International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Optimized Design and Validation of Aircraft Wing RIB Using Ansys

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A B S T R A C T

With the continuous development of science and technology, while ensuring safety and functionality, reducing aircraft life cycle energy consumption and reducing aircraft operating costs are becoming a hot topic in many researches. Starting from the quality of the fuselage, the research performance is up to the standard. The issue of reducing the mass of aircraft parts and ultimately reducing the mass of the entire aircraft is causing widespread concern in the industry. In response to this requirement, this paper selects a certain type of aircraft wing rib as the object and studies the topology optimization design method of the aircraft rib structure. Topology optimization is to reduce the weight of the structure while maintaining high performance by removing the part of the structure that supports the smallest load. The current topology optimization is a brand-new design technology that has broad application prospects in the field of structural design optimization. This paper intends to use ANSYS software to optimize the topological optimization of the aircraft rib model, and finally realize the safety of the ribs while reducing the quality of the ribs. First, the three-dimensional model of the wing rib is established with CATIA software as the basis of finite element analysis and topology optimization design; then in ANSYS, perform finite element analysis and structural topology optimization of the top full-contact force basic wing rib, the finite element analysis results of stress and strain distribution of the basic wing rib model and the topology optimization design model are obtained; after that, the influence of the wing stringer on the wing rib was considered, and the real model finite element analysis and structural topology optimization of the wing rib under the top part of the area were carried out in ANSYS, A more realistic finite element result of the wing rib model and a topological optimization design model are obtained. In this research work, by applying topology optimization to the design of aircraft wing ribs, and comparing its performance with the original design model, this paper actively discusses the use of topology optimization to guide the optimization design of aircraft components. After optimization in this paper, this type of wing rib has been effectively reduced in mass while ensuring structural strength and safety, which has a positive significance in reducing the weight of the whole machine and saving operating costs.

Keywords: Design, optimization, Aircraft wing rib, finite element analysis

1. Introduction

Nowadays, aircraft has experienced a prospect of radical changes in the aircraft industry. Aircraft optimization system is very significant in a flight vehicle system. The demonstration of the optimization techniques reduces the weight of each component and the overall weight of the aircraft will reduce [1]. An aircraft is a complex structure, but a very efficient man-made flying machine. Structural safety with the minimum weight is a necessity in the aircraft design and development process. Aircraft's progressing performances never seem to stop. The Boeing 787 and Airbus A380 are perfect examples of performing in the optimization process finding a possible solution to low operation cost and engineers have kept on pushing their limits on projects. These incredible engineering achievements were possible only because of the development of modeling and manufacturing technologies which rely today more than ever on computational power. Billions of calculations per minute allow extreme ease, precision, and quality in both design and production of modern aircraft. The tools now widely used are Manufacture (CAD/CAM) and Computer-Aided Design [2], Computer Numerically Controlled Machining (CNC Machining), and assembling.

The most recent of these tools, still very new today, in Additive Manufacturing (AM). The main variance between AM and traditional manufacturing methods is that it consists of building 3D-shaped objects progressively starting from nothing, instead of subtracting matter from an original stock to attain the final desired object. Examples of traditional or conventional methods are drilling and milling. The main advantage of AM is that it has made it possible to manufacture very complex geometries, impossible to achieve with traditional methods and even build complex assemblies made of multiple parts as one singular piece. Moreover, because of the new geometric horizons AM has revealed, another tool was born, directly linked to it: Topology Optimization (TO). TO aims at acquisition the perfect trade-off between two of the continuously primal structural engineering objectives: weight and strength. Optimization is a procedure to get an optimal solution among the number of different iteration and minimizing and maximizing the qualification properties of the product (e.g., strength, weight, strength-to-weight ratio) [3]. Topology optimization was carried out using software ANSYS. It allows engineers to remove "passive" areas of structures under load and keep the resulting performances equal if none better than before. The resulting structures are at least as efficient as before, but for a fraction of their original weight. In this current economically and ecologically challenged environment, TO could perhaps be the key to a new era of engineering, facing these challenges. Aircraft companies are now urging their research teams towards solutions to tackle new environmental issues. The obvious solution is to reduce fuel consumption, and more generally reduce energy consumption. Making systems lighter and easier to manufacture would have this very effect, which is precisely what TO allows, coupled with AM. Lighter aircraft would consume less fuel and therefore use less energy. TO can help engineers face the new environmental and financial issues and demands of the modern aircraft industry.

