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Optimized design and analysis for the development of aircraft droop nose ribs

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Abstract

This paper presents the development of a parameterized automated generic model for the structural design of an aircraft wing. Furthermore, in order to perform finite element analysis on the aircraft wing geometry, the process of finite element mesh generation is automated.

The generic model that is developed in this regard is able to automate the process of creation and modification of the aircraft wing geometry based on a series of parameters which define the geometrical characteristics of wing panels, wing spars and wing ribs. Two different approaches are used for the creation of the generic model of an aircraft wing which are "Knowledge Pattern" and "Power Copy with Visual Basic Scripting" using the CATIA V5 Software. A performance comparison of the generic wing model based on these two approaches is also performed.

In the early stages of the aircraft design process, an estimate of the structural characteristic of the aircraft wing is desirable for which a surface structural analysis (using 2D mesh elements) is more suitable. In this regard, the process of finite element mesh generation for the generic wing model is automated. Furthermore, the finite element mesh is updated based on any changes in geometry and the shape of the wing panels, wing spars or wing ribs, and ensure that all the mesh elements are always properly connected at the nodes. The automated FE mesh generated can be used for performing the structural analysis on an aircraft wing.

Topology optimization has for a considerable time been applied successfully in the automotive industry, but still has not become a mainstream technology for the design of aircraft components. Also, aircraft components are often stability designs and the compliance based topology optimization method still lacks the ability to deal with any buckling criteria. The present paper considers the use of the compliance formulated topology optimization method and detailed sizing/shape optimization methods to the design of aircraft components but also discusses the difficulties in obtaining correct loading and boundary conditions for finite element based analysis/optimization of components that are integral parts of a larger structure.

Keywords: Design; Aircraft Droop Nose Ribs; Optistruct.

1. Introduction

Aggressive weight targets and shortened development time-scales in the civil aircraft industry naturally calls for an integration of advanced computer aided optimisation methods into the overall component design process. Airbus has in a number of recent studies used Altair's topology, sizing and shape optimisation tools in an attempt to achieve lighter and more efficient component designs. Considered components include wing leading edge ribs, main wing box ribs, different types of wing trailing edge brackets as well as fuselage doorstops and fuselage door intercostals. The designs for most of these components are to some extent driven by buckling requirements but also by for example stress and stiffness requirements.

Finite element based topology, sizing and shape optimisation tools are typically used as part of a two-phase design process. Firstly, a topology optimisation is performed to obtain a first view on an optimal configuration for the structure – an initial design with optimal load paths. Next, the suggested configuration is interpreted to form an engineering design and this design is then optimized using detailed sizing and shape optimisation methods with real design requirements. Numerous examples from the automotive industry have demonstrated the ability of such an approach to quickly generate optimum components for stiffness, stress and vibration designs.

The success of the above optimisation scheme relies on a topology optimisation to suggest a good initial design. Numerous examples have shown that the major weight savings are achieved when selecting the type of design and not when doing the detailed design optimisation. The aerospace industry is very aware of this and often spends considerable time

time studying different design alternatives. Efficient designs have therefore evolved through decades of manual optimisation. However, topology optimisation methods may still have a place as new sizes/types of aircraft are designed and as new materials and manufacturing processes continue to appear.

This paper studies the use of Altair's finite element based topology, sizing and shape optimisation tools for design of aircraft components. Aircraft components are often stability designs and topology optimisation methods still completely lack the ability to deal with buckling criteria. The present work therefore uses the traditional compliance based topology optimisation method to suggest an optimal design configuration, which is engineered to provide the design with some stability. Finally, a detailed sizing/shape optimisation is performed including both stability and stress constraints.

At the start of the droop nose optimisation program Airbus UK and Altair Engineering both had very limited experience applying the topology, sizing and shape optimisation to the design of aircraft components. The very short work program left very little time to investigate how to best represent load/boundary conditions and how to best handle local and global buckling criteria in the detailed sizing/shape optimisation. A lot of problems were encountered during the work, and not all of the problems could be resolved in the short time frame. The work therefore was followed up by a validation of the designs via traditional hand stressing methods, and qualification of the ribs/structure against fatigue and bird strike is still ongoing.

