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Design and Development of Aircraft Wing RIB Optimized Weight Saving Using Optistruct

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Abstract: This master thesis work 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. Aircraft conceptual design is inherently a multi-disciplinary design process which involves number of disciplines and expertise. In this thesis work, it is investigated how high-end CAD software's can be used in the early stages of an aircraft design process, especially for the design of an aircraft wing and its structural entities wing spars and wing ribs. 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 V5Software. A performance comparison of the generic wing model based on these two approaches is also performed.

Keywords: CAD, EKL (Engineering Knowledge Language), CATIA V5Software.

I. 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 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

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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 optimisation 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 optimisation 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.

A. Motivation

The generic aircraft wing model offers a series of advantages and thus provides a motivation for its development. Some of the advantages provided by a generic aircraft wing model are listed below,

- Single model is able to represent different aircraft wing platform and configurations
- Automated CAD geometry generation
- Automated finite element mesh generation
- Less file management
- Faster start-up time for modelling & analysis
- Lower costs

II. LITERATURE SURVEY

The aircraft wings are the primary lift producing device for an aircraft. The aircraft wings are designed aerodynamically to generate lift force which is required in order for an aircraft to fly. Besides generating the necessary lift force, the aircraft wings are used to carry the fuel required for the mission by the aircraft, can have mounted engines or can carry extra fuel tanks or other armaments. The basic goal of the wing is to generate lift and minimize drag as far as possible. When theairflow passes the wing at any suitable angle of attack, a pressure differential is created. Aregion of lower pressure is created over the top surface of the wing while, a region of higherpressure is created below the surface of the wing. This difference in pressure creates adifferential force which acts upward which is called lift. For most aircrafts, where, the wingsare the primary structures to generate lift, the aircrafts wings must generate sufficient lift tocarry the entire weight of an aircraft. In modern commercial, fighter and jet aircrafts, the aircraft wings are not only designed to provide the necessary lift during the different phases of flight, but also have a variety of other roles and functions. In commercial jet aircrafts, the aircrafts wings are used as the primary storage system for the jet fuel required for the flight. The jet fuel is normally carried in a structure placed inside the outer surface of the wing called a wing box. The fuel carried inside the wing box directly delivers fuel to the jet engines. Modern commercial airplanes like the Boeing 747 and the Airbus A380 amongst many other aircrafts also have podded engines which are placed on the wing. The fuel inside the wing box feeds these jet engines. The mounting of these engines on the wing produces structural loads as well. In fighter aircrafts, weapon systems, missiles and extra fuel tanks or other armament is normally mounted below the wing surface using weapon-pods. These pods are normally attached to the wing spars running through the wing span. During the flight, the aircraft wing has to deal with aerodynamic, gust, wind and turbulence loads. Also, the aircraft wings have to deal with aero-elastic and structural loads as well.

III. PROPOSED MODEL

A. Modelling Of Wing RIB

The generic aircraft wing model is composed of both the surface and the solid model for wing panels, wing spars and wing ribs. Each wing panel, wing spar and wing ribs also have individual parameters that define the geometry and shape of each element, furthermore, there are also global parameters which control the number of wing panels, spars and ribs as well as the mesh characteristics. Whenever, a new wing panel, a wing spar or a wing rib is added into the model, a join which already exists in the model is updated with the new geometry. These joins are connected to each individual surface mesh for wing panels, wing spars and wing ribs. In order to ensure, that all the mesh elements are properly connecting at the nodes of the aircraft model, projections are required for generating the mesh in the correct fashion. This is done by defining three intersections between the join surfaces. These are Intersection between Wing and Spars, intersection between wing and ribs and intersection between spars and ribs. These projections are then used to correctly define the surface mesh for wing panels, spars and ribs. In order to perform the structural analysis, 2D properties, materials, loads and restraints are required. A 2D property adds thickness to the surface. Different types of loads and materials can be applied to the wing structure. The 2D property for each surface is linked with a material as well.

