Volume: 11 Issue: III Month of publication: March 2023

DOI: https://doi.org/10.22214/ijraset.2023.49765

Optimization of Wing Rib Configurations for Improved Aerodynamic Performance: A Computational Study

Subash Dhakal[1], Sudip Dhakal[2], Santosh Prakash[3]
[1, 2, 3]Final Year Student, Department of Aeronautical Engineering, Excel Engineering College (Anna University), Tamilnadu, India

Abstract: This research paper presents a computational study on the optimization of wing ribs configurations for improved aerodynamic performance. The wing ribs play a crucial role in supporting the wing's shape and contour, and their design is critical for achieving optimal flight performance. An aircraft's wing is a complex structure because of the complicated way it responds to different loads and manoeuvres. The main objective of this study is to develop a more efficient and optimized rib structure that can improve the aerodynamic performance of the wing, specifically by reducing drag and increasing lift. The study uses computational fluid dynamics (CFD) simulations to analyze the aerodynamic performance of different wing rib configurations. The simulations are performed on a representative wing model, and different rib designs are evaluated to determine their impact on the overall aerodynamic performance. The results of the study demonstrate that the optimized rib structure can significantly improve the aerodynamic performance of the wing, with a reduction in drag and an increase in lift. The study also highlights the potential benefits of using computational techniques for designing and optimizing aircraft components, such as reducing design time and cost, improving accuracy, and enabling rapid prototyping. The findings of this study are expected to contribute to the development of more efficient and effective aircraft design processes, benefiting both the aviation sector and the public.
Keywords: Computational, Optimization, Aerodynamic, Fluid dynamics, Designing, Ribs, Aviation,Aircraft design

I. INTRODUCTION

The design of aircraft wings plays a crucial role in achieving optimal aerodynamic performance, which is essential for efficient and safe flight. One of the key components of the wing structure is the wing ribs, which provide support for the wing's skin and any additional components, such as fuel tanks or landing gear. The design of wing ribs is critical to the overall performance and safety of the aircraft, as it must be strong enough to withstand the stresses of flight, while also being lightweight enough to avoid adding excess weight to the aircraft.

The study aims to develop an optimized rib structure that can improve the aerodynamic performance of the wing, specifically by reducing drag and increasing lift. In recent years, advancements in computational fluid dynamics (CFD) and optimization techniques have made it possible to design and optimize aircraft components with greater accuracy and efficiency. The paper begins by discussing the importance of wing ribs in the overall design of aircraft wings and the challenges involved in their design. It then provides an overview of the computational techniques used in the study, including CFD simulations and optimization algorithms. The paper then presents the results of the study, including the optimal rib structure design and the impact of the design on the aerodynamic performance of the wing.The findings of this study are expected to contribute to the development of more efficient and effective aircraft design processes, benefiting both the aviation industry and the public. The paper concludes by highlighting the potential benefits of using computational techniques for designing and optimizing aircraft components, including reducing design time and cost, improving accuracy, and enabling rapid prototyping.

II. LITERATURE REVIEW

The aerospace industry has been interested in the optimization of wing rib structure for increased aerodynamic performance for a long time. Wing ribs are essential structural components of aircraft wings that provide support to the wing skin and maintain the airfoil shape.Even though, the presence of ribs also alters the flow field, which may result in more drag and less lift. In order to improve aerodynamic performance, it is essential to optimise the design of wing ribs. Many researchers have investigated the optimization of wing ribs for improved aerodynamic performance. The following studies are highlighted:

Dharmendra P, Chaithanya K J, Ayesha Sameera, Khyati Kavathiya and Monika K M [1] Design and Analysis Of An Aircraft Wing Rib For Different Configurations. They optimised the location and shape of the ribs for a NACA 4412 airfoil section and found that the optimal combination significantly improved the lift-to-drag ratio when compared to the initial design.From their project it was found that inserting the circular hole in the plate enhance the strength of the wing rib.

Lombardi and G. Mengali [2] An Optimization Procedure For The Conceptual Analysis Of Different Aerodynamic Configurations. In their research, a scalar objective function, the take-off weight is minimized using a numerical optimisation technique that accounts for the substantial number of geometrical parameters and the problem's demands for the application of flight mechanics. The different aerodynamic configuration displays remarkably similar aerodynamic behaviour to the reference configuration in terms of the lift coefficient, drag coefficient, and efficiency, which means that the aerodynamic flow is nearly identical.

Rahul Sharma and Garima Garg [3] Design and Analysis of Wing Rib of Aircraft Review. They optimized the design for an airfoil section and found that the optimal location of the ribs was close to the maximum camber line of the airfoil.The investigation concentrated on the displacement and stress analysis of both types of wing ribs. The results of these studies can provide valuable insights into the design and optimization of wing ribs for improved aerodynamic performance, which can be applied to the design of future aircraft wings.

Bindu H C, Muhammad Muhsin Ali H [4] Design and Analysis of a Typical Wing Rib for Passenger Aircraft. In their study, the wing ribs and their design is thoroughly reviewed, emphasizing the significance of these parts in determining the overall performance and safety of an aircraft.The design method for the wing rib under examination is then comprehensively described in the report. The authors explain the many design factors taken into account, such as rib spacing, thickness, and chord length, and offer a justification for their choice. Also, they go over the finite element analysis (FEA) technique used to assess how well the wing rib performs under various loading scenarios, including bending and torsion.

