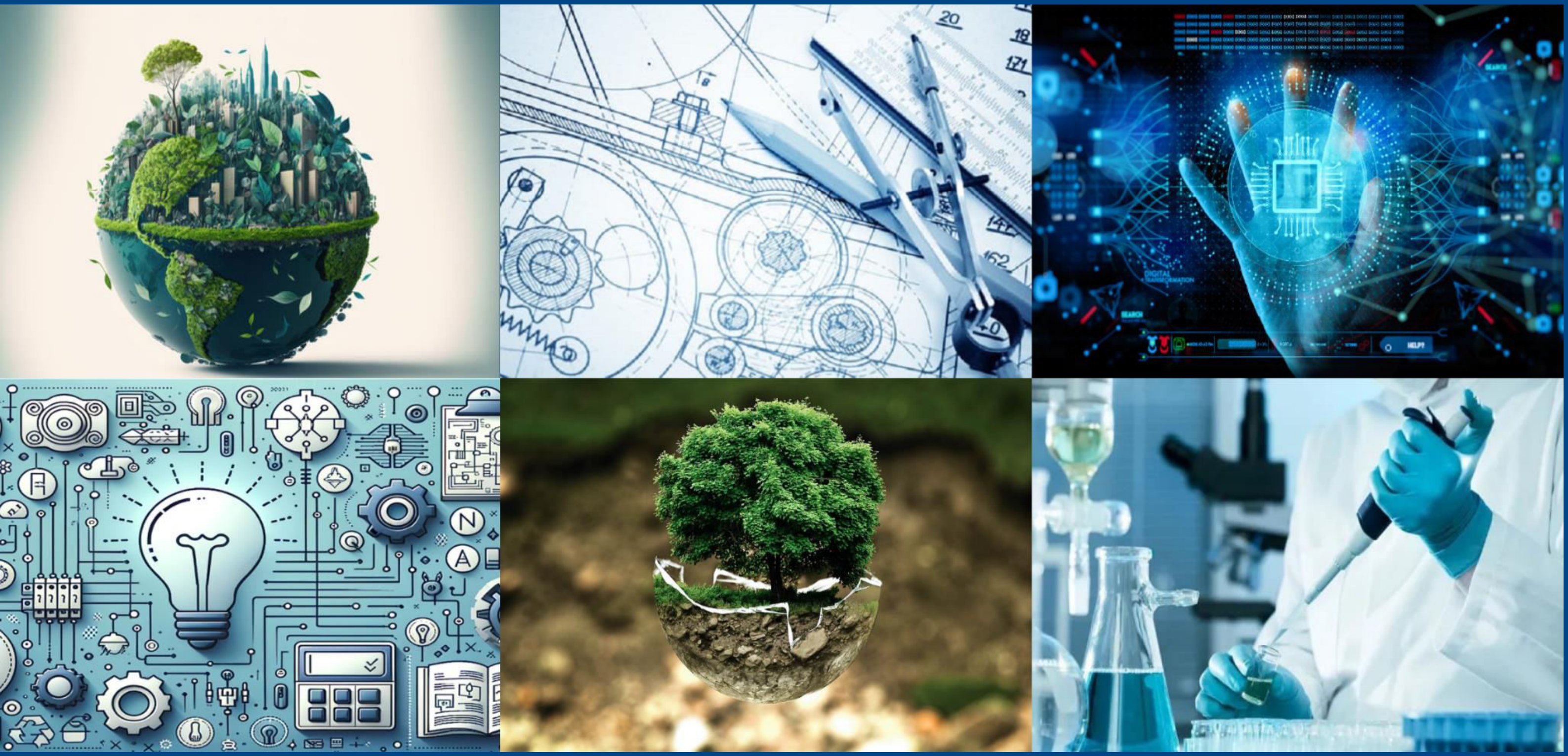
ISSN: 2582-7219

International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.206

Volume 8, Issue 2, February 2025

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ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)
(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Computational Analysis of Material and Structural Component Effects on the Strength of Semi-Monocoque Structured Aircraft Fuselage

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ABSTRACT: The design of an aircraft's fuselage structure is crucial. In business jet aircraft, the fuselage consists of stringers, frames, floor beams, and an outer skin. For heavy passenger aircraft, the fuselage incorporates a wider range of structural components, including bulkheads, longerons, frames, stringers, flat plates, and outer skin. Traditionally, a stiffened shell structure has been used in fuselage design. However, a lattice structure, which consists of individual structural components replicating the actual fuselage, presents a more complex alternative. This project replaces the stiffened shell structure with a lattice structure. The design is created using CATIA, and static structural analysis is performed in ANSYS to evaluate stress and deformation under load.