In the aircraft industry, the optimization and simulation methods are recognized by the Computer-aided engineering for analysis skeleton based on the property of mesh model in finite element (FE) method [4].

To obtain new and lightweight component design and demonstrate several systematical stages are used for any specified aircraft wing design. The development of the performance of strength, stiffness, and other condition stability of the wing rib are based on weight reduction and increase in strength. There are different methods of optimization tools CAD/CAM, CAE (Computer-Aided Engineering) tools, Assemblies, CNC machining, ANSYS, FEM optimization, etc. The structural optimization of wing rib to make perform the overall aircraft wing which the dominant part of the wing ribs if reduce the weight rib the weight of the wing will reduce up to 50% of the weight reduction as compared to other components of the wing. However, optimization of the wing rib will reduce the manufacturing cost and assembling time consumption overall the wing. In the optimization adding loop optimization of aircraft wing rib, the improvement of the geometric design and structural analysis availability of the modules is the code of analysis performing the skeleton of the design. The objective optimization can model a wing-rib more automatically and rapidly in manufacturing assembly processing [5]. Topology optimization is concerned with minimizing compliance to formulate the structural design maximizing the fundamental usual frequency, buckling loads, or design of compliant mechanism among others to consider the strength a significant issue [6]. In the area of topology optimization mainly the two elementary approaches have been tracked to include stress and volume constraints are on a finite element discretization of the problem it consists of the minimization of weight the structure subject to local enforcements and global constraints.

1.1 Objectives of this research

The main objective of this present work is toward finding the optimal design solution of wing rib and to predict the most accurate strength and weight minimizing of the geometry.

- ✓ To optimize the mass of the model based on the topology optimization method design analysis
- ✓ Develop a topology optimization algorithm based on the current trends
- ✓ Deploy a basic topology optimization algorithm
- ✓ Perform a topology optimization using the software ANSYS
- ✓ Compare the performances of the algorithms

1.2 Methodology

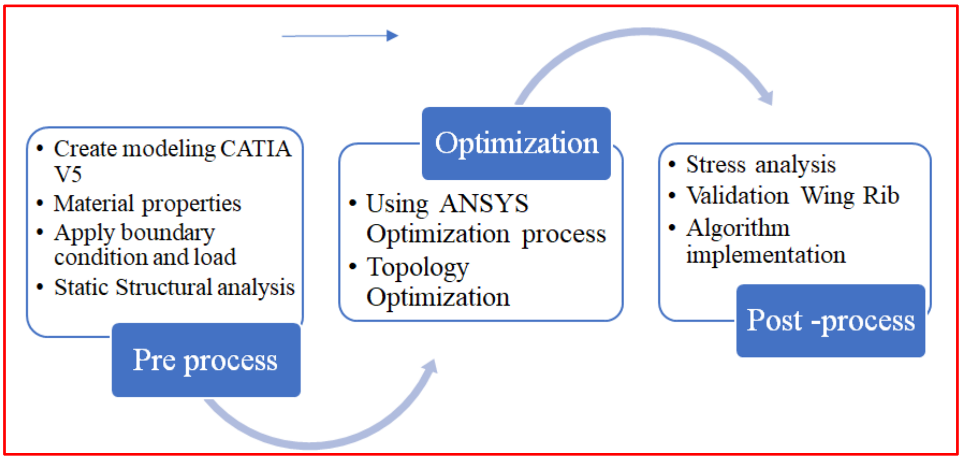


Fig. 1 – Flow chart of this research work

Figure 1 show the methodology used in this process. The wing rib used as a sample of the study case, that will be optimized, needed to be clearly defined and modeled to run the initial analysis process First, the design model of wing rib is done on CATIA V5, which will allow understanding the geometry features of the part that will influence the complication of the calculation later on and the general structural properties and original performances. Before optimizing the design will analyze the load distribution over the area by applying the load conditions which exerted the pressure stress on the wing rib at the maximum operation of aircraft. Based on the structural analysis and load distribution will be defined and organized to optimize the size and strength. Then, an algorithm will be implemented to perform TO on the part. The type of the algorithm should be wisely chosen considering the study case and available resources. And a thorough theoretical and basic study of the said algorithm simulation should follow to verify its implementation quality. Next, the reference for topology optimization performances that is chosen for this study is the software ANSYS, which includes an optimization module. The optimization module of ANSYS should be studied deeply before performing any analysis. Because the objective is to compare procedure methods and results from a quality, each should be precisely and deeply mastered so to draw the most accurate conclusions, based on specific sets of parameters.