B. Generic Aircraft Structural Wing Model

The generic aircraft structural model is developed by knowledge pattern using EKL (Engineering Knowledge Language), Visual Basic scripting and geometry automation tools and features that are available in CATIA V5 CAD software. The generative structural analysis and Advanced meshing tools workbenches available in CATIA V5 software are used to perform the structural analysis and automated mesh generation of complete aircraft wing geometry. The aircraft structural wing model is made up of different elements whose number, shape and geometry can be changed by a range of different parameters. The aircraft wing model includes,

- Wing Panels
- Wing Spars
- Wing Ribs

IV. RESULTSAND DISCUSSIONS

A. Aerodynamic Load

Aerodynamic load is applied to wing rib and solved results are shown below Figs.1 to 18:

Displacement:

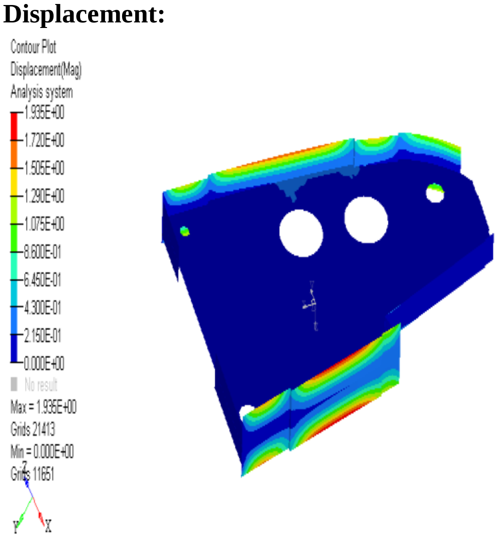

Fig.1. The value of Displacement is 1.935 mm.

Stress: The value of stress in base model is $2.378*10^2$ is converted into is 237MPa. After visualizing the static results optimization will come I the picture to get innovative shape of wing rib. Optimization techniques are shown below, different techniques are explained in brief.

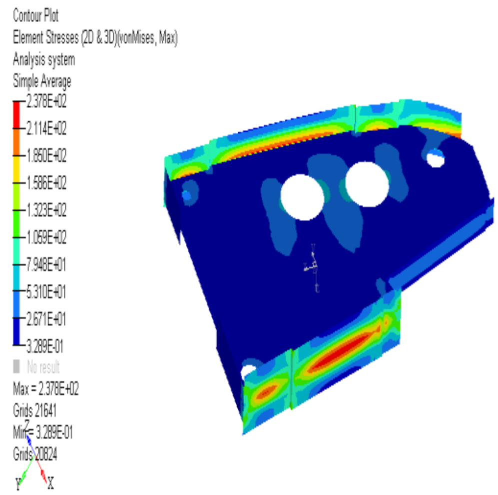

Fig.2. The value of Stress is $2.378*10^2$ MPa.

Number of Nodes and Elements: Go to Tool page-Count-select FE entities- and click on displayed, It shows nodes and elements.

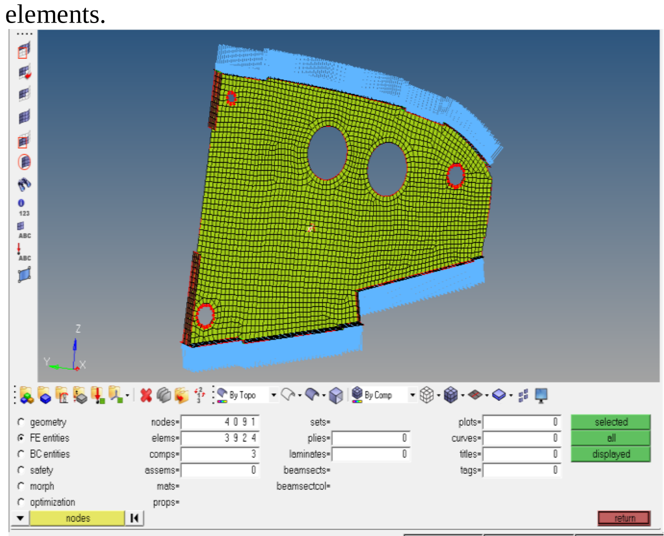

Fig.3. Nodes= 4091 and Elements= 3924.