KEYWORDS: Monocoque, von mises stress, longerons, stiffeners, longitudinal stress, deformation

I. INTRODUCTION

The term "fuselage" originates from the French word fuseler, meaning "to streamline." The fuselage serves as the main body of an aircraft, housing the crew and passengers. It must be both strong and aerodynamically streamlined to withstand the forces encountered during flight.
The primary functions of the fuselage include:

1. Providing structural support for the wings and tail
2. Containing the cockpit for the pilot
3. Enabling the aircraft to carry cargo, passengers, and equipment

To ensure structural integrity, the fuselage must resist bending moments (caused by weight and tail lift), torsional loads (due to the fin and rudder), and cabin pressurization. In transport aircraft, the fuselage is typically cylindrical or near-cylindrical, with a tapered nose and tail section.

Additionally, the fuselage plays a crucial role in aircraft stability and maneuverability by positioning control and stabilization surfaces in relation to the lifting surfaces. It is generally divided into three main sections:

- Engine section
- Cabin section
- Sheet-metal tail cone section

1.1 Fuselage Pressurization

The fuselage structure, primarily composed of frames, stringers, and external skin, is designed to efficiently withstand shears and bending moments caused by air and inertial loads. However, when internally pressurized, this structure becomes an inefficient pressure vessel due to bending in the stringers and frames.

The structural implications of fuselage pressurization can be categorized as follows:
Primary Structural Effect – Pressurization induces longitudinal and circumferential stresses in the skin panels between adjacent stringers and frames. Since the stringers are positioned next to the outer skin panels and supported internally by the frames, part of the pressure load is transferred through these elements into the frames.

Stringer Stresses – The outer skin panels impose additional stresses on the stringers. Due to variations in frame shape and cross-sectional properties, shears are transmitted to the frames, leading to warpage and outward deflections.
Impact of Cutouts and Components – Openings, floors, splices, and other smaller structural components influence the stresses within the primary load-bearing elements (frames, stringers, and skin).

Bulkhead and Sectional Stresses – Pressurization also induces stresses at closing bulkheads and the nose or tail sections of the aircraft.
These combined effects, along with stresses from aerodynamic and inertial loads, form the overall fuselage stress system. Because the pressure load on a panel is balanced through a complex interaction of deflections and stresses, the structural effects of pressurization and external loads cannot be simply added together. In some cases, internal pressurization may even stabilize certain structural sections.

1.2 Construction of Semi monocoque structure

The primary function of an aircraft's structure is to withstand and distribute all applied loads while also serving as a protective covering that maintains aerodynamic shape. Fuselage construction is generally classified into two types: welded steel truss and monocoque designs. However, the monocoque design is predominantly used in aircraft structures due to its ability to bear various loads. This design is further divided into three categories: monocoque, semi-monocoque, and reinforced shell. In large passenger aircraft, the standard aluminum fuselage typically follows a semi-monocoque construction, incorporating a shell, stringers, and frames. The fuselage houses the cockpit and passenger compartment, both of which experience significant internal pressure.

The semi-monocoque fuselage design typically incorporates a combination of stringers, bulkheads, and frames to reinforce the skin and maintain the fuselage's cross-sectional shape. The fuselage skin is fastened to these structural members to resist shear loads, while the longitudinal members work together to withstand tension and bending loads. In this design, stringers primarily bear the fuselage bending loads, providing rigidity and support for the skin. Both stringers and frames play a crucial role in preventing tension and compression stresses that could cause bending.

II. STRUCTURAL COMPONENTS OF SEMI MONOCOQUE FUSELAGE

A typical semi-monocoque fuselage is made up of several key components:
Stringers or Longerons are the longitudinal members of the structure, primarily designed to carry axial loads (tension and compression) that result from the fuselage bending under load. The stringers also support the skin, and when combined with the frames, form bays where the skin is attached.

