \gamma \frac{\sigma_x}{E} = \frac{53}{73000} - 0,33 \frac{27}{73000} = 6.10^{-4} \text{ mm}$$

- Longitudinal strain:

$$\varepsilon_x = \frac{\sigma_x}{E} - \gamma \frac{\sigma_{\theta}}{E} = \frac{27}{73000} - 0,33 \cdot \frac{53}{73000} = 1,3.10^{-4} \text{ mm}$$

The formulas above are only applicable for estimating stress in the case of thin shells. However, airplanes have complex designs with many factors such as windows, doors, reinforcement frames, and dynamic loads during flight, so more advanced analysis methods are needed. To be more accurate, finite element analysis (FEA) is needed.

- Stress $\{\sigma\}$: Using Hooke's law with the material matrix $[D]$

$$\{\sigma\} = [D].\{\varepsilon\} = \{D\}[B]\{U\}$$

6.4 Steps to perform computational simulation using Abaqus software

Step 1: Draw the 3D model of the body frame assembly using Catia software

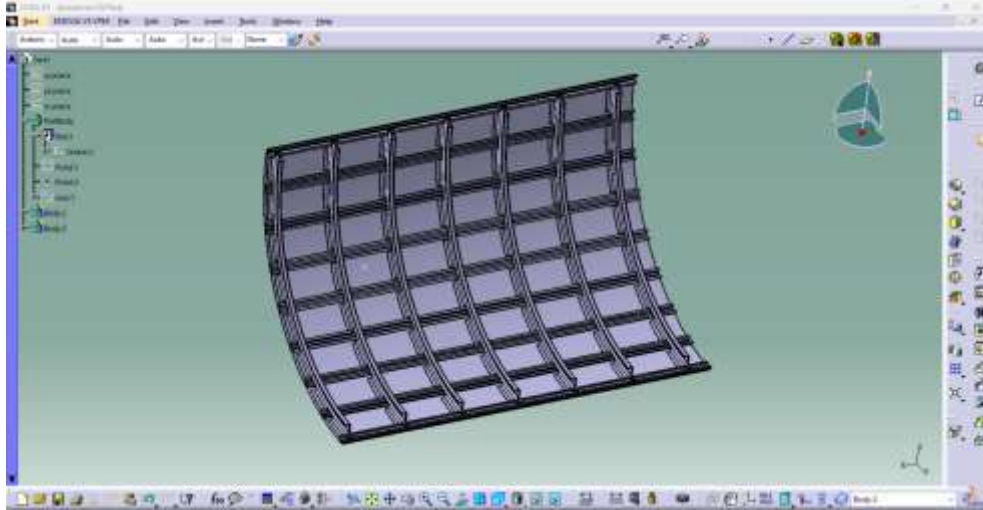


Figure 6. 4 Design the model on Catia V5

Step 2: Import the assembly into the Abaqus software by going to file → Import

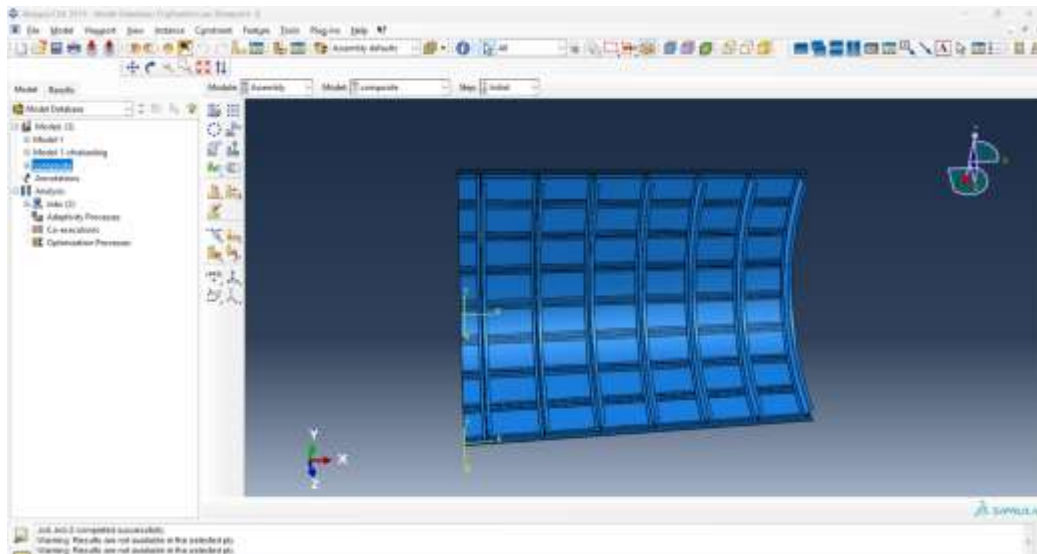


Figure 6. 5 Import the model into the Abaqus simulation software.