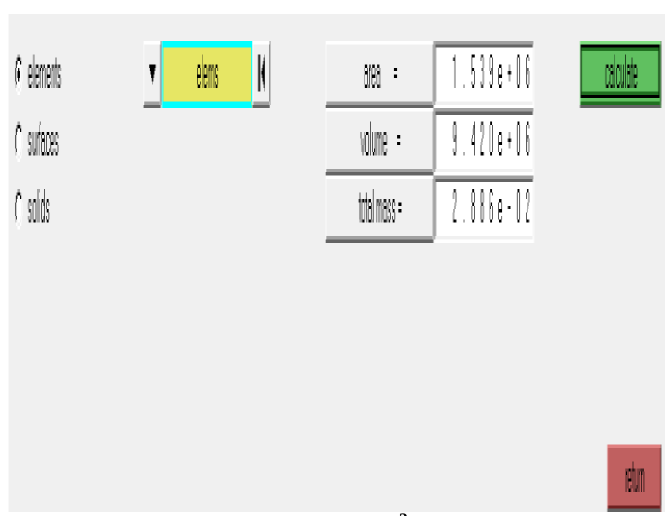

Fig.4. Base model Mass= $2.886*10^{-2}$ tones.

The value of mass in base model is $2.886*10^{-2}$ tones is converted into 28 kg.

Re-Design Of The Optimized Model And Pre-Processing Methodology: Basic reference model is changed to the above design after applying the OptiStruct application to that. Design changes had been generated in Hypermesh using osssmooth option.

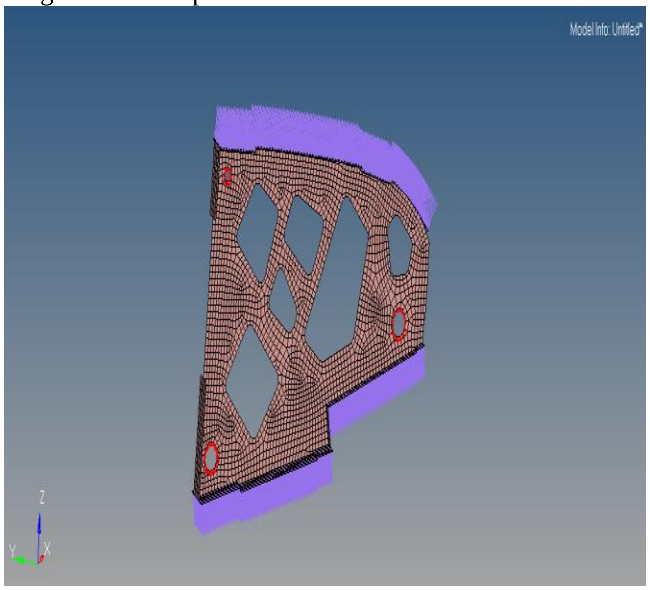

Fig.5. New design of optimized result is meshed in hyper mesh.

To this redesign model we have to assign material, thickness, load step and run the base run analysis as we did for reference model. the thickness to each area with different thickness as per base model. Sheet is having 6mm thickness, flanges in between is having 6mm and upper and lower flanges having 7mm thickness.

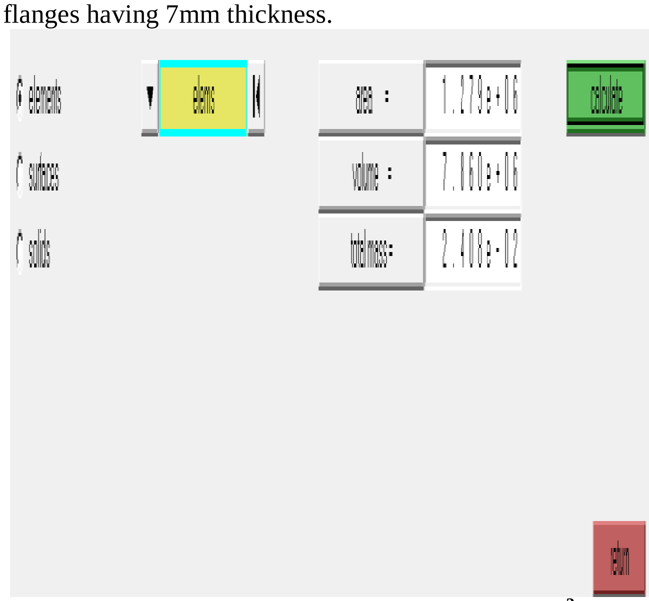

Fig.6. Mass of New Model of wing rib is $2.408*10^{-2}$ tones.