General performance factors will be examined such as calculation time, complexity, and overall quality. Since most TO algorithms rely on the discretization of structures, and therefore matrix operations, a preliminary theoretical study is conducted and MATLAB is used as support for the progress of the algorithm. There are several options for the algorithm. The choice is based on the part's complexity and the complexity of the algorithms. However, in all cases, the calculation and implementation are performed using Finite Element Method (FEM) analysis. As the design and digital testing of the parts, the software CATIA is used, and for optimization, the already linked ANSYS software. Furthermore, performances and results quality are compared between ANSYS and the newly designed algorithm. To evaluate product performance to get the requirements and optimize designs.The new topology optimization method was established to experiment with wing rib to verify efficiency. The performing of the wing rib within the actual aircraft design and compare the performance the quality of the optimized result. Topology optimization is technique optimizing design contribute weight saving to obtain new lighter component and verifying the performance design optimization mechanism.

2. Illustrations Modeling and Topology Optimization Algorithm

Primary work is conducted before the development and implementation of the algorithm. First, the mechanical structure design of the wing rib detail has to be precisely modeled. Modeling aims to understand the geometry and load cases of the product in its life cycle to build the initial topology that would be later optimized. Also, the designing of aircraft constructions to different approaches is modeled in the 3D structure modeling and defines the design analysis parameters and material properties orientation. Then, the algorithm type for optimization is decided early. There exist many types of algorithms and each has its complexity, both in implementation and in deployment. The available computation resources are also engaged into consideration in the operation of the design algorithm based on the results to be obtained.

2.1 Construction

The design configuration of the wing rib is used effectively to control the flow of aerodynamic pressure and increase the strength of the spar by balancing the load distribution. The manufacturing of the aircraft wing rib is based on the specification of data and the application which is recommended to design upon the ratio of drag and lift. The assembly of the wing rib with wing skin-stringer boards has different configurations due to the various application requirements. In aircraft wing rib reducing holes are introduced in the web of the rib to reduce mass, accessibility and to arrange a passage aimed at wiring and fuel pipes. Different types of wing ribs assemblies are required in aircraft design due to their applications.

Figure 2 is shown the configuration of the rib along the span between the two spars in an aircraft wing. the assembly of the wing strongly depends on the quality and loading support of the spars and the stringers to minimize the bending deflections due to the flight and ground occurs the aerodynamic loads remained applied to the perimeter of the skin of the wing.

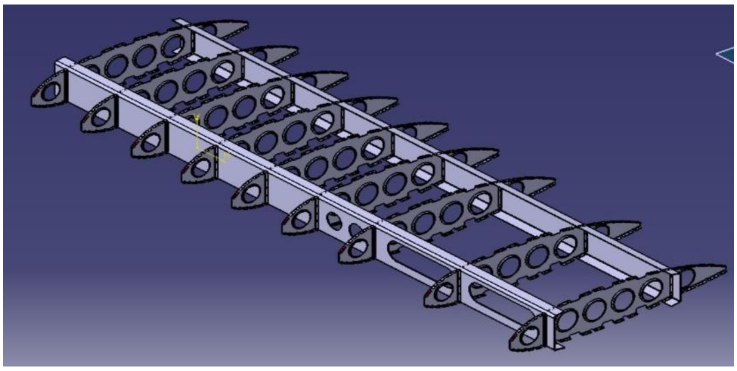


Fig. 2 –Aircraft wing Assembly

2.2 Analysis of the Design

Design formulation is applied to the optimization of an aircraft wing rib to deal with reliability based on topology optimization problems. The optimization leads to a reduction of the weight of the design rib geometry. The topology optimization application in technology is widespread in different industrial aviation, manipulating the potential to design frivolous aircraft. Topology optimization is a finite element-based structural optimization process, increasingly used by engineers to support the development of minimum weight structures by helping to determine the most efficient method to carry a given set of loads using the minimum proportion of material and designing within a predefined design space.

Analysis of the structure is completed using ANSYS software. Equivalent stress, strain energy, and displacement for the given structure are determined and characteristic graphs are obtained for various configurations stress. The meshing size used is 50mm regarding the dimensions of the parts are roughly equivalent. The force of 1KN is applied to the structures and the optimization will be 3D done, the structural analysis is conducted in the 3D model also, making the finite element method (FEM) analysis faster. The results get from the analysis are used to govern the Von-Mises stress in the structure and extreme displacements. The maximum Von-Mises stress occurs at the tip edges and displacements occur at the center of the structures.