Step 3: Determine the material parameters for each detail in the Property module

For the shell made of 2024 aluminum alloy: Density = 2.78 g/cm³, Poisson's ratio = 0.33, Young's Modulus = 73 GPa.

For other components made of 7050 aluminum alloy: Density = 2.8 g/cm³, Poisson's ratio = 0.33, Young's Modulus = 71 GPa.

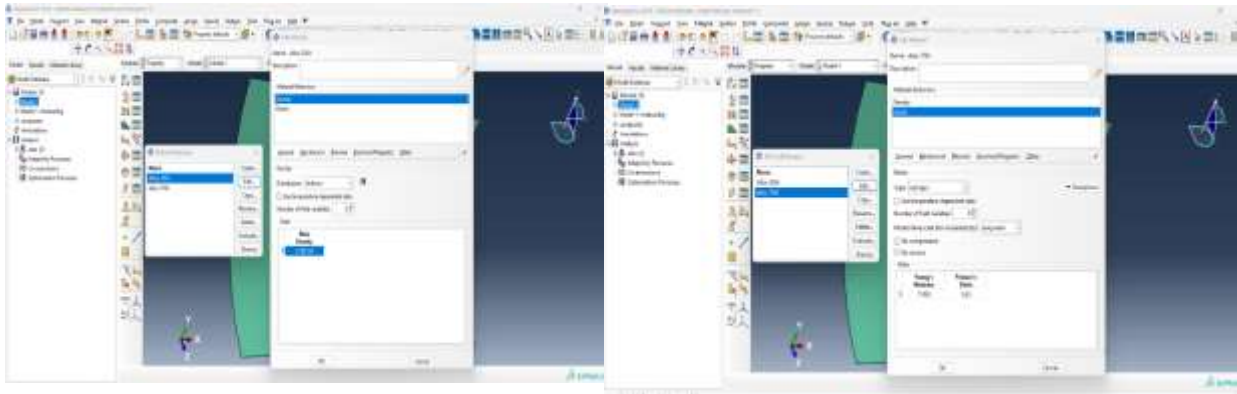


Figure 6. 6 Enter the necessary parameters for the software to calculate

In the case of composite materials, select Create composite layup, choose the number of layers, fill in the necessary coefficients, and the orientation angle of the composite layers.

Properties such as the modulus of elasticity in the fiber direction and the modulus of elasticity in the transverse direction are selected according to the table below:

	E-glass/ Epoxy	S-glass/ Epoxy	Kevlar-49/ Epoxy	Carbon/ Epoxy(a)	Carbon/ Epoxy(b)
V_f (-)	0.55	0.55	0.55	0.55	0.55
ρ (g/cm ³)	2.0	2.0	1.4	1.6	1.7
E_1 (GPa)	40	48	73	130	330
E_2, E_3 (GPa)	10	11	5	10	8
ν_{12}, ν_{13} (-)	0.30	0.30	0.35	0.28	0.28
ν_{23} (-)	0.40	0.40	0.45	0.50	0.50
G_{12}, G_{13} (GPa)	3.8	4.2	2.2	4.5	4.0
G_{23} (GPa)	3.4	3.6	1.7	3.5	2.7
α_1 (10 ⁻⁶ /K)	7.0	4.0	-1.0	-0.5	-0.7
α_2, α_3 (10 ⁻⁶ /K)	22	20	50	30	30
X_T (MPa)	1000	1300	1400	1800	1000
Y_T, Z_T (MPa)	40	40	20	40	40
X_C (MPa)	700	800	300	1200	800
Y_C, Z_C (MPa)	120	140	120	180	100
S_{12}, S_{13} (MPa)	70	70	40	70	70
S_{23} (MPa)	40	40	20	40	40

Figure 6. 7 Properties of fiber composites

(Source <https://nilspv.folk.ntnu.no/TMM4175/material-properties>)