The value of mass in optimized model is $2.408*10^{-2}$ tones is converted into 24 kg5.5.

B. Results Of Base Model Aircraft Rib Wing Displacement:

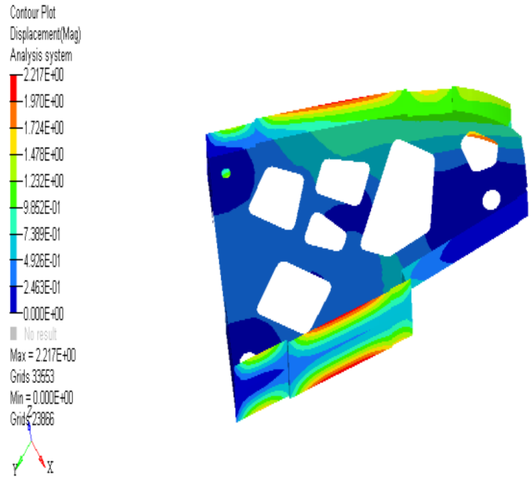

Fig.7. Displacement for optimized model is 2.217 mm.

Stress:

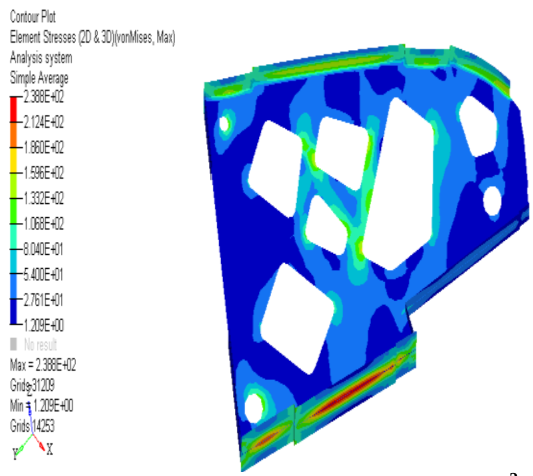

Fig.8. Stress for optimized model is $2.355*10^{2}$ tones.

The value of stress in optimized model is $2.355*10^{2}$ is 238 Mpa.

C. Optimization Process

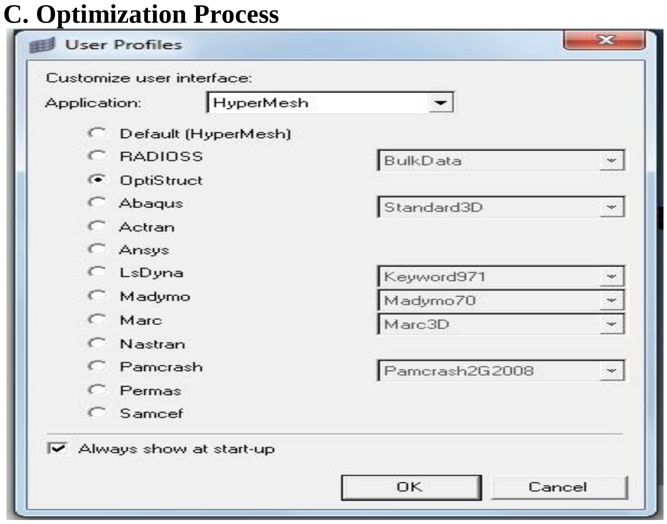

Fig.9. User profile to solve Optistruct.

Optimization is done to the control arm model the steps of optimization technique are mentioned below. First step is user profile should change to Optistruct in hypermesh interface. By using above option weight and free size is optimized and solved using Optistruct and seen the analysis results.