Guguloth Kavya, B C Raghukumar Reddy [5] Design and Finite Element Analysis of Aircraft Wing using Ribs and Spars. They provide the aircraft wing model in 3D modeling software and a comprehensive overview of the key design considerations and optimization techniques for aircraft wings.They describe ,the use of ribs and spars in aircraft wing design is a common practice as they provide structural support and improve the strength and stiffness of the wing.

III. OBJECTIVE

The main objective of the research work is to investigate the effects of different rib configurations on the aerodynamic performance of a wing using computational simulations. The specific objectives of this research are:

1) Design of wing rib using airfoil NACA 64(2)-415 series such as circular, elliptical, and rectangular shape.
2) To analyze the aerodynamic performance of different rib configurations in terms of lift, drag, and lift-to-drag ratio using computational fluid dynamics (CFD) software.
3) To optimize the rib configuration for improved aerodynamic performance using a multi-objective optimization method.
4) To provide light on how rib layout impacts a wing's aerodynamic performance and what it means for aircraft design.

IV. PROBLEM STATEMENT

The requirement for enhanced wing rib aerodynamic performance in aircraft design is the problem discussed in this paper. The authors employ computational methods to improve the lift, reduce drag, and increase fuel efficiency of wing ribs. Wing ribs on modern aircraft are cut to allow fuel tanks and other equipment to flow through. As a result, it lessens the drag on the wing as well as its weight.The purpose of this study is to address the difficulty of combining structural strength and aerodynamic performance of wing ribs while keeping the aircraft's total weight and cost in range. The structure of the wing ribs must be optimised in order to generate more efficient and sustainable aeroplane designs.

V. METHODOLOGY

A. Step 1. Knowledge And Requirement

Exploring a broad range of NACA series airfoils and selecting the NACA 64(2)-415 airfoil for developing the wing rib is necessary. After selecting the required NACA series for your design then the design is further examined with analysis software.

B. Step 2. Designing The Wing Rib Structure

The wing rib structure is typically composed of a series of ribs, spaced evenly along the span of the wing, and connected by a series of stringers or spars.

Wing ribs in the NACA 64(2)-415 airfoil series are designed using Solidworks software in a variety of configurations, including circular, elliptical, and rectangular shape.

C. Step 3. Performance Analysis Of The Design

The optimized design of the wing ribs is evaluated using computational fluid dynamics (CFD) simulations. The optimized design is evaluated for its aerodynamic performance in terms of drag, lift, and fuel efficiency using computational fluid dynamics (CFD) simulations. Analysis of the structure is done using ANSYS software.The performance of the optimized design is compared with the initial design and other existing designs.

D. Step 4. Comparison Of Various Aerodynamic Parameters

Various aerodynamics parameters are used to evaluate the performance of an aircraft.Some of the commonly used parameters for comparing the aerodynamic performance of different aircraft or wing designs are: Lift Coefficient (CL), Drag Coefficient (CD) and Lift-to-Drag Ratio (L/D).

VI. DESIGN

A. Selecting the Airfoil Series

Different airfoil of NACA series are studied and NACA 64(2)-415 is selected.The NACA 64(2)-415 airfoil has a thickness-to-chord ratio of 0.15 and a camber-to-chord ratio of 0.02. It features a relatively flat upper surface and a curved lower surface, which results in a favorable lift-to-drag ratio at low to moderate angles of attack. This airfoil has a maximum thickness located at 41.5% of the chord length and a relatively sharp leading edge.The NACA 64(2)-415 airfoil has a number of advantages, including low drag properties that make it ideal for high-speed applications. Also, it displays positive stall behavior, which is crucial for steady and safe flight operations. This airfoil is a popular option for a variety of applications since it is also fairly simple to produce and maintain.The NACA 64(2)-415 airfoil has been used in a variety of aircraft designs, including the Piper PA-28 Cherokee, the Cessna 172, and the Northrop F-5.

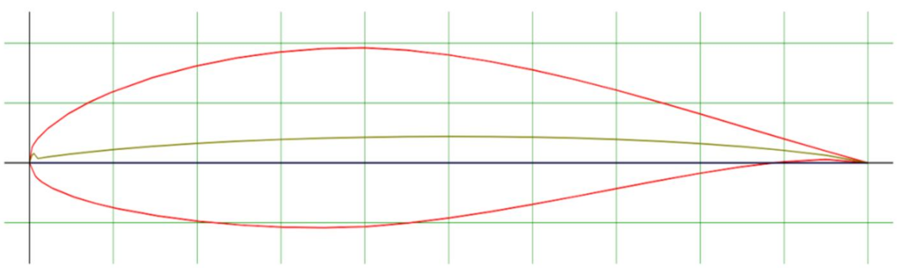


Fig 1. Airfoil NACA 64(2)-415

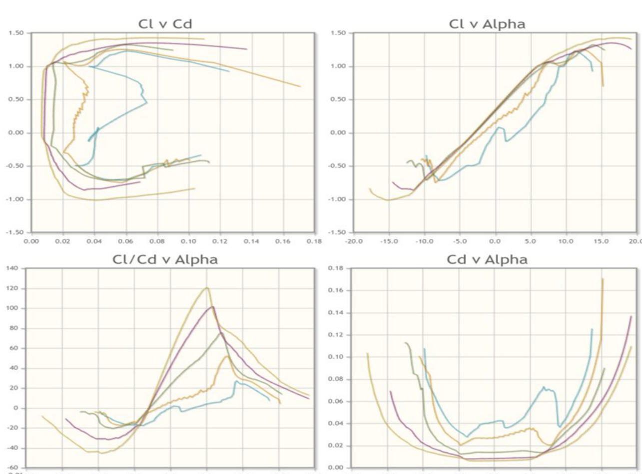


Fig 2. Graphs of NACA 64(2)- 415 airfoil

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue III Mar 2023- Available at www.ijraset.com