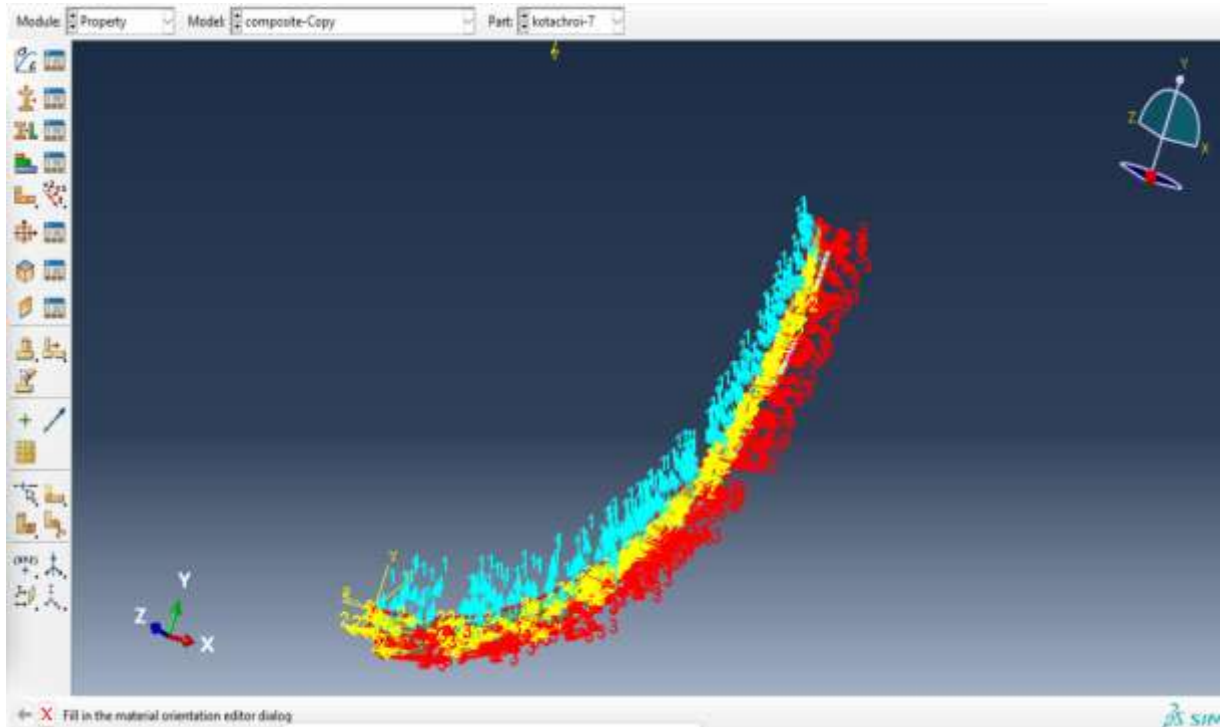


Figure 6. 8 Arrange the carbon fiber orientation

Step 4: Select the module step to create a static calculation mode (static)

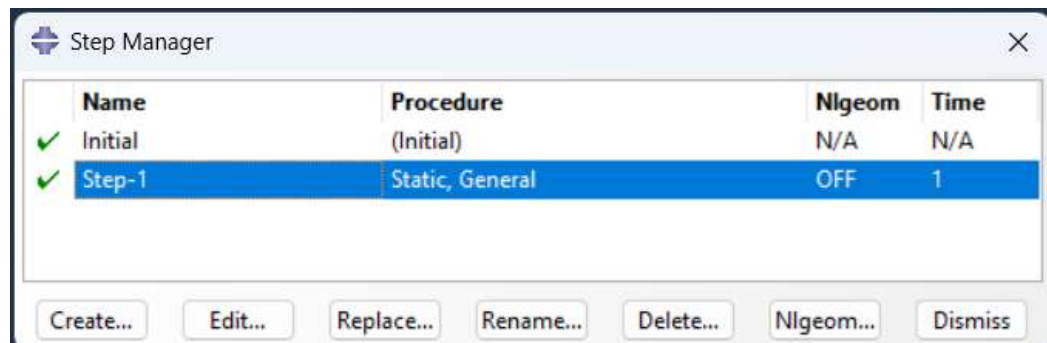


Figure 6. 9 Choosing a module for the static problem

Step 5: In the Interaction module, create the constraint type between the components as Tie.

There are 3 types of constraints in the aircraft fuselage assembly: Skin with stringer, Shear clip with skin, and Shear clip with frame.