Frames are transverse structural elements that define the fuselage's cross-sectional shape. Typically spaced about 20 inches apart, they contribute to the aerodynamic profile of the fuselage. The arrangement of the frames and stringers ensures that the bays they create can support the skin and prevent buckling. Frames also provide a means of transferring point loads into the fuselage. Larger frames are necessary at the interfaces between the wing-fuselage and tail-fuselage, as they transmit the loads generated by these lifting surfaces.

The load-bearing skins are riveted to the stringers and frames of the fuselage. The skin bears loads through shear forces, transferring this shear into the stiffeners. In a pressurized aircraft, the skin works in conjunction with the frames to resist the internal pressure load. However, the skin's ability to handle shear is diminished if it buckles, which limits the spacing of the stringers and frames.

2.1 Loading

Throughout flight, the fuselage experiences various loads. Bending loads are generated by the wings and tail, and torsional loads are created by the wing's pitching moment. The fuselage also experiences aerodynamic loads during flight, in addition to internal pressure loads if the cabin is pressurized. Landing loads can be especially significant if the landing is rough. Additionally, the movements of the crew and passengers, as well as baggage, must be accounted for in the structural design. All these load cases and their interactions must be considered in the final design to ensure the structure can withstand the ultimate load factor as per airworthiness regulations, ensuring safety for passengers and crew.

2.1.1 Loads on Aircraft

Aircraft loads are the forces and moments that act on the airplane's structural components (such as the wings, tail, and fuselage) to ensure the aircraft can handle all required loads. These loads can result from air pressure (lift), inertia (weight), or ground reactions during takeoff and landing. The determination of design loads requires analyzing the aircraft's response to air pressure and inertia forces during specific maneuvers, both in flight and on the ground.

2.1.2 Loads on Fuselage

The fuselage is generally treated as a beam supported by the main wing-fuselage joints. The primary sources of fuselage loads include:

The reaction forces from other components attached to the fuselage, such as the horizontal and vertical tail, landing gear, and payload.

- Aerodynamic loads.
- Loads due to cabin pressurization.
- Forces from engines and power units attached to the fuselage.

Fuselage loads can be classified as either concentrated or distributed. Concentrated loads come from the attachment points, such as bolts connecting the wing, tail stabilizers, and landing gear. These forces are the primary load on the fuselage. In contrast, aerodynamic loads and dynamic pressure are distributed loads, causing the fuselage to experience shear forces, bending moments, and torsional moments. Additionally, the weight of the fuselage structure and payload can cause the fuselage to bend downward from its support at the wing, resulting in tension at the top and compression at the bottom of the fuselage.

2.2 Cabin Pressurization Loads

Pressurized cabins have been a source of fatigue-related failures in aircraft. Contributing factors include:

- Cut-outs in the fuselage shell, which create high local stresses.
- Countersunk rivets near cut-out edges, which exacerbate stress concentration.
- Aluminium, with a high yield-to-ultimate strength ratio, is prone to rapid tearing at relatively low stress levels.

The fuselage structure must be strong enough to withstand both flight loads and the pressure differential from the cabin pressurization, which can range from zero to the maximum relief valve setting. The relief valve is a safety device that reduces cabin pressure when the pressure difference between the fuselage's inner and outer skins exceeds a specific threshold. In the event of a pressurized cabin landing, these loads must be combined with the landing loads. The aircraft must be capable of withstanding the pressure differential loads, accounting for a 1.33 multiplier over the maximum relief valve setting, excluding other loads. Critical loading conditions arise when no pressure difference is felt, or when the maximum allowable pressure difference is reached, as set by the relief valve.