Topology optimization is conducted on the material Aluminum which is common in aircraft structural design of components with the given physical and mechanical properties. The material used for wing rib is Aluminum Alloy. The key property of Aluminum alloy for the designing structural Analysis is summarized in Table 1. The material properties influence the outcomes of the optimization based on their input values. The most common imperative factor for an efficient structural analysis is the proper definition of the material properties.

Table 1 – Mechanical Properties of Aluminum

Properties	Values
Density	2770 Kgm-3
Modulus of Elasticity	71000 MPa
Poisson's Ratio	0.33
Shear Modulus	2.6692e10 Pa
Tensile Yield Strength	2.8e08 Pa
Tensile Ultimate Strength	3.1e08 Pa

2.3 Implementation of a Topology Optimization Algorithm

This section tackles the issue of selecting the best type of optimization algorithm to implement for the design part. This choice takes into explanation the complexity of the possible algorithms as well as the resources available. The objective of this research is also to develop a new tool that can be improved in future work. The developing a variety of complex design solution algorithms used for light in weight structural compliance, shape optimization, and Multiphysics designs to several engineering applications. All the functions will be detailed and implemented to have full control of its deployment.

The topology optimization algorithm is categorized into two methods which are the gradient and non-gradient algorithm based on its constraints and objectives. TO algorithms in the wide area that apply to its fast numerical algorithm. In This [27] proposed the concept of topology gradient using the level set method to evaluate the shape of the geometry the algorithm works to all topology optimization. The gradient algorithms rely on the calculation of gradient values of an objective function such as the strain energy or the volume to determine whether to remove or add matter to each element at each iteration. Explained the advantage of level set function to shape optimization can get a precise description of fixed mesh boundaries. Another category of TO algorithms is non-gradient algorithms or free gradient algorithms. The non-gradient algorithm implies to compute the objective useful in solving problems does not rely on the gradient of objective functions or the sensitivities information. In a non-gradient topology algorithm to obtain an optimized solution various methods of search algorithm are used those are genetic algorithm, simulated annealing particles, ant colonies, and differential evolution. This method commonly routine to solve problems leads to the significant approach of optimization with a combination of the genetic search algorithm. These algorithms produce a population of conceivable solutions and modify it according to performance criteria or ranking. In the case of topology optimization, the use of Genetic Algorithm (GA) processes in (control point coordinates) and discrete (load path existence) combination of continuous and discretize the parameters by creating a population of design and compare their performance based on the nature objective functions search of the problem space for final requirements. At each iteration; the population evolves according to precise functions to make the individuals progress towards the best solution. The problem here is that these types of algorithms also require a lot of computational power since they require to simulate a large number of individuals that is possible designs, in this case, to achieve good results.

2.4 Analysis and Optimization Simulation

Topology optimization of stress constraint and the construction requirement are reduced the sensitivity cost-optimized. The stress of element constrained subjected to the load applied and the optimization work to adjustment and transferring operation (Figure 3). The optimization dealing with changing stress boundaries and design space adjustment. The adjustment does not affect the property of the structure and materials. The structural topology design property solid or empty during the optimization adjustment and this is a robust and practicable method. The number of constraints in the optimization problem is large numbers and singularity. The local stress imposition in TO and design space optimization and the construction of topology optimization method construction stiffness and mass topology variables. The analysis of stress in the wing rib is calculated in the applied load and the geometry boundary condition design. The topology optimization work on the feasibility of the material required for manufacturing and to design with strong and light material for various configuration of design requirement. Set the preserved mass to 50% of the design solid material and the weight will be lighter than the original almost by half.