The first question that arose when considering topology optimisation of the droop nose ribs was how to best represent the attachment of the ribs to their surrounding leading edge structure (droop nose skin, main wing box front spar and skin overhang) and also how best to model the diffusion of air pressure loads into the droop nose ribs. In the section on optimisation of main wing box ribs, this was done applying super element techniques. However, for the optimisation of the A380 droop nose ribs we had not investigated such modelling techniques and therefore had no experience on how they would work with topology optimisation.

Some preliminary studies had been undertaken at Airbus UK, studying issues with boundary conditions. Leading edge droop nose ribs had been topology optimized considering the ribs in isolation and considering the ribs as part of the leading edge

droop nose structure. The global compliance formulation used in the traditional formulation of the topology optimization method had shown difficulties giving any structure, when optimizing ribs as an integral part of the leading edge droop nose structure.

This problem was put down to the global compliance objective function, which included the total elastic energy in both the droop nose rib being designed but also in all of the surrounding structure. Better results had been obtained optimizing ribs in isolation, but again the topology optimization was shown to be very sensitive to stiffness of the rib/droop nose skin attachment flange. This problem was put down to the global compliance objective function used in the traditional topology optimisation method. The objective function now included both the energy in the designable area of the rib but also the energy in the rib flange that was generally considered to be non-designable.

From the very start of the new droop nose optimisation program, the decision was taken not to attempt to model the surrounding structure, as this would result in several detailed modelling issues and also increase the optimisation run times. Instead simplifying assumptions were made and all attachments to the surrounding structure were modelled using single point constraints. All lateral translations around the edge of the ribs were for example restrained to represent the very stiff span wise support from the main wing box front spar, sub spar and the droop nose skin. Constrained degrees of freedom in the plane of the ribs were also used to represent the attachments to the main wing box front spar and skin overhang.

2. Generic Aircraft Structural Wing Design Concept

2.1. Aircraft Design Process

Aircraft design process is a complex undertaking, however, the design process can generally be divided into three phases which are outlined in the figure below. There is a certain amount of overlapping between these three phases and the number of people, resources and cost associated with the design gradually increases between these phases