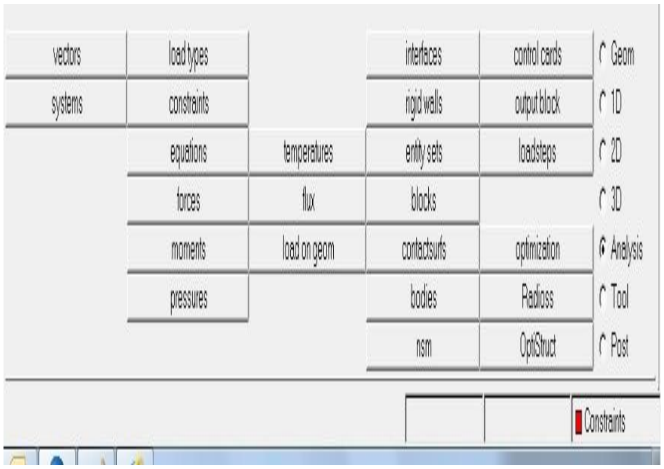

Fig.10.Optimization problem setup in Analysis page.

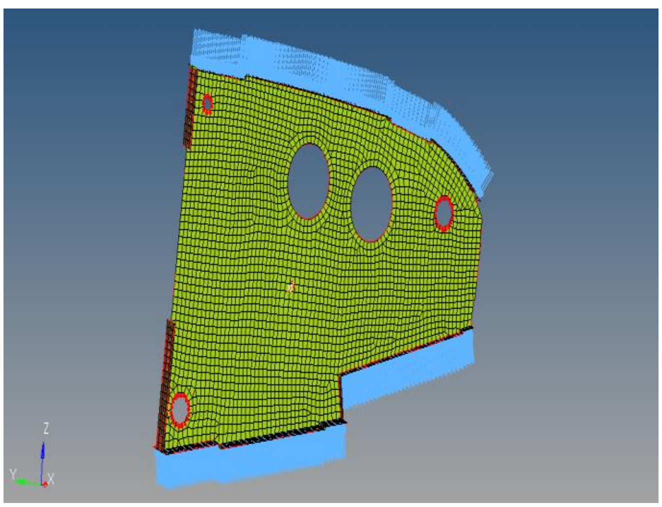

Fig.11. Design area is green colour area and non design area is flanges.

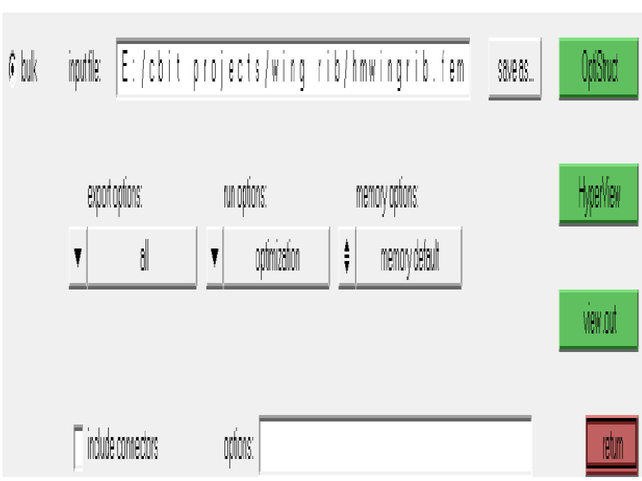

Fig.12.Optistruct Solver Window in Hypermesh.

D. Optimized Model Results

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

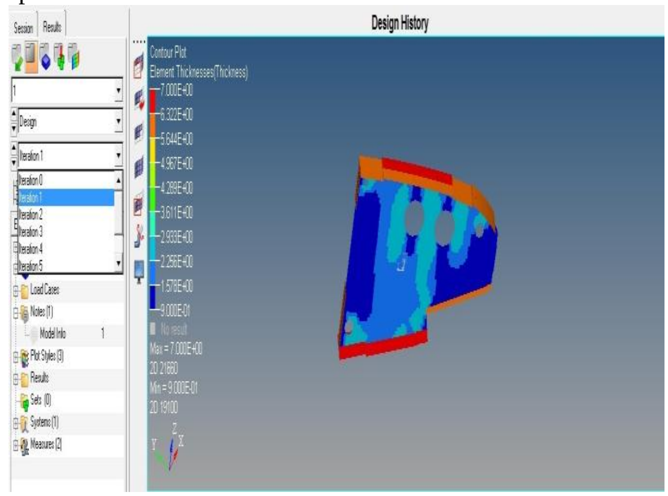

Fig.13. Iterations for free Size optimization.