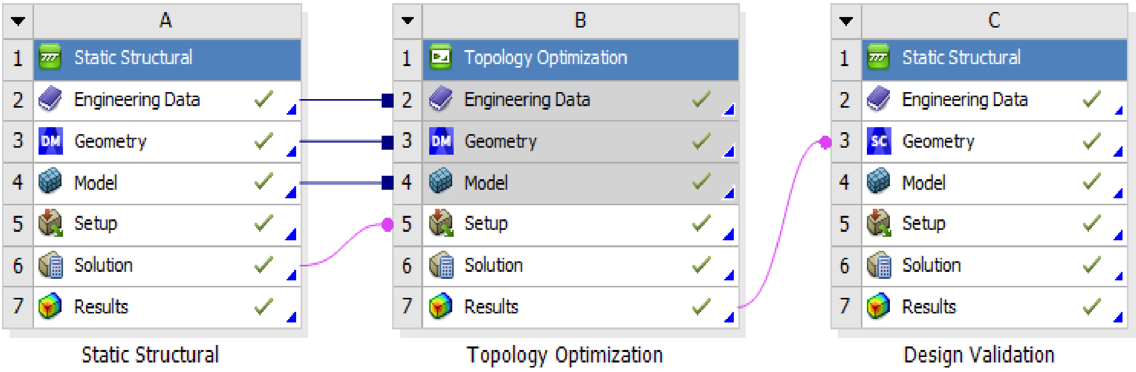
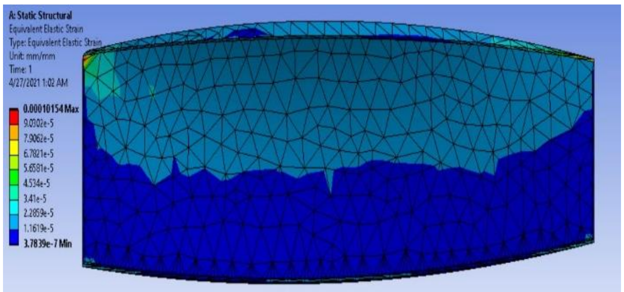


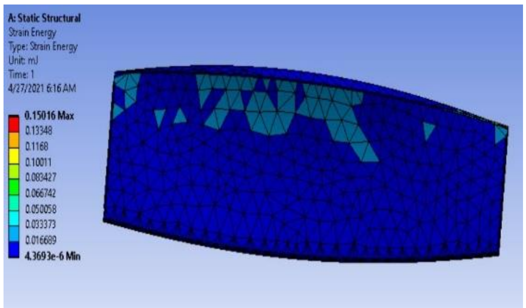
Fig. 3 –Topology Optimization Process

3. Finite Element Analysis

The material used for both parts is Aluminum, as summarized in Table 1 the key properties of Aluminum for static structural analysis. It is also important to understand that material specification which is useful for industrial requirements. If such requirements are not necessary, the material characteristics can be input arbitrarily and their values have little influence on the results.



(a)



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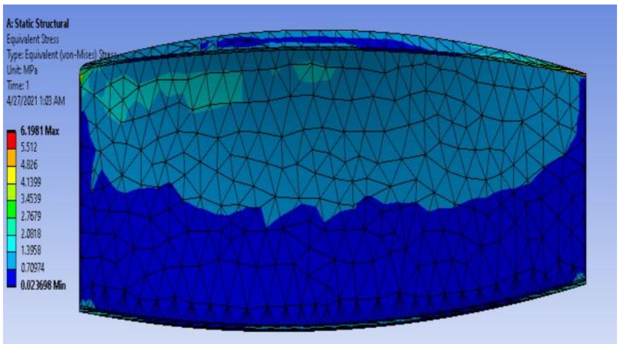

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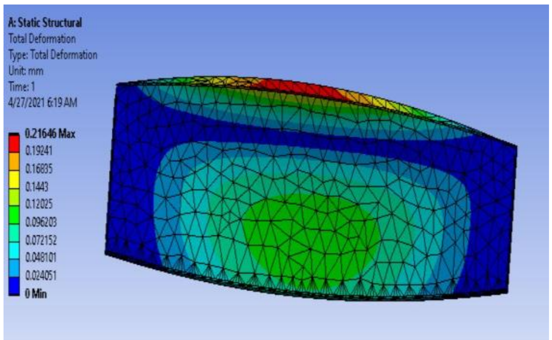


(d)

Fig. 4 – (a) Elastic strain of the wing rib, (b) Strain Energy of the wing rib, (c) Von-Mises Stress of the wing rib, (d) displacement of the wing rib

For the overall procedure, the optimal point is reached when the mass of the part has been met or when the obtained result does not meet the requirements. The key element analyzed is the maximum displacement as it is usually one of the main requirements in engineering problems. FEM analysis is conducted to evaluate both the first objective function and the original maximum displacements. To prepare so, the load cases must first be defined. The meshing used is defined in this study regarding the dimensions of the wing rib the default mesh is 77mm but for better analysis reduce the mesh size to 50mm used for the structure. The force applying as explained before 1000N is applied to the structures at the top of the edge. The analysis is 3D geometry results of the FEM structural analysis is conducted in ANSYS will be displayed in the contour view in the model. And the results used in the structure are the Von-Mises stress, strain energy, elastic strain, and the maximum displacements. In this case, the maximum displacements occur in the tip of the edge wing rib the structures. Figure 4 shows the contour view of the FEM analysis distribution over the model. The value considered here is the minimum weight of the wing rib. Generally, the design more or less met towards one close to that of the obvious design. However, in some cases, the parameters of the optimization situation caused the result to be slightly different and therefore result exceptionally. As already mentioned, all the design parameters initially look to meet the obvious design. All of the matter in the area link between the top and bottom is removed at some stage in the optimization stages when using the procedure ANSYS topology optimization directly remove. The results indicate that the objective functions of the method showed the matter in this part, far from the connection, was non-important and could be removed. This is due to the stress distribution in the simplified wing rib under load. The result of the ANSYS topology optimization for the first phase of optimization is shown below in Figure 5 with a mass reduction of 50% of the original model mass.

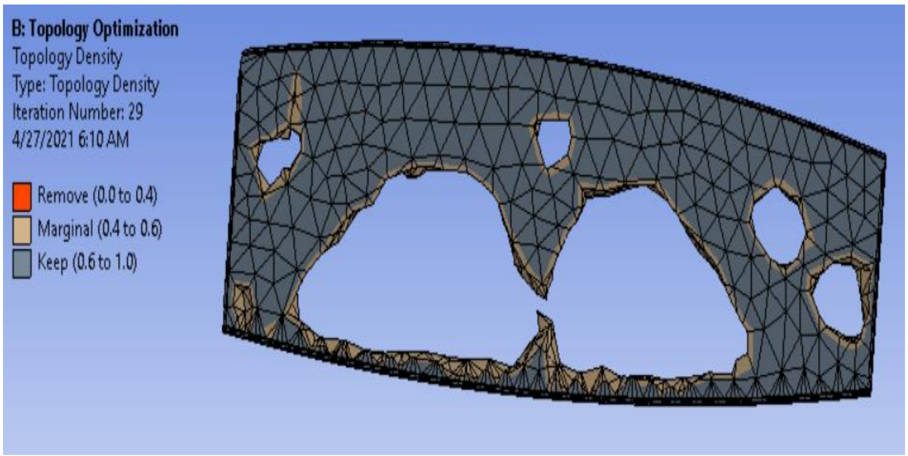


Fig. 5 - Topology Optimization Results

3.1 Validation

Validation (Figure 6) of modified wing rib achieved through topology optimization by comparison to topologies obtained design problem using the density approach. Topology optimization from the aerospace perspective to reduce the mass is required for the design cost compliant structure to achieve the required design shape without the material failure. Define the characteristic of the material and structure to more efficient in determining the final optimum topology solution. To validate the model for this study case on the removal of mass from ribs considering the effect of Bending load and shear flow on ribs throughout the internal structure of the wing of an aircraft by modified the topology optimization result.