For the NACA 64(2)-415 airfoil, the lift coefficient increases linearly with increasing angle of attack up to around 15 degrees, after which it reaches a maximum value before dropping off sharply. At an angle of attack of 10 degrees, the lift coefficient for the NACA 64(2)-415 airfoil is approximately 0.8.

The drag coefficient for the NACA 64(2)-415 airfoil is relatively low, particularly at low angles of attack. However, as the angle of attack increases, the drag coefficient also increases, eventually surpassing the lift coefficient and resulting in a decrease in the lift-to-drag ratio. At an angle of attack of 10 degrees, the drag coefficient for the NACA 64(2)-415 airfoil is approximately 0.03.The lift-to-drag ratio is an important measure of the efficiency of an airfoil, as it represents the amount of lift generated per unit of drag produced. The NACA 64(2)-415 airfoil exhibits a high lift-to-drag ratio at low angles of attack, indicating that it is an efficient airfoil design for generating lift with minimal drag. At an angle of attack of 10 degrees, the lift-to-drag ratio for the NACA 64(2)-415 airfoil is approximately 25.

Overall, the NACA 64(2)-415 airfoil exhibits good lift and drag characteristics over a range of angles of attack, making it a popular choice for a variety of aerospace applications. Its relatively high lift coefficient and low drag coefficient at low angles of attack, combined with a high lift-to-drag ratio, make it an efficient airfoil design for generating lift while minimizing drag.

TABLE I
COORDINATE POINT OF NACA 64(2)-415 AIRFOIL

Sl.No	X (mm)	Y (mm)	Z (mm)
1	1.00000	0.00000	0
2	0.95032	0.00976	0
3	0.90066	0.01982	0
4	0.85092	0.03020	0
5	0.80109	0.04062	0
6	0.75115	0.05084	0
7	0.70111	0.06055	0
8	0.65096	0.06954	0
9	0.60087	0.07762	0
10	0.55040	0.08456	0
11	0.50000	0.09016	0
12	0.44954	0.09414	0
13	0.39904	0.09614	0
14	0.34853	0.09541	0
15	0.29803	0.09260	0
16	0.24756	0.08771	0
17	0.19714	0.08066	0
18	0.14681	0.07122	0
19	0.09662	0.05864	0
20	0.07162	0.05075	0
21	0.04673	0.04121	0
22	0.02207	0.02883	0
23	0.00996	0.02038	0
24	0.00526	0.01579	0
25	0.00299	0.01291	0
26	0.00000	0.00000	0
27	0.00701	-0.01091	0
28	0.00974	-0.01299	0
29	0.01504	-0.01610	0
30	0.02793	-0.02139	0
31	0.05327	-0.02857	0
32	0.07838	-0.03379	0
33	0.10338	-0.03796	0
34	0.15319	-0.04430	0
35	0.20286	-0.04882	0
36	0.25244	-0.05191	0
37	0.30197	-0.05372	0
38	0.35147	-0.05421	0
39	0.40096	-0.05330	0
40	0.45046	-0.05034	0
41	0.50000	-0.04604	0
42	0.54960	-0.04076	0
43	0.59928	-0.03478	0
44	0.64904	-0.02834	0
45	0.69889	-0.02167	0
46	0.74885	-0.01504	0
47	0.79897	-0.00878	0
48	0.84908	-0.00328	0
49	0.89934	0.00086	0
50	0.94968	0.00288	0
51	1.00000	0.00000	0

Macro coding generates airfoil points which is created in MS excel spread sheet are imported to Solidworks design software.