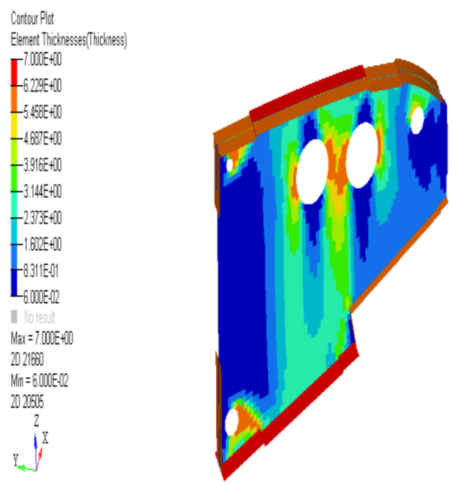

Fig.14. Thickness optimization is given perfect results for the given loads.

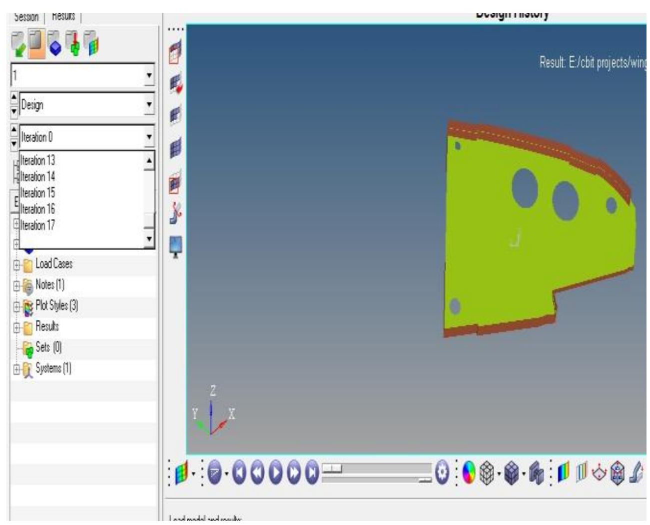

Fig.15. Iterations for topology optimization.

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.

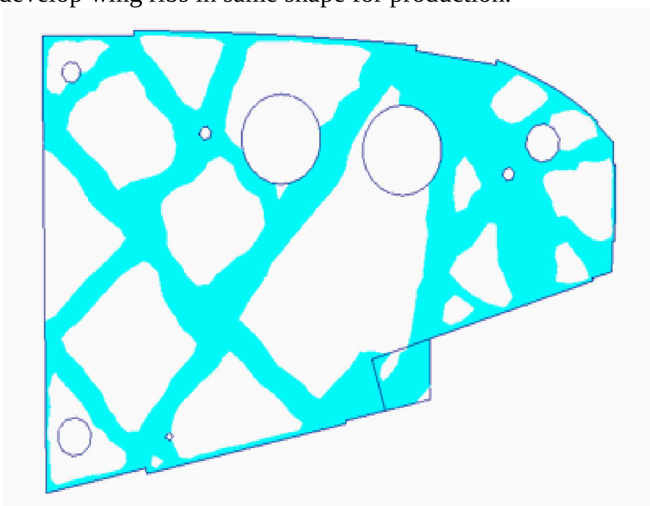

Fig.16. Topology Shape given by Optistruct Software.

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.