III. METHODOLOGY: FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) has been extensively applied to the study of semi-monocoque fuselage structures in aerospace engineering. Below are several scholarly references that discuss various aspects of FEA in the context of semi-monocoque fuselage design and analysis:

Amirashoyal Tankasli, S.G. Saraganachari,et,al. [1] study models a panel of a semi-monocoque structure to understand the effects of material changes on the aircraft. The panel is analyzed under varying loading conditions to identify regions of high stress and strain, aiming to select the optimum material for the given conditions. [2] Dababneh, O. and Kayran, A. (2014), "Design, analysis and optimization of thin walled semi-monocoque wing structures using different structural idealization in the preliminary design phase, presents a comprehensive study on the effect of using different structural idealizations on the design, analysis, and optimization of thin-walled semi-monocoque wing structures during the preliminary design phase. B. Karthick, S. Balaji, P. Maniiarasan, [3] This research presents the structural analysis of a fuselage with a lattice structure, focusing on the finite element analysis of the design to assess its rigidity and safety. Karthik S S, Gurusiddayya, [4] in their study discusses experiences in modeling and developing methods for the nonlinear finite element analysis of the loading behavior of aircraft fuselage panels, aiming to optimize the design for both static and dynamic loads.

In the fuselage structure, helical and circumferential ribs serve as stiffening elements. In this study, the skin with stringers and the floor beam are initially modeled and analyzed separately to examine the stress distribution at each node. Following this, the combined analysis of these elements is performed. All components are designed using CATIA V5R20 and analyzed with ANSYS for finite element analysis. The fuselage structure can generally be divided into three sections: the cockpit, tail, and cabin sections. This research specifically focuses on the cabin structure, utilizing a lattice design that incorporates both helical and circumferential ribs. The fuselage has a diameter of 1600 mm and a length of 2500 mm.