The different stages of the aircraft design process are,

1. Conceptual Design
2. Preliminary Design
3. Detail Design



Fig. 1: General Overview of Aircraft Design Process

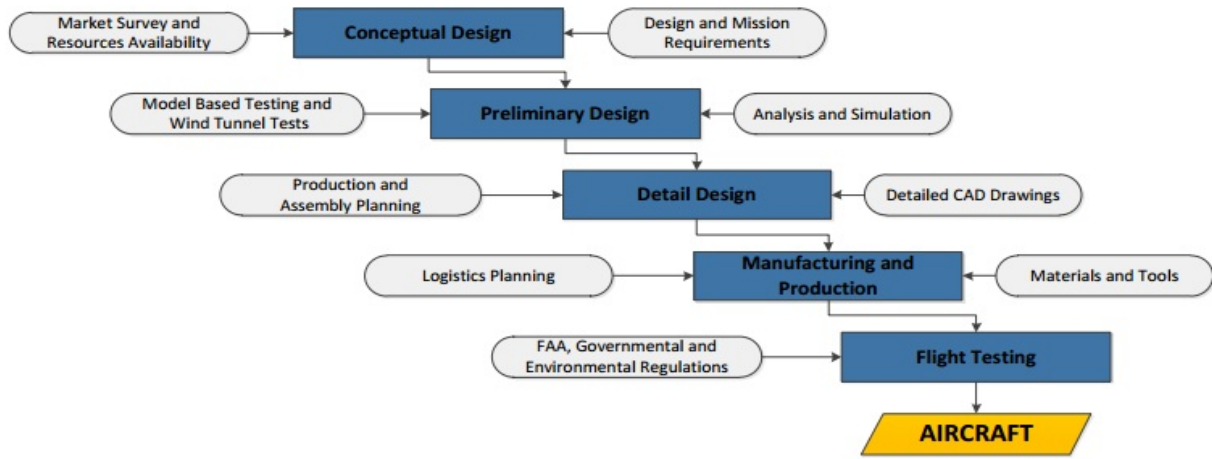


Fig 2: Detail Overview of Aircraft Design Process

The conceptual design phase is the most fundamental stage of the design process where a small number of people are involved. The primary aim of the conceptual design phase is to come up with a design that is able to meet or exceed the design requirements. The conceptual phase of design is driven by mission and design requirements; furthermore, it is also influenced by resource availability and market factors. Here, in this phase, the designers have a wide variety of options available to them for choosing the external shape of the aircraft. Thus, in this phase, a large number of alternative aircraft configurations are studied and feasibility studies are done. The designers normally look at both conventional and unconventional designs at this stage, and also compare their designs with existing aircrafts. The freedom for design modification especially to the external shape decreases as the design moves from the conceptual to the detailed phase. The conceptual phase of design is important because it lays the foundation on which the entire aircraft would be built. It is of utmost importance that the design that is come up in the conceptual phase is feasible and is a design that is able to be manufactured and developed. Normally, at this stage of the design process, statistical methods are common that drive the design. No sophisticated and detailed CAD models are developed at this stage for the design. The amount of resources and cost is also quite less as compared to a detailed design phase where, the manufacturing of the prototype and product takes place and a large number of people are involved.

After the conceptual design phase, a single or a few suitable candidates are chosen for the preliminary design. The preliminary design is an advanced stage of the conceptual design, where, there is a certain overlap between the two phases. The goal of the preliminary design is to completely fine tune the external geometry of the aircraft. In order to do this, detailed modelling and simulation studies are carried out which look at each specific characteristic of the design in detail. The details of all sub-systems and components are worked out. In this stage, many experimental and computational or numerical methods are used for simulation and analysis of the design. Flow analysis using wind tunnels and structural analysis using FEM (finite element methods) are also performed.

A detailed comparison between the different alternative configurations are performed based on a number of parameters including cost, performance, fuel efficiency, range, speed, payload, marketability, lifetime and manufacturability amongst many others. A detailed cost and market analysis is also

carried out to fine tune the region and the type of role that the aircraft would be used for. The outcome of the preliminary design process is a final aircraft configuration which is said to be “frozen” which means that no further design modifications will take place relating to the geometry and shape of the aircraft. Only small minor changes to the design can be made. The design is frozen at this stage so as to avoid significant penalty in terms of cost, time and resources for any design modification in a detailed design phase which would eventually influence a large number of sub-systems. The conceptual and the preliminary design are critical in what eventually becomes an aircraft. A large number of specialists are involved in this design phase and every aspect of the design is worked out.

The aircraft design eventually runs into the detailed design after passing the phases of conceptual and the preliminary design. The detail design is the final phase of an aircraft design process, where, each and every component of the aircraft is designed in detail and manufactured. All manufacturing drawings and methods are developed and used for the manufacturing and assembly of the aircraft. A very large number of people are involved in this stage not only specialists but other technicians as well. The amount of cost and resources are also quite significant. It is of utmost importance that all flaws in the design are ironed out in the preliminary or conceptual design phase, because, any fault found in the detailed design phase can put the design in jeopardy which can lead to the aircraft design project been cancelled or impacting this process with significant cost and time penalties. All manufacturing details, CAD geometry and models for all including the smallest of components are worked out for the design that is frozen at the end of the preliminary stage. In the detailed design process, precision and accuracy is very important and a range of tools and methods are used at this stage.

After the detailed design phase, the manufacturing and production of the prototype takes place. This involves lots of logistical planning and a large number of materials and tools for the actual manufacturing and assembly. Once, the aircraft prototype is manufactured, the prototype runs into the flight testing phase, where, the aircraft goes through a series of flight and ground test to gauge the performance of the aircraft. This phase is influenced by aviation authorities like FAA, Governmental and environmental agencies, and all the requirements set out by these agencies must be met.

3. Modelling of Wing Rib

The surface model of the aircraft wing is specifically designed to be used for the finite element analysis of an aircraft wing. The surface model includes only surfaces which represent the wing shape including spars and ribs. The surface model is chosen for the finite element analysis because it is faster to do a finite element analysis on a 2D surface rather than a 3D one.

It is also easier to mesh a 2D surface than a 3D one and also it is computationally beneficial. In a conceptual phase, it is also not necessary to carry out a very precise finite element analysis for the aircraft wing. So, a 2D analysis will give sufficient information to be useful in the conceptual phase while saving time and resources compared to a full 3D FE analysis.