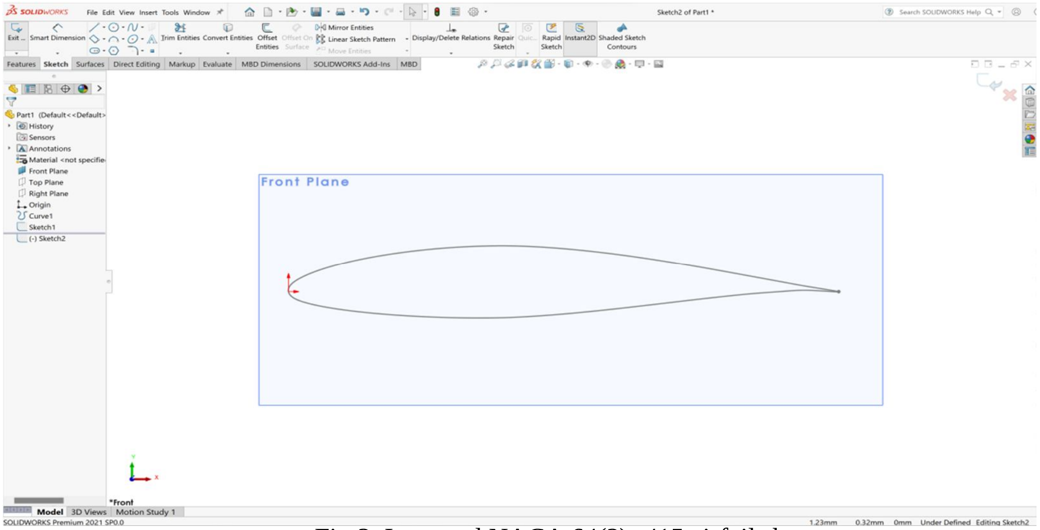


Fig 3. Imported NACA 64(2)- 415 airfoil shape

B. Designing Of Wing Ribs

Designing wing ribs in Solidworks is a simple method that involves creating a 3D model of the rib based on the design requirements.After selecting and importing the airfoil as mentioned in the above step, designing is done using solidworks 2021 CAD software. The thickness of the airfoil is 2 mm and the chord length is 85 mm is given to obtained the required shape.

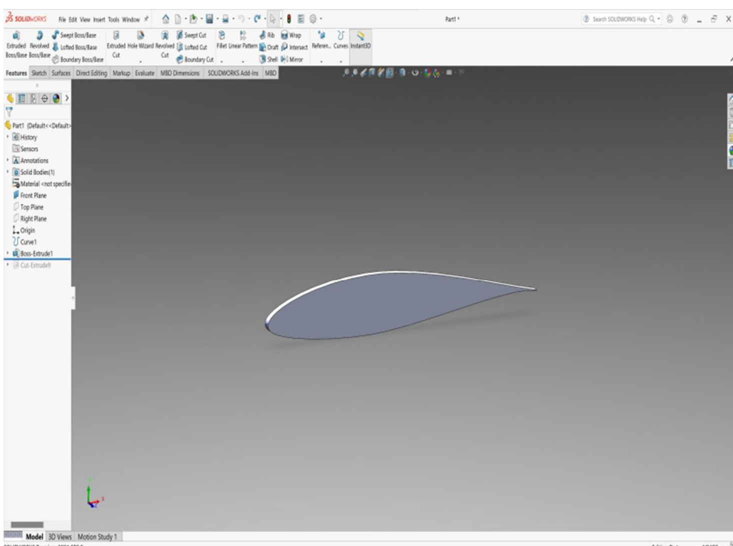


Fig 4. Wing rib without cut-out

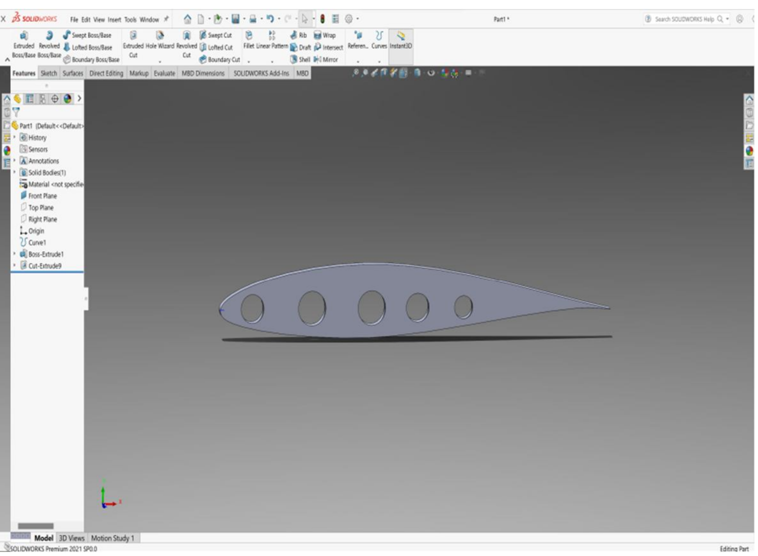


Fig 5 Wing rib with cut-out

There are several different wing rib configurations that can be used in aircraft design, each with its own advantages and disadvantages. Different model of wing rib is designed in same way as wing rib without cut section. Same procedure is followed to obtain shapes such as rectangular with fillet , elliptical and circular with and without cut section.

1) Rectangular Wing Rib Design

Rectangular ribs are a straightforward and widely used rib shape for aircraft wings.Rectangular ribs are a simple rib shape that can be utilised in a variety of aircraft, including light general aviation, ultralights, and homebuilt planes. Since the loads are relatively light, they may also be utilised in gliders, unmanned aerial vehicles (UAVs), and other tiny or low-performance aircraft. However, more intricate rib designs can be required for high-performance aircraft or aircraft carrying larger loads in order to give the required strength and stiffness. The thickness of the rectangular wing ribs is 2 mm and the chord length is 85 mm is given to obtained the above shape.