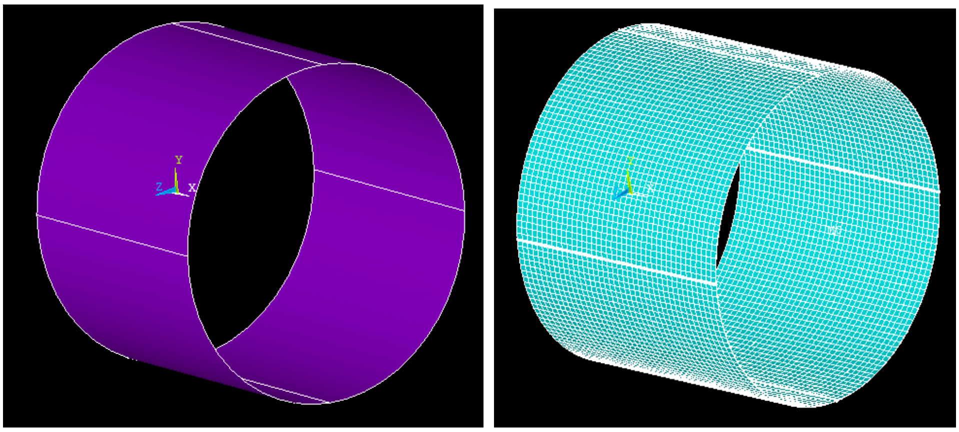


Figure -1: Geometric Model & Finite Element Model

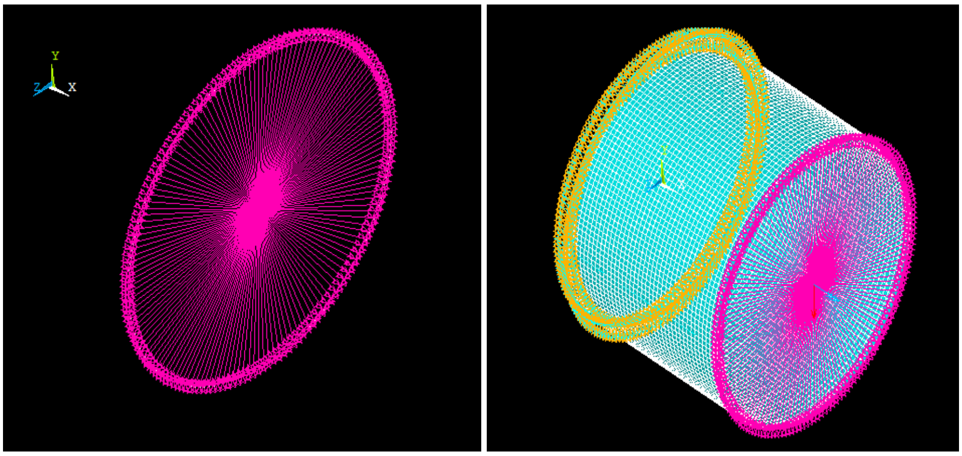


Figure:2- Coupling master node with slave nodes

Boundary conditions for Semi monocoque structured fuselage

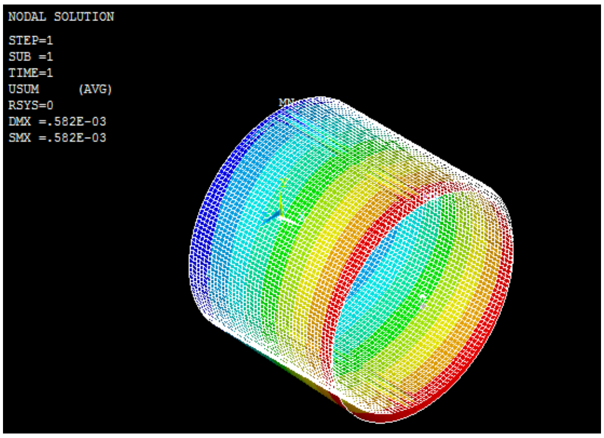
Condition	Value
End Condition	One End Fixed (Constrained) and Other end Free
Internal pressure load	1 Atm
Solver type	Mechanical APDL
Result Type	Total Deformation
Material	Aluminium Alloy
Youngs Modulus	$3x10^7$
Poisons ratio	0.3
Density	1.23

3.1 Forces and moments applied on the entities:
Force applied about Y-axis, FY= -10000
Moment applied about X-axis, MX= 1000

IV. RESULTS AND DISCUSSIONS

This study focuses on analyzing stress modes derived from a program developed in ANSYS. The equivalent stresses (von Mises) obtained from the static analysis provide a reliable estimation of stress distribution within the structure and highlight the locations of maximum stress. A linear stress analysis is conducted using the ANSYS finite element software, beginning with a static solution to assess stress occurrence in the structure.

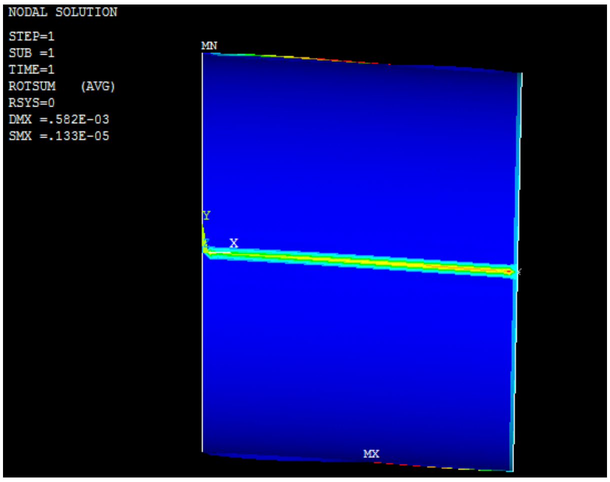
Results from the finite element analysis indicate that the design is both rigid and safe. The analysis examines the fuselage skin with stringers under an internal pressure of 1 atm. In this scenario, both ends of the fuselage structure are fixed, and the internal pressure is applied solely to the fuselage stringers. The material used is aluminum alloy, and the maximum stress recorded is 0.582×10^{-3} MPa, which remains well below the material's yield strength.



```
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
USUM      (AVG)
RSYS=0
DMX =.582E-03
SMX =.582E-03
```

Figure:8- Contour plot for internal pressure showing internal stresses



```
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
ROTSUM    (AVG)
RSYS=0
DMX =.582E-03
SMX =.133E-05
```

Figure: Contour Plot showing Maximum deformation of the semi monocoque structure under applied pressure

V. CONCLUSION & FUTURE SCOPE

The structural analysis of a fuselage with a semi-monocoque structure for a light jet aircraft has been conducted. The results indicate that this fuselage design is rigid and safe according to failure theory analysis, as the working stress remains well below the material's yield strength. While the current findings show that the semi-monocoque structure performs better than a stiffened shell structure, particular attention is required for critical areas due to the fuselage being an assembly of multiple components rather than a single body. The study also examines the joints that connect these components. To ensure reliability and safety, further validation through experimental testing and analysis under static and dynamic loads is necessary before proceeding with aircraft production.