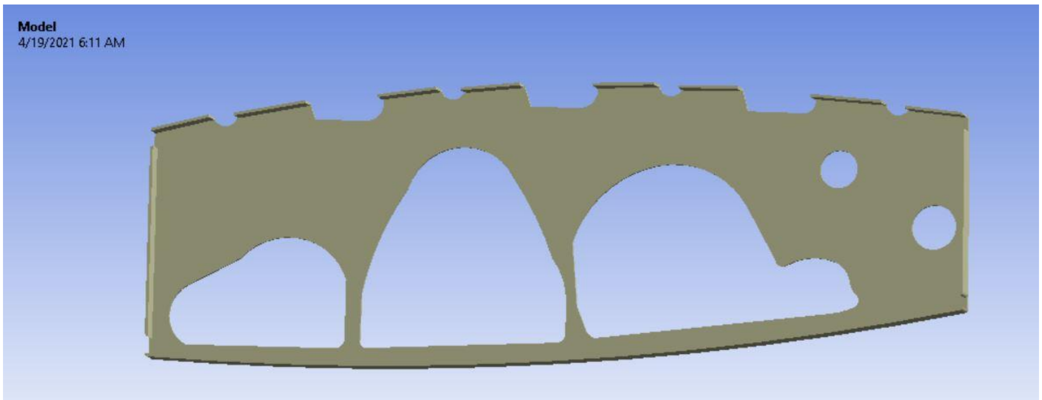


Fig. 6 - Modified Optimized Aircraft Rib

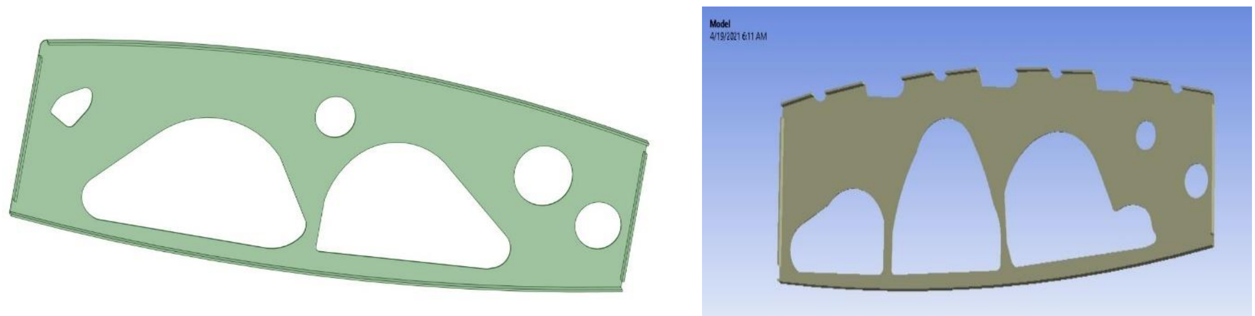
4. Results and Discussion

Overall, the procedure developed in this paper returned several possible solutions for the optimization of the aircraft wing rib in its design, according to the requirements discussed earlier. The results are listed in Table 2 the results should be tested to compare performances. As the optimization results using ANSYS, the 50% mass reduction of the basic design resulted in a 38% mass reduction compared to the original design, and the 50% mass reduction of the top surface contact force area design resulted in a 35% mass reduction compared to the original design. The procedure developed in this work looks to return designs of similar quality compared to ANSYS. The optimization criteria which are a consideration in the topology optimization procedures are maximum displacement, stress, and weight those are the characteristics to compare the part with conventional and optimized model design to achieve the significant performance improvement. The shape of the current structure is the optimization of the improved mechanical performance. The main challenge of structural system optimization is used to performing the location of optimal design of the components of the topology optimization. Based on the analysis the importance of topology optimization improved the mechanical characteristics of the system.

Table 2 – Comparison of the Model with Conventional Design

Contents	Conventional Model	Optimized model
Weight (kg)	8.0968	6.686
Max.Displacement (mm)	0.37211	0.87371
Max. Stress (MPa)	8.0897	21.433
Max. Strain Energy (mJ)	0.09885	0.14226
Max.Elastic Strain	1.195e-4	3.2583e-4

The above Table 2 shows the comparison of the results among the conventional model and the optimized model of the part after redesign the optimization process at applied load. Figure 7 illustrates the result shapes of the optimization. The structures with different contact force area designs (a) show a redesigned model when under the load with a simplified wing rib of contact area case and (b) when the wing rib considering the influence of stringer support to the contact area of load.



(a) (b)

Fig. 7 – (a) Optimized Modified Model Full Contact Force Area; (b) Reduced Contact Force Area Optimized Modified Model

5. Conclusion

Topology Optimization has advantages on many levels of industrial benefit in optimizing structure. Being able to reduce the weight of systems while not undermining their performances is something that can be applied and capitalized in quality demanding industries, such as the aircraft or the aerospace industry. Topology optimization is used to reduce the weight of the wing rib based on the finite element model method optimization. Validate the performance of the rib based on given load conditions and modify the irregularity of the geometry design. Finite element analysis of an aircraft rib will be able to compare with actual design considerations and loading conditions. Topology optimization analysis the design structure of the product and the stress of the load concentration used to reduce the redundant part for saving the cost of manufacturing and materials.

This work proposes a new method for optimizing structural parts. The newly obtained designs are as performance in terms of structural resistance as the original one but for a portion of the weight. The finite element-based method, using ANSYS is an effective method of predicting the failure mode of an aircraft wing rib during the rib design stage. Using this procedure ANSYS Topology optimization module new design obtained and comparing it with the conventional design, and already renowned method, the results can help to document the benefits of Topology Optimization in the industry but also the challenges that stand in the development of such procedure. To predicted locations on the wing-rib is subjected to stress concentration and identical to the actual occurs at the most stress concentrated regions of the wing rib which are the critical regions of the rib that are consistent with order reports.

In this study, a Topology Optimization algorithm has been developed and implemented. Topology optimization in ANSYS and the SIMP optimization algorithm is implemented on MATLAB software's are to simulation methods. To experiment with it, the Topology Optimization procedure developed in this paper was deployed on an actual case of aircraft wing rib. The rib stiffness is utilized near the peak stress nor compliance is explicitly considered in the optimization problem the highly improved value mass reduction effectively. Furthermore, precisely in the aircraft industry, the mass-saving results of Topology Optimization also have an impression on the energy usage of the aircraft in their life cycle. A lighter aircraft would require low energy and therefore consume less, both during manufacturing and usage cycles. That is why it is necessary to continue researching Topology Optimization. It can be unified into the industry on a major scale only if it is better understood and mastered.

This research will analyze the wing rib design methods and simulated mathematical calculations based on the applied load on the wing rib and show that both procedures confirm the potential benefits of Topology Optimization. Finally, the simulation of the topology optimization will be done using ANSYS software with FEM analysis. This method exposed similar performance, however, the newly developed method proved easier and low demanding in computational power.

Furthermore, using this paper's method, according to industrial necessities, a novel design for the studied part was gained, with a weight reduction of 38 % of the original weight of the wing rib. Topology optimization proceeding the method which is used to minimize the weight of structural geometry design in consideration of the stress distribution and the compliance effects on the components. The procedure illustrations its applicability to general parts in deployment on a definite aircraft part. The results attained include a solution reducing its weight by over 30%. This mass reduction denotes a considerable opportunity for costs and materials savings.

The optimization is conducted to reduce the weight and to maximize the strength of the wing rib using topology optimization analysis. The structural design analysis of aircraft wing rib to remove the unstressed area due to the applied load during the flight upward lifting force applied. The advantage optimization of wing rib to become light in weight and reduce the cost of the component as compare with the design before optimization but for the safety case, both designs are safe wing ribs. Topology optimization use to determine an optimal solution design concept as a result of a novel design that will be producing it is more significant in weight savings. The optimization of the design maximizes the performance in conducting the load applied and boundary conditions on geometry. The design is stronger, lighter weight, and requires less material.

In general, topology optimization can be performed in the sizing and shape optimization, to provide stiffness optimal design concepts and detailed sizing against stiffness, stress, fatigue, and buckling. In optimization design, the result of the stress less concentration for select the design and the volume fraction required have to attained reduced. Facing the current environmental challenges is a real issue, and Topology Optimization can open the path towards finding a new technique to design while reducing mass and therefore reducing energy consumption during a product's lifecycle while keeping its performances.

Acknowledgements

First and foremost, I would like to address my gratitude to Almighty GOD with his mother St. Mary for the wisdom and enable me to complete successfully my thesis paper and indeed throughout my life.

I wish to express my sincere thanks to my supervisor Professor Wei Wei 魏巍 for his patience in supervising this study paper his willingness to spare and given up his scarce time to give me his invaluable help, guidance, and motivation. The door to Professor Wei Wei's office was always open whenever I encountered a problem or had a question about my research or writing. This thesis would not have been possible without his guidance, as well as inspiring, idea comments, and suggestions. I am also glad to be part of his rich, broad, and deep knowledge of the course optimization computing system. He always allowed this paper to be my own work but pointed me in the right direction whenever he felt I needed it. Besides my advisor, I would like to thank all professors in the School of Mechanical Engineering and Automation who have taught/instructed me courses in the past three years of my study at BUAA and my heartfelt gratitude would go to all International school and School 7 Administration staff for unwavering support during the epidemic of Covid 19 situation.

I would like to express my sincere gratitude to my lovely wife Mrs. Adiam Yonas and my parents, for all the moral support, patience, and love she had given me and stayed by my side and her family that is unable to be listed here who have directly or indirectly involved incompletion of my thesis. And also, I would adore expressing superior thanks to my beloved family for their loving considerations and great confidence in me through all these years. And those who have been a constant source of inspiration and encouragement besides my thanks go to my friends for their moral support. Additionally, owe my honest gratitude to my classmates and friends Chen Zheng 陈政, Wanyu Fei王宇飞, Yuan Jun 袁君 who gave me their assist and time taking note of me and assisting me training session my troubles all through the hard path of the thesis.

Last but not least, I feel to acknowledge my indebtedness and a deep sense of gratitude to all my colleagues in the Eritrea Institute of Technology, Eritrea for their encouragements and professionalism while I was studying. I would also like to thank all my friends, especially under the group name called "Mahber Krstos" and another individual who has rendered valuable assistance to my study. He has walked me through all phases of the writing of this thesis.

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