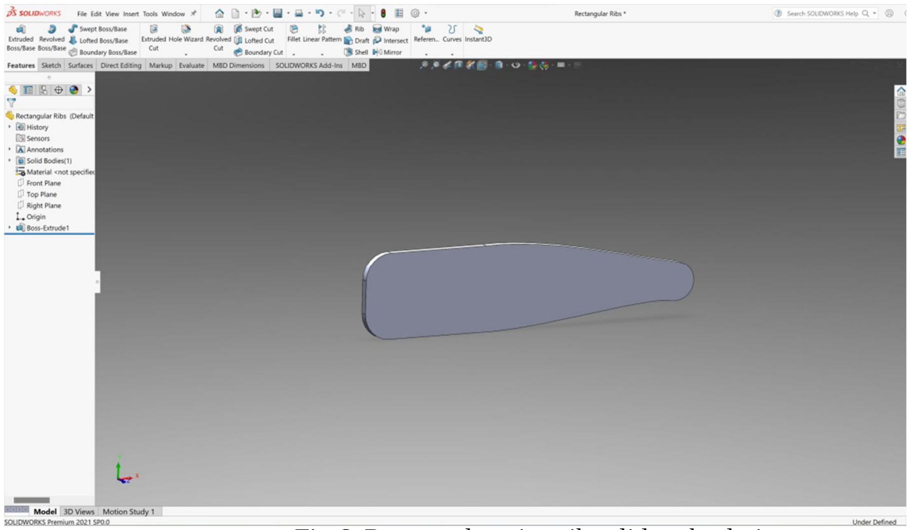


Fig 6. Rectangular wing rib solidworks design

2) Circular Wing Rib Design

Circular ribs are a type of rib design that are shaped like a circle or arc.In modern aircraft, circular ribs are a very uncommon rib type, but they have been utilised in some historic aircraft, particularly those with wooden wings. The de Havilland DH.60 Moth, a well-known light aircraft from the 1920s and 1930s, is one example of an aircraft that utilised circular ribs.Certain glider designs, where weight reduction is very crucial, also include circular ribs. However, due to their lower strength and stiffness compared to more recent rib designs, circular ribs are often not employed in the construction of current aircraft. The thickness of the Circular wing ribs is 2 mm and the chord length is 85 mm is given to obtained the above shape.

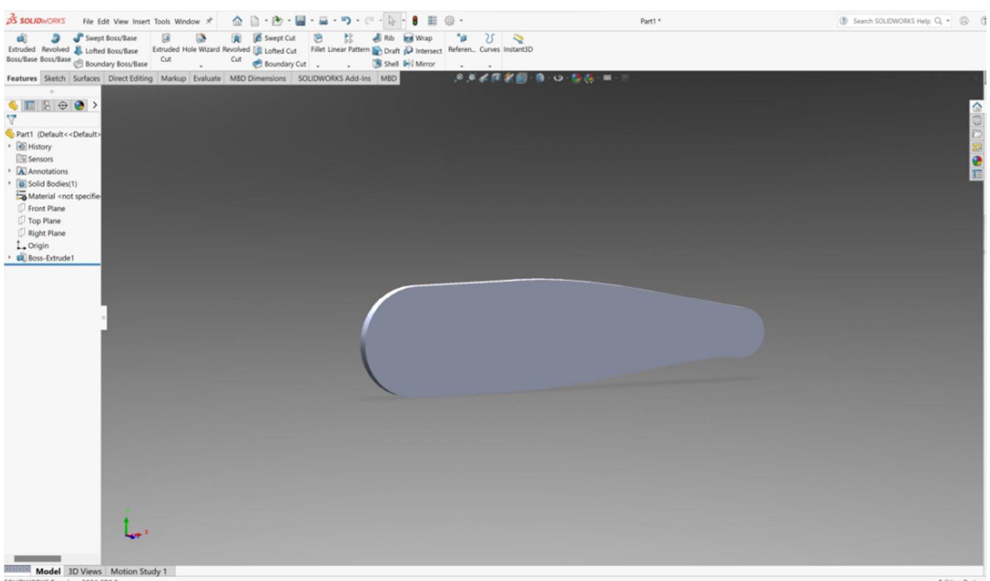


Fig 7. Circular wing rib solidworks design

3) Elliptical Wing Rib Design

Elliptical ribs are a particular style of rib design that have an oval or elliptical shape. A more uniform lift distribution along the wing's span is achieved by the elliptical shape's ability to produce a smooth and gradual variation in the chord (the distance between the leading edge and the trailing edge) and camber (the curve of the wing). A number of historical aircraft, most especially the Supermarine Spitfire, have utilised elliptical ribs as rib design. The Spitfire's elliptical wing planform, which has elliptical ribs, was utilised to enhance lift distribution, leading to superb maneuverability and handling characteristics. The thickness of the elliptical wing ribs is 2 mm and the chord length is 85 mm is given to obtained the above shape.