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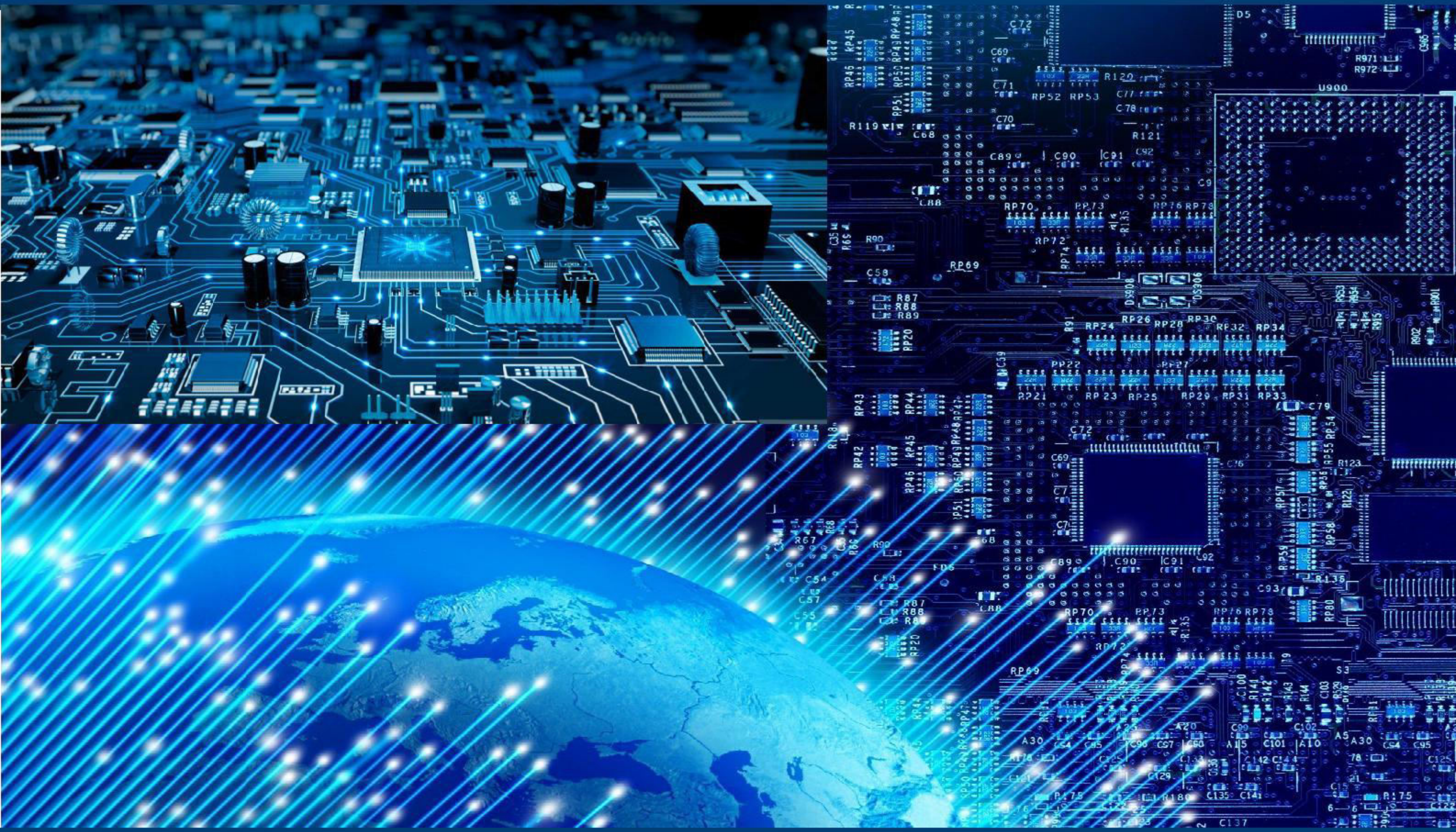

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