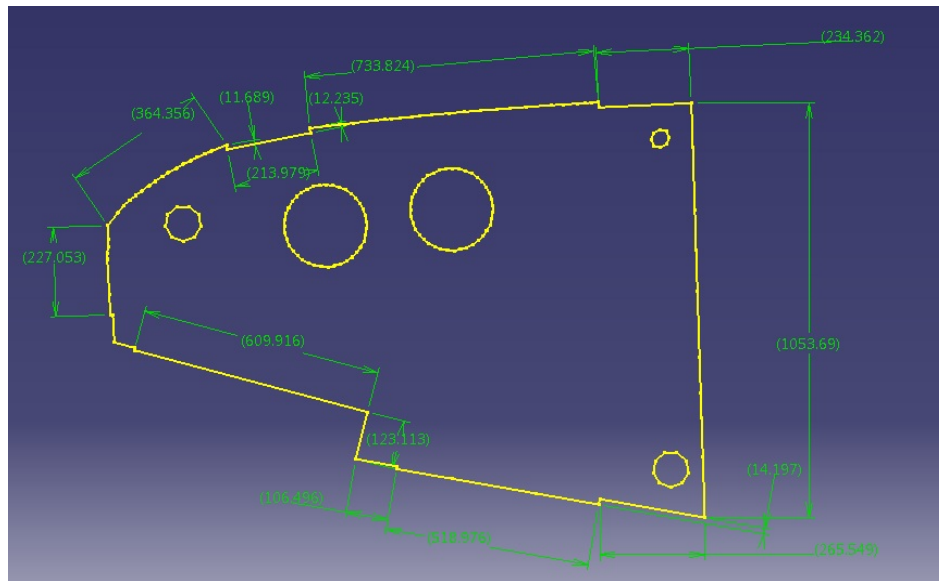


Fig 3: 2D drawing Using CATIA V5R19 Software

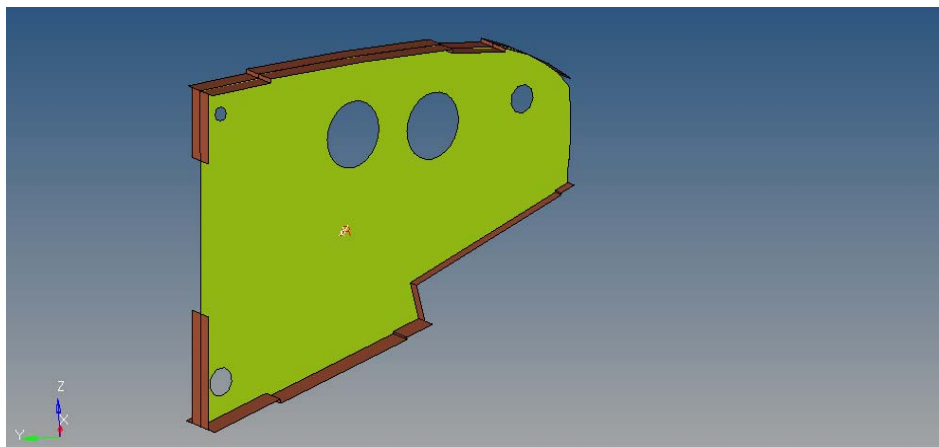


Fig 4: 3d model is developed in catia v5r19 software model

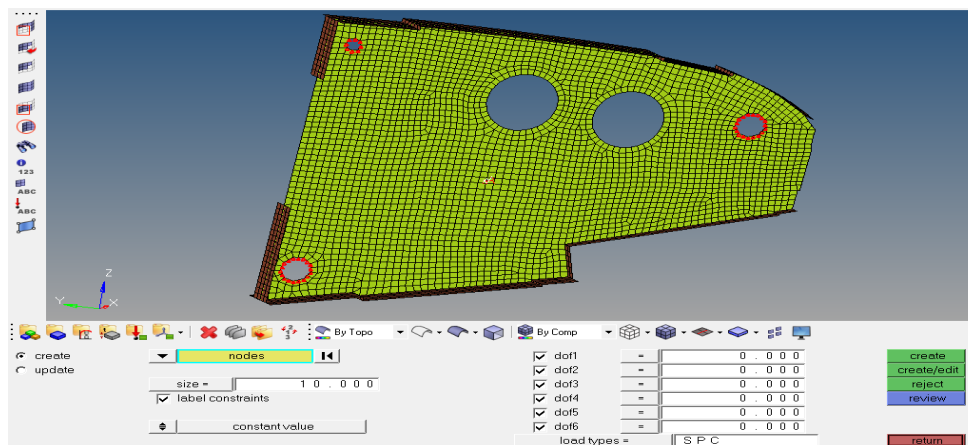


Fig 5: Analysis page- Constraints (FIX) in all DOF, selected nodes are highlighted.