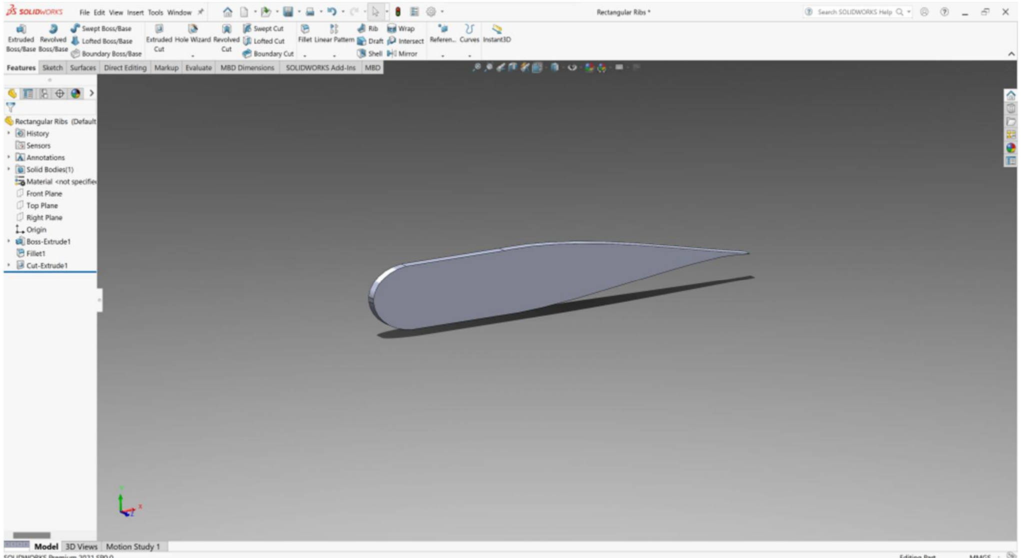


Fig 8. Elliptical wing rib solidworks design

VII. ANALYSIS OF THE DESIGN

After designing the various wing rib configurations, the analysis is done by the software called Ansys 19.2 (CFD software).In Ansys analysis, aerodynamic analysis of wing ribs involves analyzing the airflow around the wing rib in order to understand the aerodynamic forces acting on the rib. This can help by decreasing drag, increasing lift, and improving performance by helping to design the wing rib. The design imported to ANSYS is meshed using edge sizing and face meshing method. Meshing is an important step in Ansys analysis since it breaks down the 3D model into smaller pieces or cells to make analysis easier. The mesh should be precise enough to capture the key wing rib characteristics without making the study computationally expensive.

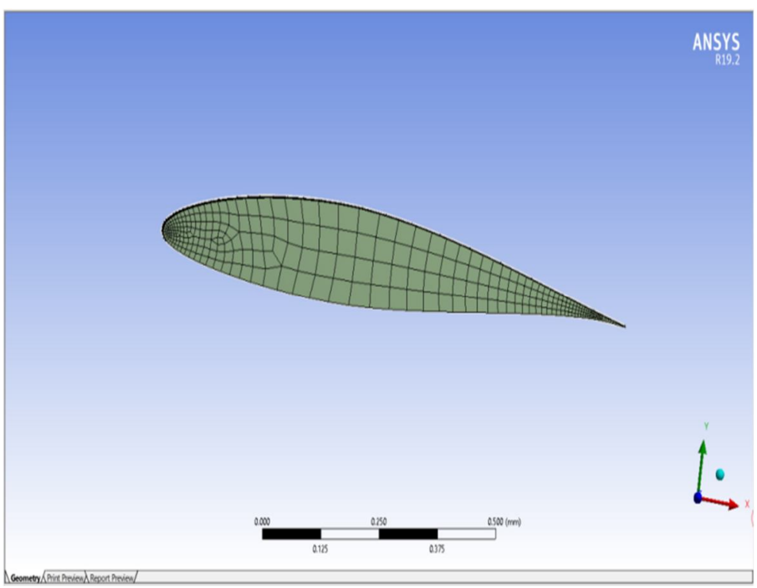


Fig 8. Meshing of wing rib without cut-outs

A. Analysis of the aerodynamic efficiency of different wing rib configurations

1) Rectangular Wing Rib

The analysis of rectangular wing ribs in ANSYS primarily uses finite element analysis (FEA) techniques. In order to analyse rectangular wing ribs in ANSYS, the geometry must be created, meshes must be defined, material characteristics must be defined, boundary conditions must be defined, and an appropriate analysis type must be selected. Then, ANSYS offers resources for post-processing and results analysis.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue III Mar 2023- Available at www.ijraset.com

Table II
RESULT OF RECTANGULAR WING RIB

Lift Force	4.8463 [N]
Drag Force	2.1782 [N]
L/D Ratio	2.2207

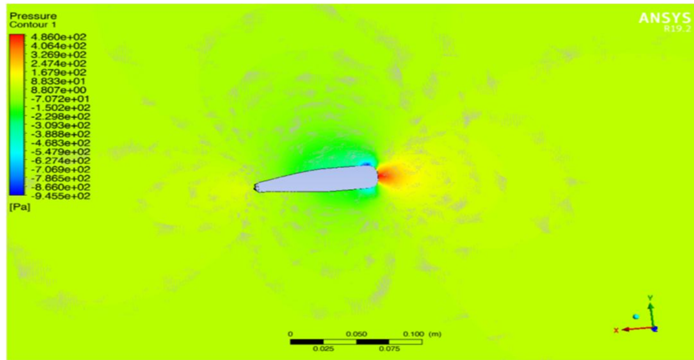


Fig 9. Result of Rectangular wing rib analysis

2) Circular Wing Rib

The aerodynamic study of circular wing ribs in ANSYS involves simulating the airflow around the rib. Creating the geometry, meshing, specifying the material characteristics, setting the boundary conditions, and selecting the right analysis type are all steps in the analysis of circular wing ribs in ANSYS. The meshing method, which divides the circular cross-section into a number of smaller parts or segments, is the primary distinction when studying circular wing ribs. Aerodynamic analysis seeks to improve the performance of the circular wing rib by analyzing the lift and drag forces operating on it.