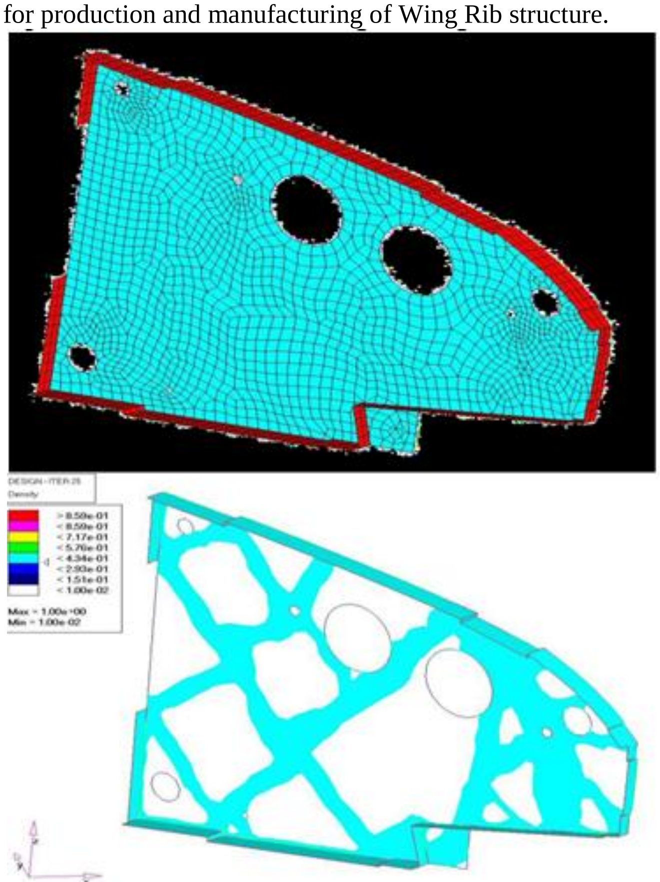

Fig.17. Compared Base model and optimized Shape.

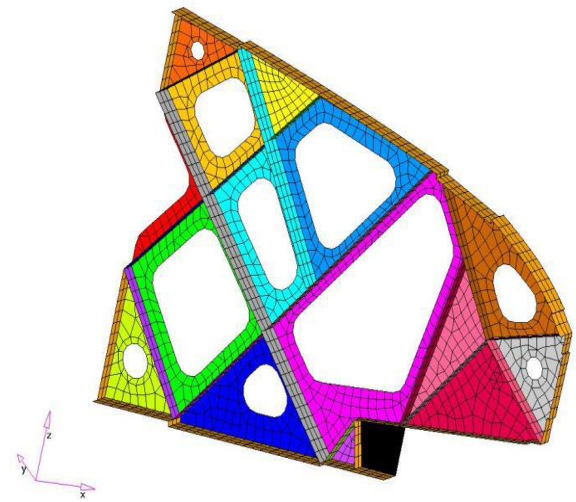

Fig.18. Final Shape and thickness are applied as mentioned in Free Size optimization result.

Ideally, all of the dimensions of the truss-member cross-sections as well as the shear web thickness should be allowed to vary as design variables in the optimisation, allowing a detailed optimisation of the in-plane and out-of-plane stability of the ribs. In practice the height/thickness of the vertical stiffeners were allowed to vary, but only the thickness of the horizontal segments. Allowing the width of the horizontal segments (w1 and w2) to vary would involve changing the shape of the cut-outs in the ribs, and design variables would have to be linked to ensure for example that the vertical stiffeners remained along the centreline of the truss-members. With the current shape optimisation pre-processing tools for OptiStruct this would have been time consuming to set up, and with the short time scales of the project this complexity was not implemented. Having constructed finite element models for detailed sizing and shape optimisation, optimisation was now performed designing for minimum mass with both manufacturing requirements and stress and buckling allowables as design criteria in the optimisation process. For stress, a Von Mises stress allowable was used with a reduction factor for fatigue. For buckling, the design philosophy was not to allow buckling of the structure below ultimate loads. The buckling constraints for the optimisation were defined requiring the buckling load factor in linear eigenvalue buckling to be greater than unity for all ultimate loads. To avoid optimisation convergence problems, due to buckling mode switching, buckling constraints were formulated for the five lowest buckling eigenvalues in each load case.

The optimisation as it stood converged to a feasible design for all thirteen ribs, with the final masses summing to a total close to the weight target specified for the work package. Subsequent to the optimisation, the new rib designs have had to be analysed / tested for several other criteria including local flange buckling, fatigue and birdstrike. Both fatigue tests and machining trials are currently ongoing. Fig.19 shows a prototype rib for the Aircraft droop nose rib.

Fig.19. Present Dummy and trail prototype for Viewing the thickness and optimized model.

E. Stress Comparison For Two Models

TABLE I: 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 Alluminium 2024-T3 material

V. CONCLUSIONS

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 optimization 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 varaiation 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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