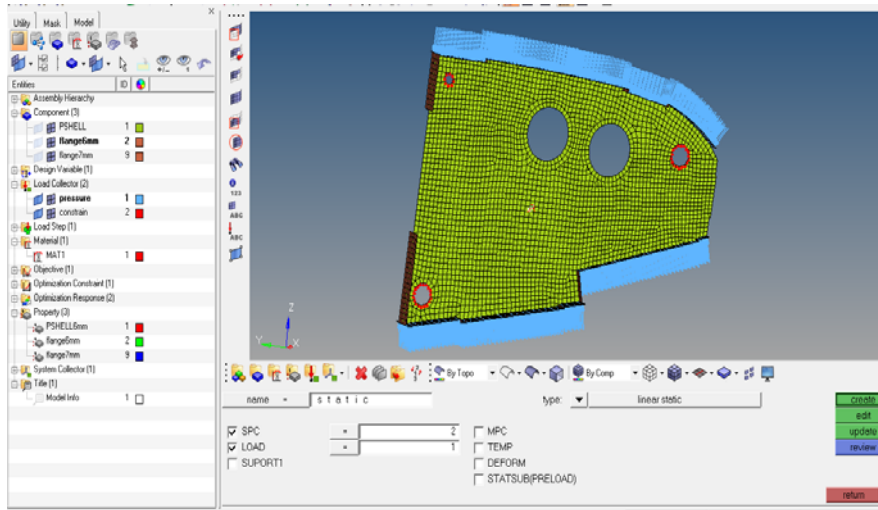


Fig 6: Fixing and pressures are linked in loadstep where type of analysis is chosen.

4. Results and Discussions

4.1 Displacement

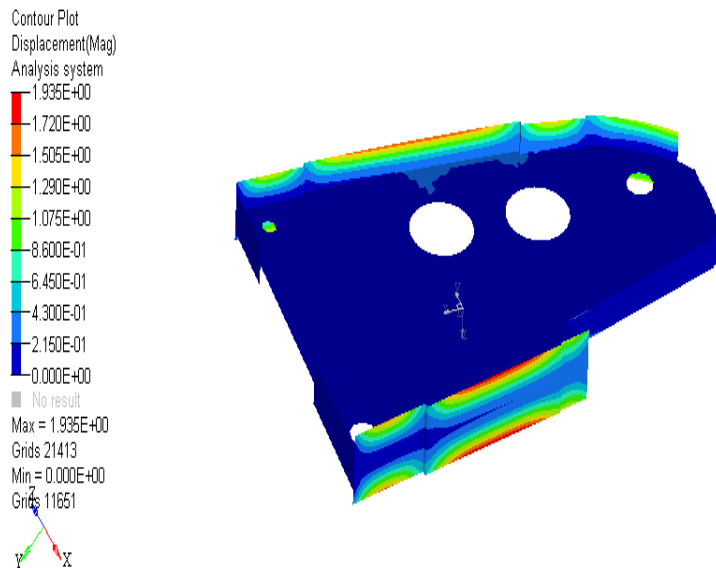


Fig 7: The value of Displacement is 1.935 mm

The value of stress in base model is 2.378×10^2 is converted into is 237MPa

5. Results of Base Model Aircraft Rib Wing

5.1 Displacement

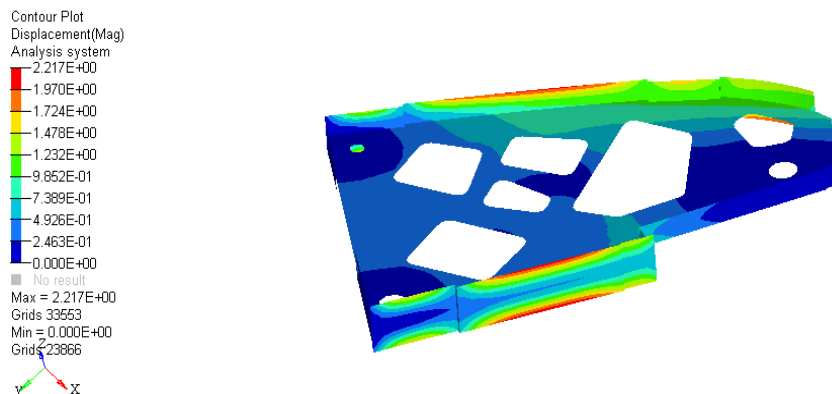


Fig 8: displacement for optimized model is 2.217 mm

The value of stress in optimized model is 2.355×10^2 is 238 Mpa

6. Optimized Model Results

Optimization is completed and results are taken 6 iterations to complete the thickness and topology optimization.

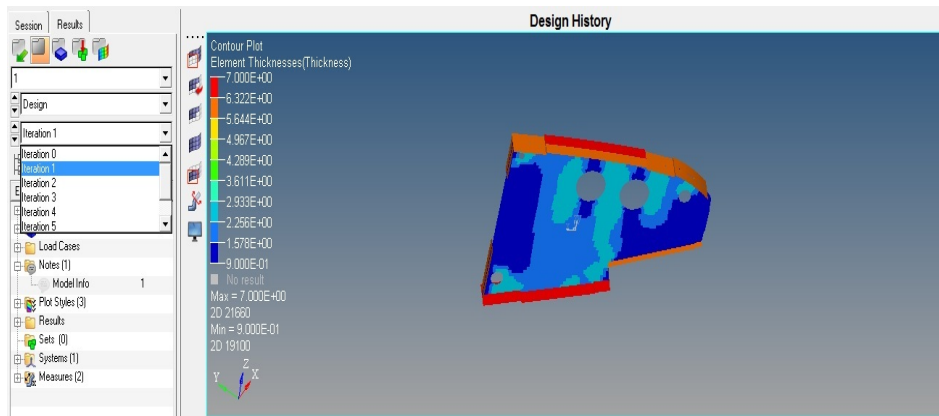


Fig 9: Iterations for free Size optimization

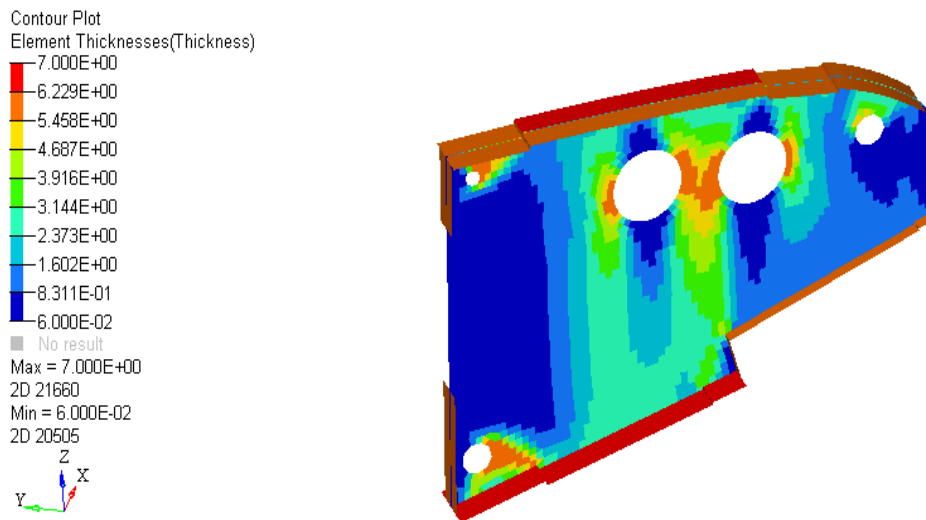


Fig 10: Thickness optimization is given perfect results for the given loads.

Topology method using Optistruct is shown in above figure, steps are involved is same like free size optimization. Response is given for volume fraction as 0.3% from the total volume and weight compliance as a objective which will reduce the weight of the component by giving innovative shape to wing.

Topology optimization problem setup takes 17 iterations to solve and to give innovative design to develop wing ribs in same shape for production.

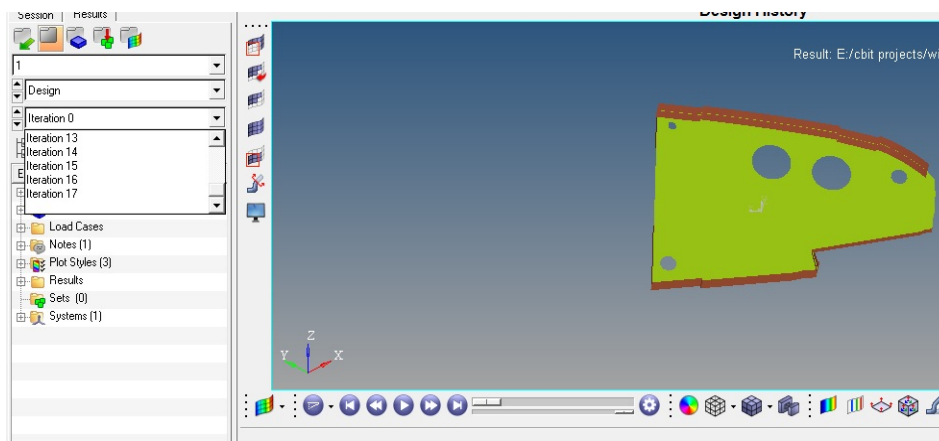


Fig 11: Iterations for topology optimization

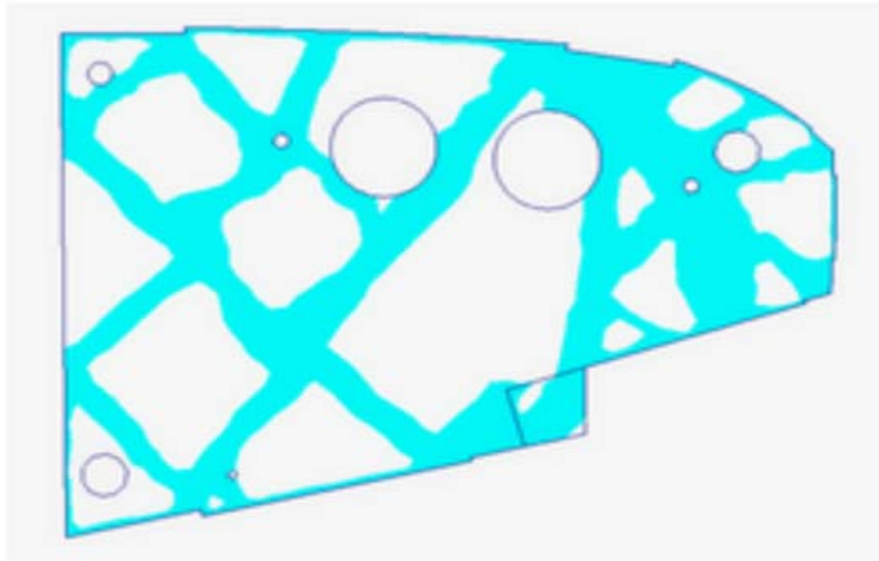


Fig 12: Topology Shape given by Optistruct Software

After getting thickness and topology results redesign of model is designed in CATIA V5R19 software and submitted for

production and manufacturing of Wing Rib structure.

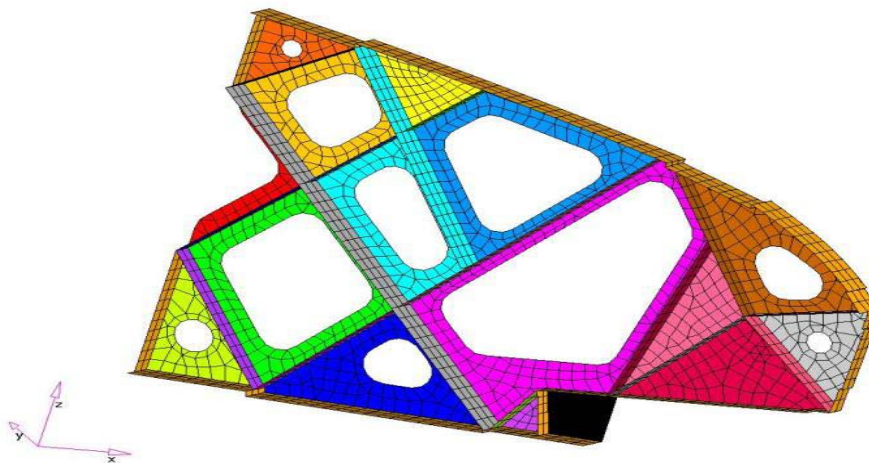


Fig 13: Final Shape and thickness are applied as mentioned in Free Size optimization result.