TABLE III
RESULT OF CIRCULAR WING RIB

Lift Force	6.6363 [N]
Drag Force	1.8457 [N]
L/D Ratio	3.5955

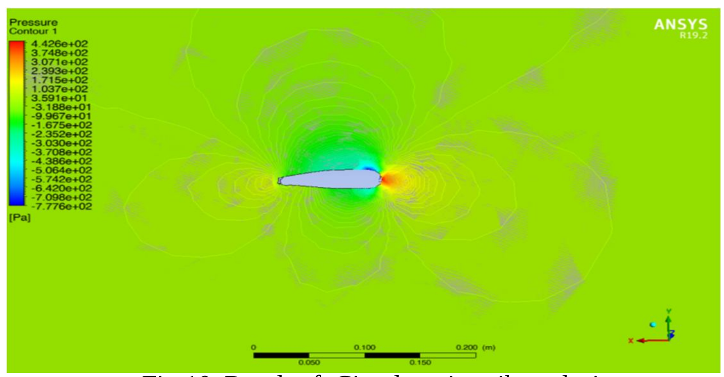


Fig 10. Result of Circular wing rib analysis

3) Elliptical Wing Rib

The lift and drag force analysis of elliptical wing ribs in ANSYS involves simulating the flow of air around the wing using Computational Fluid Dynamics (CFD) techniques. To perform a lift and drag force analysis, ANSYS provides several turbulence models, such as k-epsilon and Reynolds-averaged Navier-Stokes (RANS) equations, which are used in this analysis. The wing rib's elliptical form can be modified to reduce drag and enhance lift coefficients by varying the aspect ratio, taper ratio, and angle of incidence, as found from the analysis.

TABLE IV
RESULT OF ELLIPTICAL WING RIB

Lift Force	121.2921 [N]
Drag Force	16.3201 [N]
L/D Ratio	7.4320

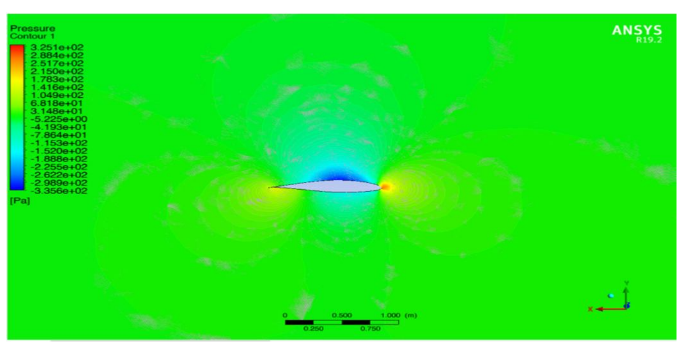


Fig 8. Result of Elliptical wing rib analysis

VIII. COMPARISON OF VARIOUS AERODYNAMIC PARAMETERS OF DIFFERENT WING RIB CONFIGURATION

The lift, drag and lift to drag ratio (also known as aerodynamic efficiency) is compared in the below Table V & Table VI. By evaluating these parameters for different wing rib configurations, the comparison can provide insights into the effects of various design parameters on aerodynamic performance.The study's conclusions can be used to improve the aerodynamic performance of the wing rib structure, which could ultimately result in the creation of more effective and efficient aircraft. Rectangular, circular, and elliptical wing ribs are different in shape and geometry, and therefore have different aerodynamic characteristics. In general, elliptical wing ribs often offer the best aerodynamic performance, especially in terms of lift coefficient and induced drag.

Table V
COMPARISON OF LIFT AND DRAG FORCES OF DIFFERENT WING RIB CONFIGURATIONS

Sl.No	Wing rib	Forces	Value (N)
1	Rectangular	Lift Force	4.8463 [N]
		Drag force	2.1782[N]
		L/D Ratio	2.2207
2	Circular	Lift Force	6.6363 [N]
		Drag force	1.8457 [N]
		L/D Ratio	3.5955
3	Elliptical	Lift Force	121.2921 [N]
		Drag force	16.3201 [N]
		L/D Ratio	7.4320