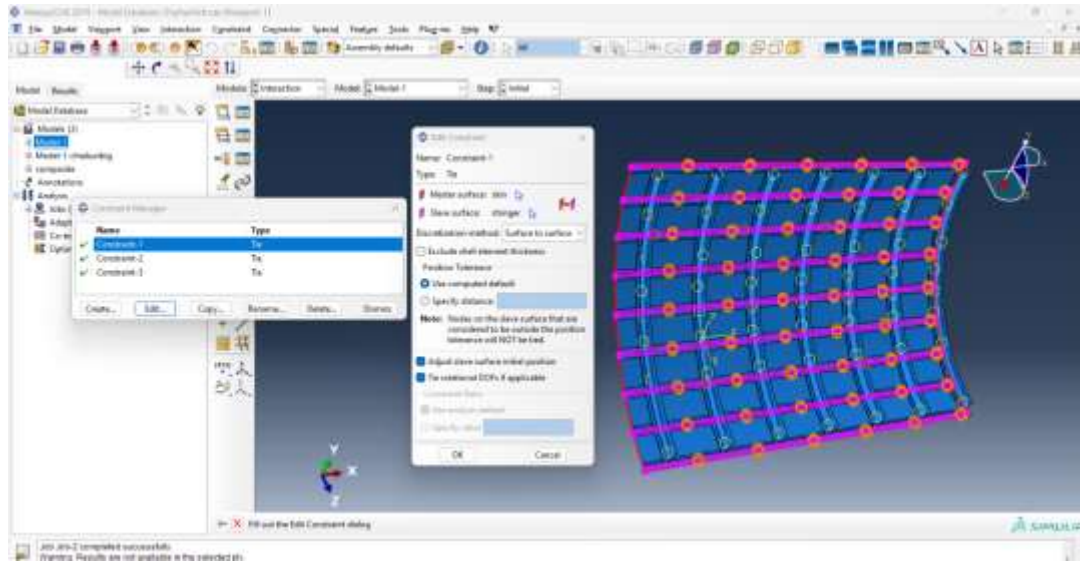


Figure 6. 10 Create interaction between the parts

Step 6: Go to the Load module to create the necessary boundary conditions and forces. Assuming the airplane is at an altitude of 8000m and experiences a cabin pressure of 80 kPa, ignoring other factors such as wind direction, air friction, etc.

The external atmospheric pressure is about 35 kPa.

=> The pressure differential that the aircraft fuselage must withstand is

$$\Delta P = P_{cabin} - P_{outside} = 80 - 35 = 45 \text{ kPa}$$

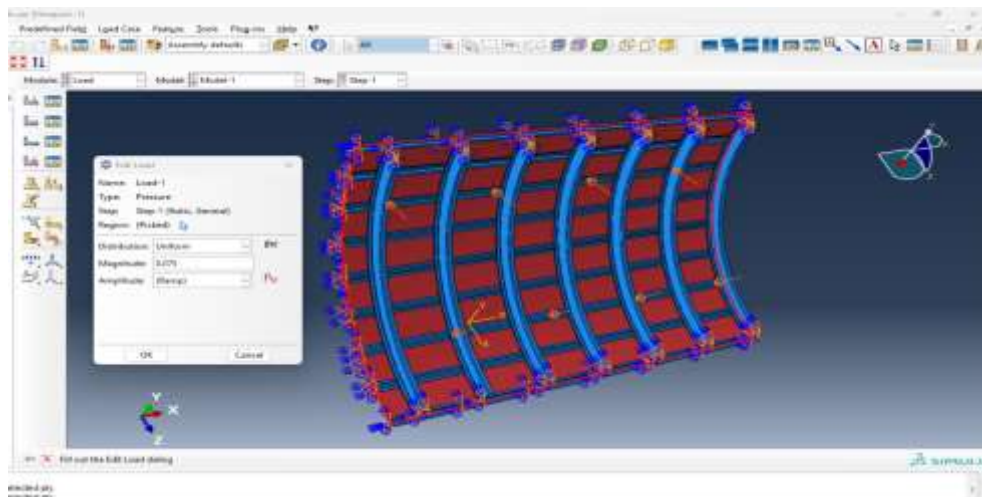


Figure 6. 11 Set the forces and boundary conditions for the model.

Step 7: Mesh the parts in the mesh module

In Abaqus, the Mesh (meshing) is a core step in finite element method (FEM) simulations. Mesh converts the geometric model into a set of discrete elements so that

Abaqus can perform numerical calculations to find stress, strain, temperature, etc., in the model. Linear and quadratic are two types of elements that differ in interpolation order, directly affecting the accuracy, smoothness of the results, and computation speed.

Table 6. 5 Differences between linear and quadratic

Criteria	Linear	Quadratic
Number of nodes on the element (e.g., 3D)	8 nodes (C3D8, C3D8R)	20 nodes (C3D20, C3D20R)
Deformation interpolation	Linear (straight line between nodes)	Second degree (curve)
Deformation profile	Rough, angular	Smoother, closer to reality
Stress/strain results	Less accurate	Higher accuracy
Element requirement (mesh)	Need a fine mesh if the shape is curved/complex	can use a coarser mesh and it will still be accurate.
Calculation time	Faster	Slower because there are more buttons
Suitable application	Large model, needs speed	Detailed model, high accuracy

In this study, both linear and quadratic interpolation cases will be performed, with the grid size being the same for both cases.

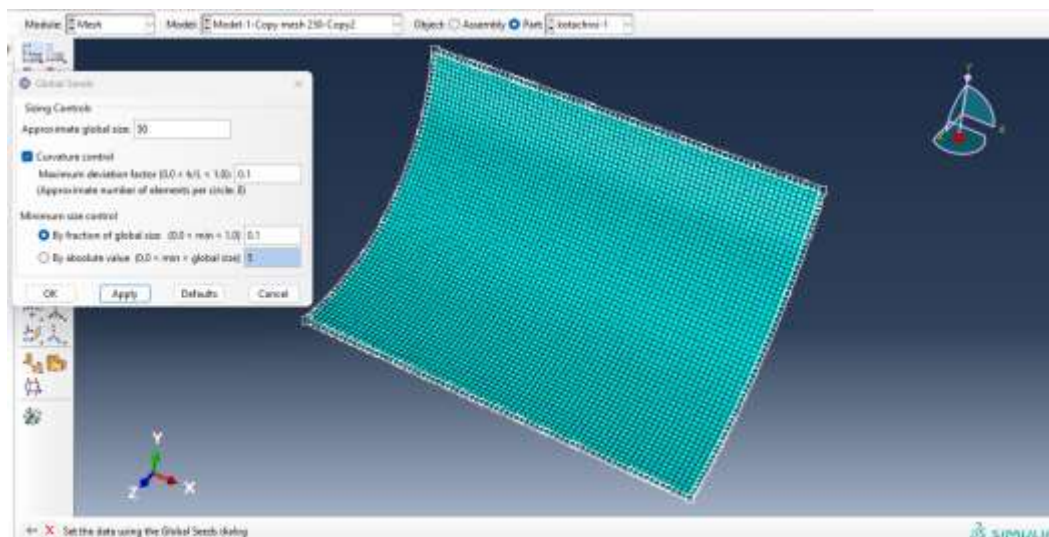


Figure 6. 12 Mesh for parts

Step 8: Analyze the results in the Job module, select Create Job to generate the result processing file, and select submit for the software to calculate.

Calculate multiple times with each division of nodes and different elements to find the most accurate result. The problem will stop when the error between two mesh divisions is no greater than 5%.

Case 1: Mesh with 51633 nodes and 10328 elements

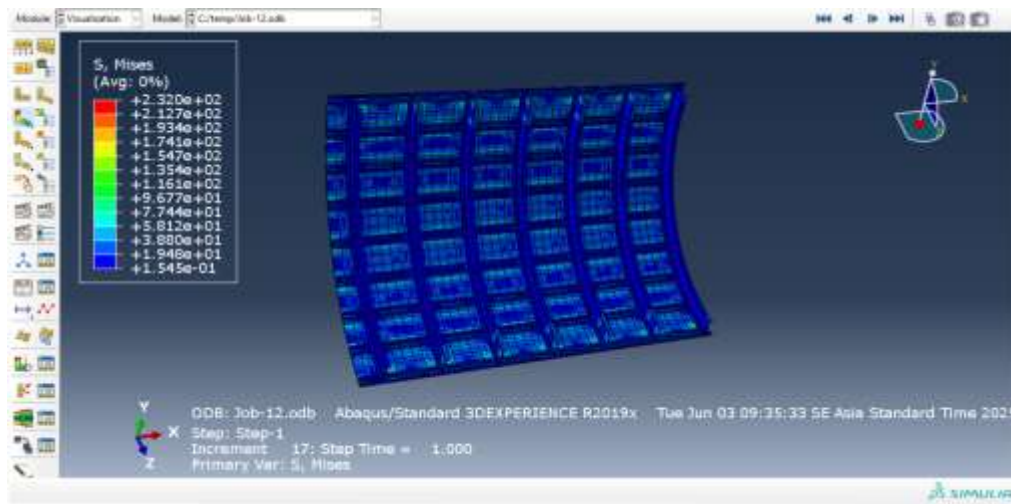


Figure 6. 13 The stress result of case 1

Case 2: Mesh with 54112 nodes and 11610 elements

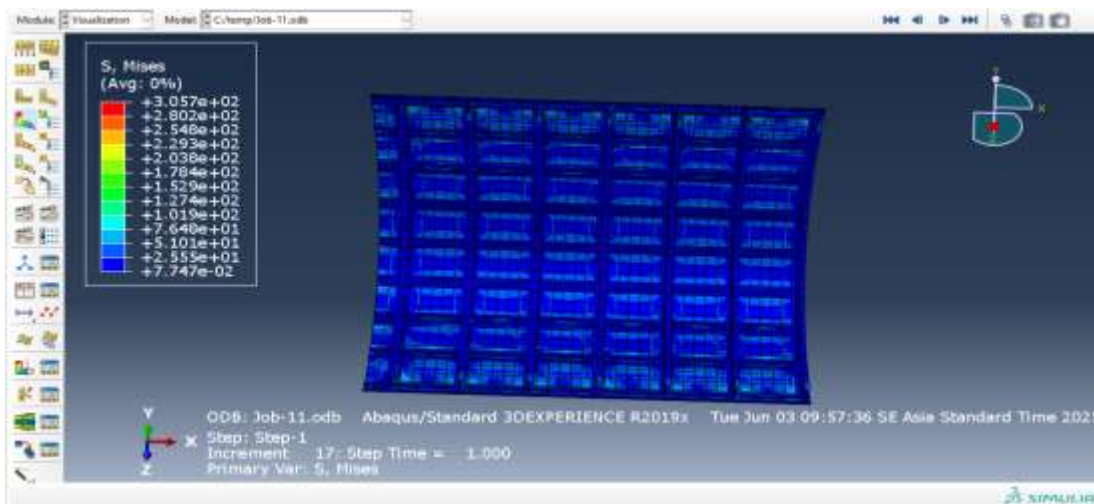


Figure 6. 14 The stress result of case 2

The error between case 1 and case 2:

$$\varepsilon = \frac{|\sigma_{TH2} - \sigma_{TH1}|}{\sigma_{TH2}} \cdot 100 = \frac{|305 - 232|}{305} \cdot 100 = 23\%$$

Because the error between the two THs is greater than 5%, dividing the grid according to the number of elements and nodes as in the two THs is not reasonable. Continue to refine the mesh to find the final result.

Case 3: Mesh with 120841 nodes and 25997 elements

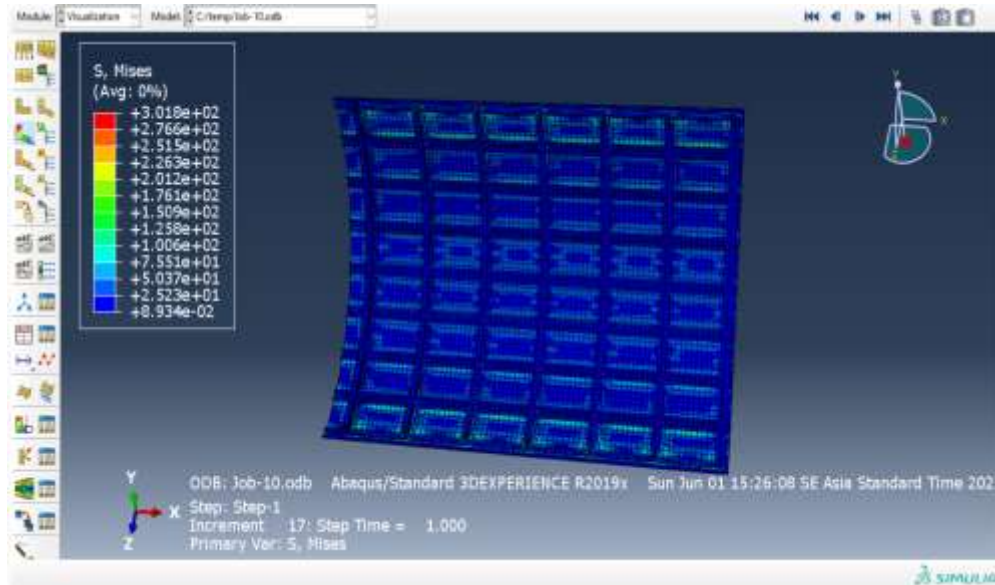


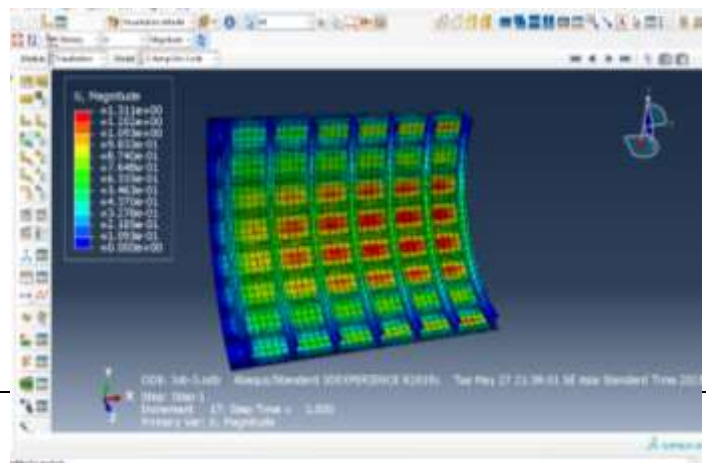
Figure 6. 15 The stress result of case 3

The error between case 2 and case 3:

$$\varepsilon = \frac{|\sigma_{TH3} - \sigma_{TH2}|}{\sigma_{TH3}} \cdot 100 = \frac{|301 - 305|}{301} \cdot 100 = 1,32\%$$

The error between case 3 and case 2 is less than 5%, so we can use the number of nodes and elements from case 3 as the analysis result.

Case: Interpolate using Linear (1st degree) with aluminum alloy material



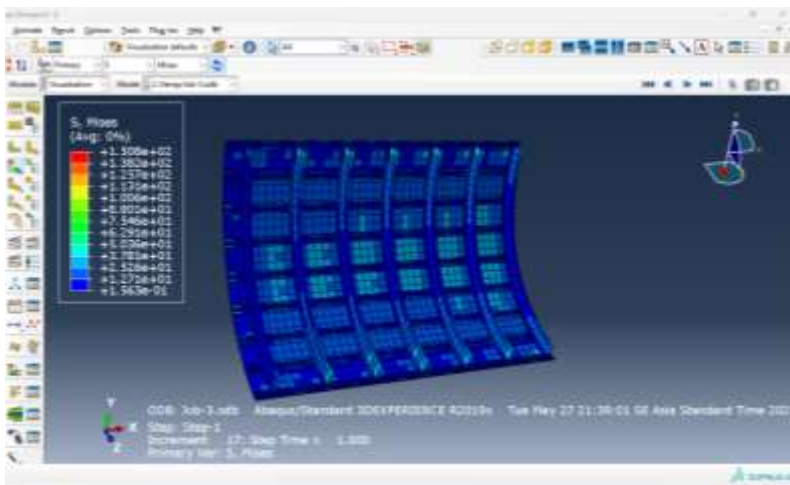


Figure 6. 16 The stress and displacement of case Linear
Case: Quadratic interpolation (2nd degree) with aluminum alloy material

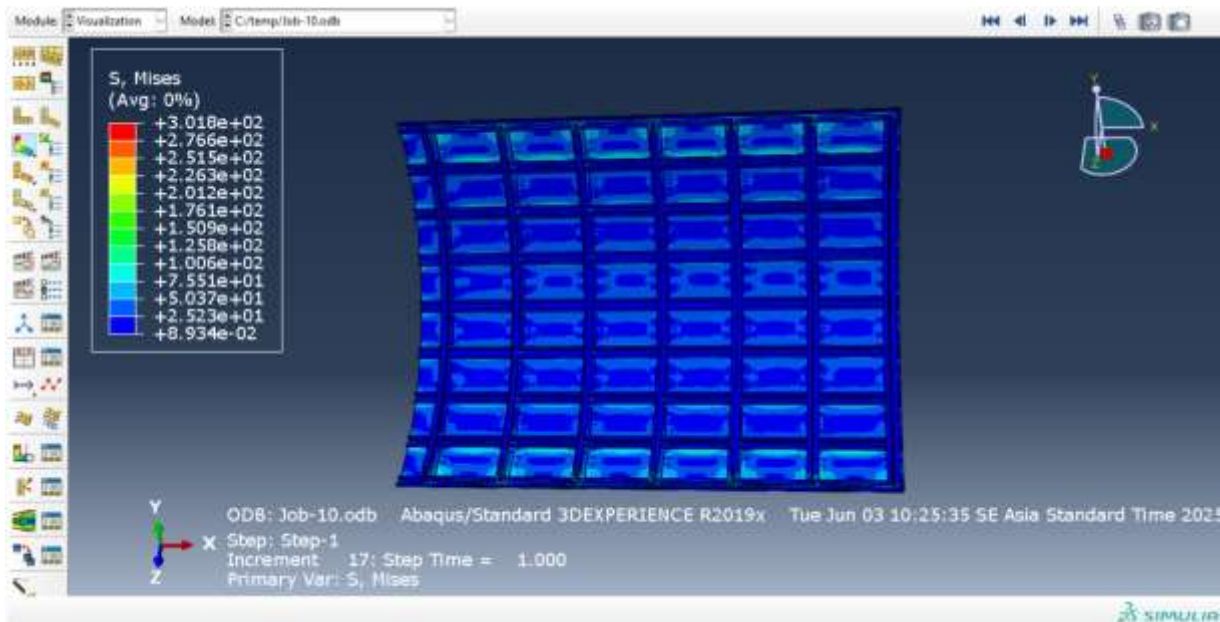


Figure 6. 17 The stress result of case Quadratic

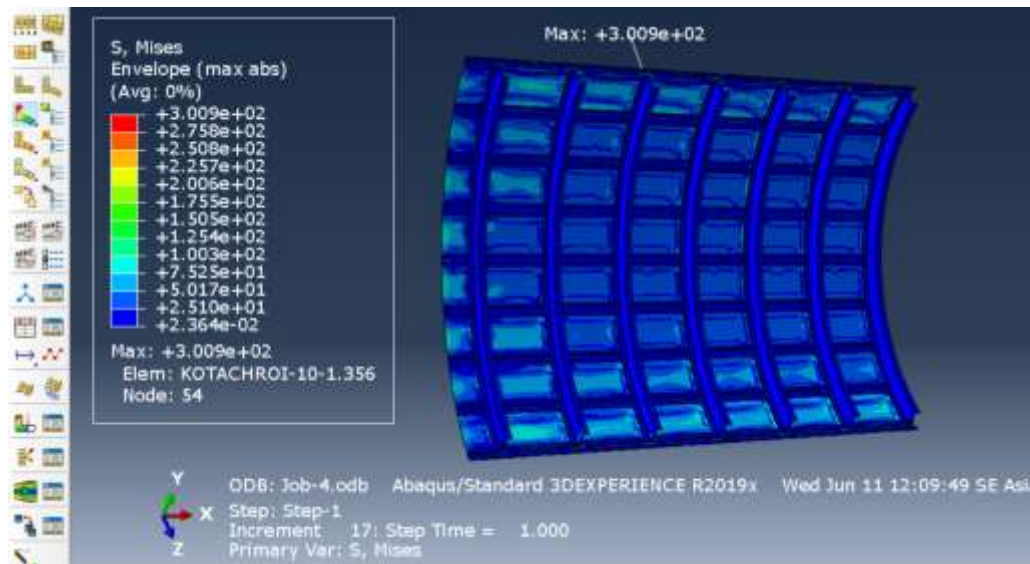


Figure 6. 19 The stress result of composite material

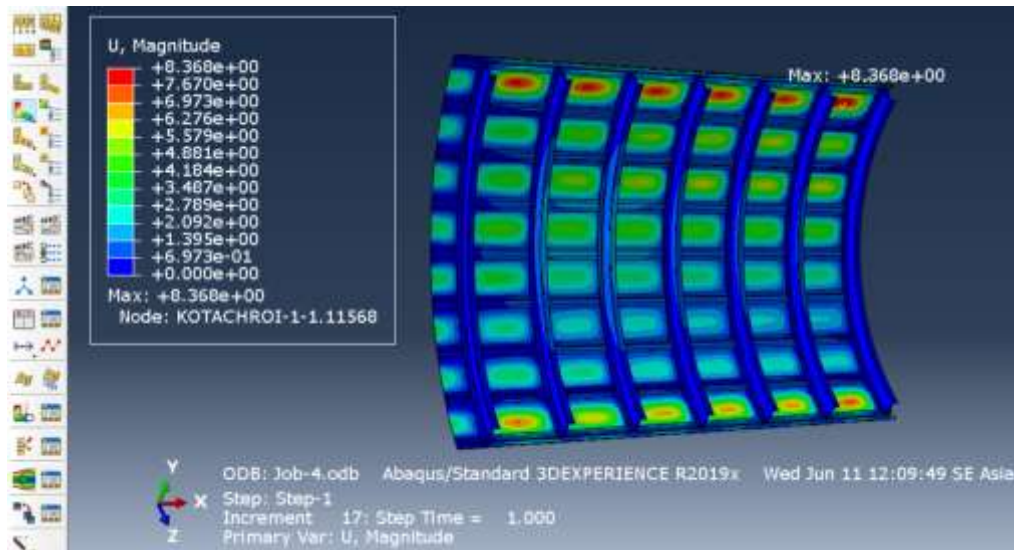


Figure 6. 20 The displacement result of composite material

The results show that the maximum stress is 300 MPa, which is still lower than the yield strength of the material (1200 Mpa), proving that the composite material is strong enough to be used for the aircraft fuselage. At the same time, for composite materials, the stress between the layers is not uniform.

Conclusion: The research and implementation of composite materials instead of aluminum alloys is not because aluminum alloys are not strong enough, but due to the many other benefits that composites provide.

Benefits of composite fibers in aviation:

Table 6. 6 Benefits of composite compared to aluminum alloy

Reduce weight – increase fuel efficiency	Composite has a higher strength-to-weight ratio than aluminum, helping to reduce the weight of the fuselage/wing structure by 20–25%.
Better corrosion and fatigue resistance	Composite does not suffer from electrochemical corrosion or mechanical fatigue like aluminum, helping to extend lifespan and reduce maintenance.
Reduce noise and vibration	Composite absorbs vibrations better than aluminum, making the aircraft quieter.
Better heat resistance and insulation	Some types of composites can withstand higher temperatures or insulate better than aluminum (for example, in airplane wings near the engine).
Developing custom materials	The fiber direction can be customized to optimize the force in each region of the structure – something that is not possible with isotropic metals like aluminum.
Strength, fatigue resistance	Very high (especially tensile strength, 2-10 times stronger than aluminum, superior resistance to fatigue under repeated loads)

CONCLUSION

Following the research and execution of the project "Design of fixture, assembly process and inspection for the Boeing 757 fuselage frame assembly" the following key outcomes were achieved:

- The project successfully synthesized and systematized fundamental knowledge regarding aircraft structures, as well as technical requirements for manufacturing and assembly. This knowledge forms a crucial foundation for understanding the technical demands in both assembly and operation.

- Fixture structures used in the aircraft fuselage assembly process were designed and analyzed, ensuring the accuracy and consistency of components. The significant role of these fixtures in minimizing technical deviations and enhancing production efficiency was also clearly demonstrated.

- The project outlined a scientific, step-by-step assembly process, from component preparation to the final frame assembly. This process integrates advanced assembly methods, focusing on optimizing time and reducing the risk of errors during production.

- A comparative analysis and simulation of the differences between aluminum alloys and composite materials were conducted. This yielded insightful results, providing manufacturers with a basis for selecting suitable materials based on their specific needs and application objectives.

The project "Design of fixture, assembly process and inspection for the Boeing 757 fuselage frame assembly" successfully met its initial design objectives and requirements. However, due to constraints in time, resources, and practical knowledge, some aspects of the implementation might not be fully optimized.

If feasible, collaboration with enterprises should be considered for real-world testing. This would not only help validate the feasibility of the proposed solutions but also provide opportunities for improvements and process optimization based on actual production data and feedback.

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