7.0 Comparison of Results

7.1. Stress Comparison for Two Models

Table 1: Stress comparison for two models

Contents	Base Model	Optimized Model
Stress(Mpa)	237	238
Displacement(mm)	1.93	2.21
Mass(kg)	28	24

The above table shows the comparison of stress, displacements and mass of two models, which is below the yield point value of Aluminium 2024-T3 material

Optistruct software was developed to produce an innovative rib design, which resulted in an optimized weight saving over 500kg per aircraft.

Wing Rib will sit in aircraft wing structure as shown in below figure

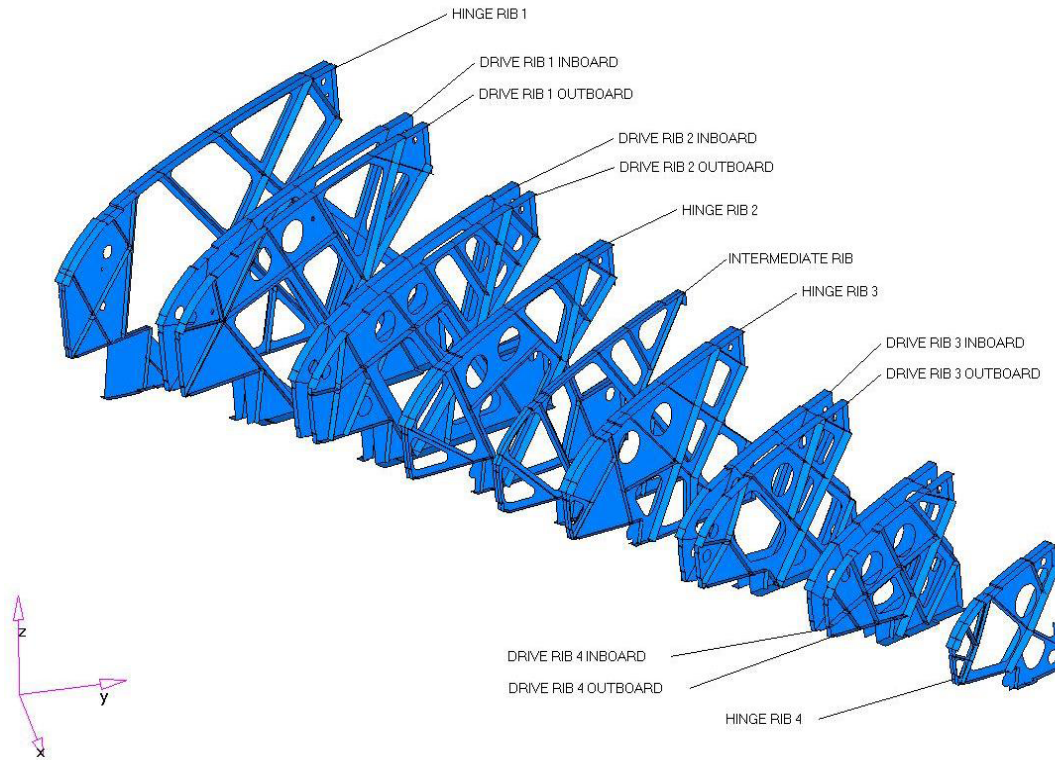


Fig 14: Wing Ribs will Sit in to aircraft wing assemble.

8. Conclusion

The present work illustrates how topology, sizing and shape optimisation tools may be used in the design of aircraft components. The technology has been successfully used in an industrial environment with short industrial time scales and has on a single application proved to be able to provide efficient stress and stability component designs.

Initial studies have shown that care should be taken in the modelling of the load and boundary conditions of the components. For aircraft component design it is also important to be aware of the impact of changing loading situations. The truss type designs obtained using the topology optimisation are highly specialised designs optimised for certain loading situations.

Load definitions generally change as the design of an aircraft mature, and this could seriously affect the optimality of the structure. It could therefore prove important to carefully select applications for topology optimisation and only use the technology on structures with well defined loading conditions. The variation of pressure is induced in optimized model compared to base model as per the requirement of below yield point stress which is 325 Mpa and as well as the variation of displacement is induced in optimized model compared to base model which is lower than the 3 mm as per the requirement.

As per the given requirement the reduction of weight is 16% decreased compared to reference model. Hence the cost analysis also reduces by using the base model and optimized model readings.

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