IX. CONCLUSION

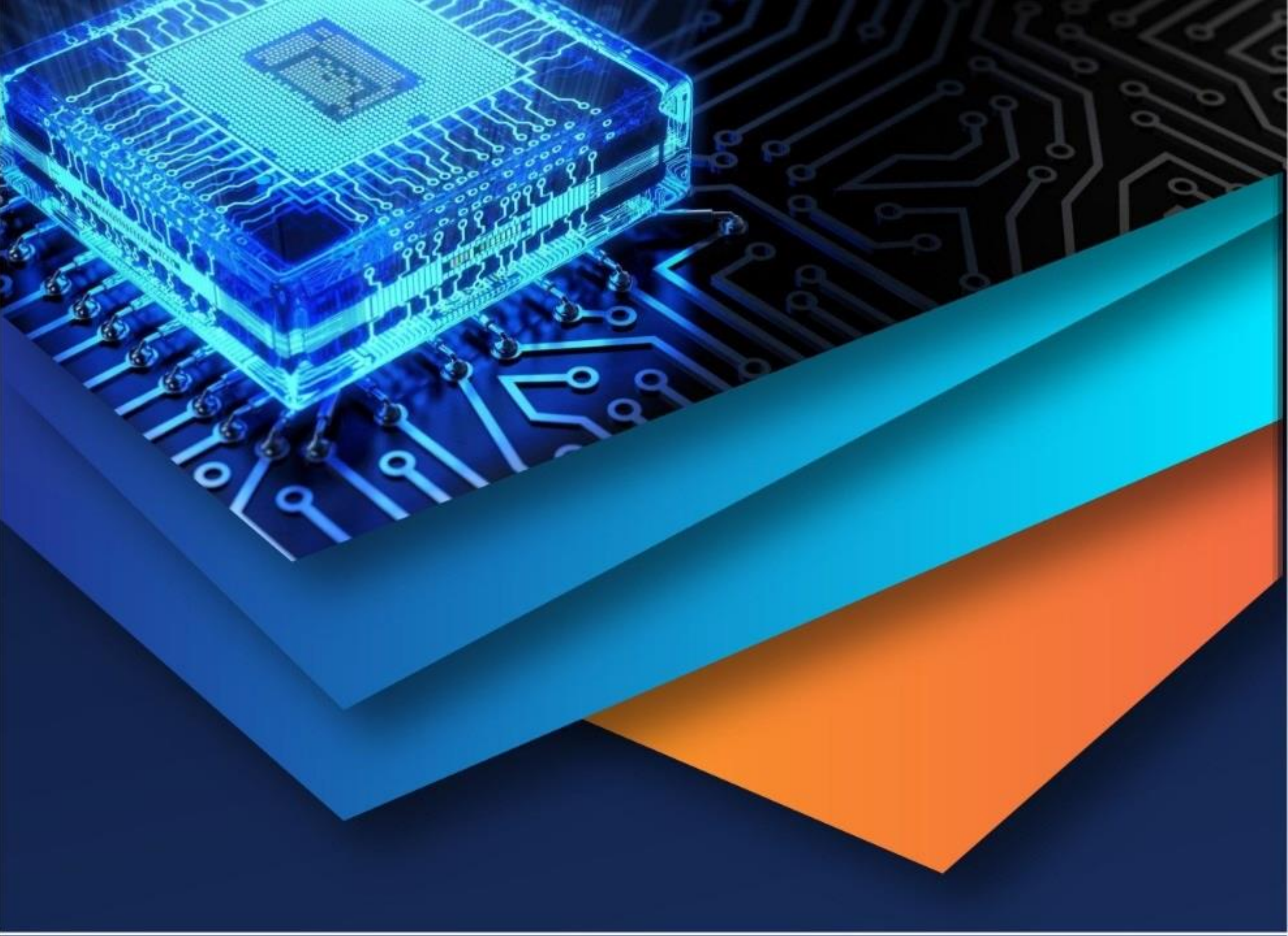
The results of the study show that elliptical wing ribs have the highest lift coefficients and lowest drag of the three wing rib configurations. Even though, the selection about the wing rib design is based on the particular needs of the aircraft and the operational circumstances.In conclusion, this research paper investigates the optimization of wing rib configurations for improved aerodynamic performance through a computational study using CFD simulations. The results show that the elliptical wing rib configuration is the most efficient for improved aerodynamic performance. The design parameters such as Chord length , camber, and wing area have a significant impact on the aerodynamic performance of the wing ribs. The results of this computational study can be utilised to optimise the wing rib configuration of aircraft for improved aerodynamic performance. Overall, this study's computational methodology provides a strong tool for studying and improving wing rib designs. This method can help to cut down on design iterations and related expenses, resulting in more effective and efficient aircraft designs. Improved aerodynamic performance can ultimately lead to higher fuel efficiency, lower emissions, and increased safety, all of which contribute to a more sustainable and environmentally friendly aviation industry.

X. FUTURE WORK

Based on the results of this study, there are a number of potential areas for future work. Investigating the effects of additional design factors, such as wing sweep, twist, and taper ratio, on the aerodynamic efficiency of various wing rib configurations is one area of prospective future research. Furthermore, experimental verification of the CFD simulations used in this research could add to the evidence to support the accuracy and trustworthiness of the computational approach. This can include testing of scaled-down versions of the various wing rib designs in a wind tunnel or in flight. Overall, the results of this study offer a solid basis for further investigation into the optimization of wing rib designs with the goal of enhancing aircraft wing aerodynamic performance.

REFERENCES

[1] Dharmendra P, Chaithanya K J, Ayesha Sameera, Khyati Kavathiya And Monika K M " Design And Analysis Of An Aircraft Wing Rib For Different Configurations" International Research Journal of Engineering and Technology (IRJET) Volume: 07 Issue: 06 (June 2020)
[2] G. Lombardi and G. Mengali [2] An Optimization Procedure For The Conceptual Analysis Of Different Aerodynamic Configurations.
[3] Rahul Sharma and Garima Garg "Design and Analysis of Wing Rib of Aircraft Review" International Journal of innovative Research in Science and Engineering Technology, Vol. 3, Issue 12, (December 2014)
[4] Bindu H C, Muhammad Muhsin Ali H "Design and Analysis of a Typical Wing Rib for Passenger Aircraft" International Journal of innovative Research in Science and Engineering Technology, Vol. 2 Issue 7 (July 2013)
[5] Guguloth Kavya, B C Raghukumar Reddy, "Design and Finite Element Analysis of Aircraft Wing using Ribs and Spars" International Journal and Magazine of Engineering, Technology, Management and research, Issue No. 2348-4845



doi crossref

10.22214/IJRASET

INDEX COPERNICUS

45.98

ISRA JIF

IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

ISI

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY