International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 04 Issue: 09 | Sep -2017 www.irjet.net p-ISSN: 2395-0072

Structural Analysis and Optimization for Spar Beam of an Aircraft

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Abstract- Spar beam is an I-cross sectioned cantilever beam which is fixed to the fuselage for supporting of the wing. Geometric model of spar beam of a passenger aircraft is done using solid edge ST8 modeling tool. Once the geometry is created as per specification and it is imported to ABAQUS for meshing. This finite element model is imported to ABAQUS explicitly to evaluate the explicit static analysis. Stringers are added on to the beam in order to connect both the segments. And meshing is carried out according to it. The load which will be acting on the beam are given to be as the point load at the center of the fuel and an uniformly distributed load along the face of the beam with one end of the beam been constrained with all degrees of freedom. The obtained results of stress and displacement are tabulated.

Topological optimization is carried out giving the same values as the input and loading parameters. Hence, extra materials from the surface of the spar beam are scooped out.

1. INTRODUCTION

Airframe is the basic structure of the aircraft which carries the load. Aircraft is symbol of a high performance mechanical structure, which has the ability to fly with a very high structural safety record. Aircraft experiences variable loading in services. Rarely an aircraft will fail due to static overload during its service life. For the continued airworthiness of an aircraft during its entire economic service life, fatigue and damage tolerance design, analysis, testing and service experience correlation play a pivotal role. An aircraft is a complex structure, but a very efficient man-made flying machine.

Aircrafts are generally built-up from the basic components of wings, fuselage, tail units and control surfaces. Each component has specific functions and must be designed to ensure that it can carry out these functions safely. Any small failure of these components may lead to a catastrophic disaster causing huge destruction of lives and property. When designing an aircraft, it's all about finding the optimal proportion of the weight of the vehicle and the payload. It needs to be strong and stiff enough to withstand the exceptional circumstances in which it has to operate. Durability is an important factor. Also, if a part fails, it doesn't necessarily result in failure of the whole aircraft. It is still possible for the aircraft to glide over to a safe landing place only if the aerodynamic shape is retained-structural integrity is achieved.

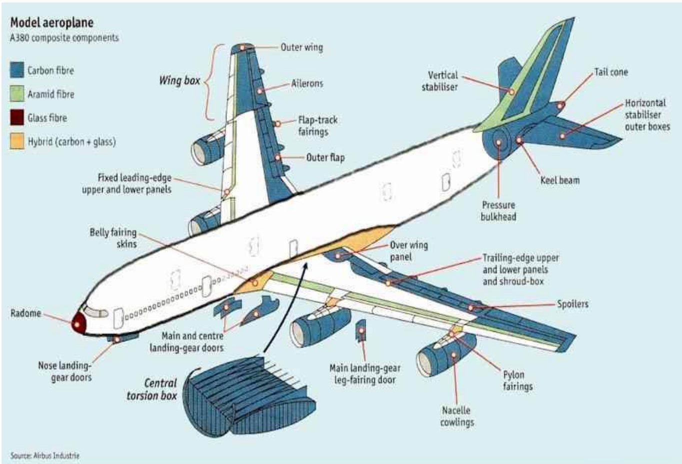

Figure 1.1: Aircraft structure

1.1. Major Parts of Aircraft

A. Fuselage
B. Empennage
C. Wing
D. Landing gears

1.2. Fuselage

The fuselage is the main structure, or body, of the aircraft. It provides space for personnel, cargo, controls, and most of the accessories. The power plant, Wings, stabilizers, and landing gear are attached to it. There are two general types of fuselage construction—welded steel truss and monologue designs. The welded steel truss was used in smaller. Navy aircraft and it is still being used in some helicopters. The monologue design relies largely on the strength of the skin, or covering, to carry various loads. The monocoque design may be divided into three classes—monocoque, semi monocoque, and reinforced shell. The true monocoque construction uses formers, frame assemblies, and bulkheads to give shape to the fuselage.

1.3. Empennage

The empennage also known as the tail or tail assembly, of most gives stability to the aircraft. Structurally, the empennage consists of the entire tail assembly, including the fin, the tail plane and the part of the fuselage to which these are attached. On an airliner this would be all the flying and control surfaces behind the rear pressure bulkhead.

1.4. Wings

Providing lift is the main function of the wings of an aircraft. An aircraft wing is shown in the Figure 1.4. The wings consist of two essential parts. The internal wing, structure, consisting of spars, ribs and stringers, and the external wing, which is the skin. The internal structure of an aircraft wing is shown in the Fig 1.5. Ribs give the shape to the wing section, support the skin (prevent buckling) and act to prevent the fuel surging around as the aircraft maneuver's. They serve as attachment points for the control surfaces, flaps, undercarriage and engines. The ribs need to support the wing-panels, achieve the desired aerodynamic shape and keep it, provide points for conducting large forces, add strength, prevent buckling, and separate the individual fuel tanks within the wing.

1.5. Landing gears

Landing gear is the undercarriage of an aircraft or spacecraft and is often referred to as such. For aircraft, the landing gear supports the craft when it is not flying, allowing it to take off, land and usually to taxi without damage. Wheels are typically used but skids, skis, floats or a combination of these and other elements can be deployed depending both on the surface and on whether the craft only operates vertically (VTOL) or is able to taxi along the surface. Faster aircraft usually have retractable undercarriage, which folds away during flight to reduce air resistance or drag.

1.6. Material

Mild metallic is used for the layout of torque container beam column. It's far an Iron-carbon alloy containing less than 0.25 percentage carbon which makes it more ductile and much less hard as a result rendering it flawed for structural work.

2. Problem Definition

To maintain its all-important aerodynamic shape, a wing must be designed and built to hold its shape even under extreme stress. Basically, the wing is a framework composed of spars the main members of the wing. They extend lengthwise of the wing and crosswise of the fuselage. The entire load carried by the wing is ultimately taken by the spars. In flight, the force of the air acts against the skin. From the skin, this force is transmitted to the ribs and then to the spars. Spars carry shear forces and Bending moments of the wing. Ribs provide buckling strength and serve as attachment points for the control surfaces, flaps, under carriage and engines.

The current study is aimed to design and validate tapered spar beam for the high altitude flight loading conditions. Stress, strain and displacements of the wing structures are studied using commercial software of Finite Element Analysis. The results shall be compared with the allowable strength of the material.

3. Methodology

The basic step is to create a geometric model of a tapered spar beam structure of a transport aircraft using SOLIDE EDGE ST8 modeling tool. Once the geometry is created as per specifications it is imported into ABAQUS CAE for messing. The finite element model is prepared by meshing it with appropriate elements like linear hexahedral, contact elements and constraining the model by applying material properties and boundary conditions. This finite element model is imported to ABAQUS to conduct static and structural analysis. And Optimization of Tapered spar beam by using optimization software "TOSCA" is carried out for optimizing weight of spar beam. Finally the results are viewed by using ABAQUS software and these results are interpreted.

4. Geometric Modeling

The geometric model of a section of the Spar beam. The modeling has been done using SOLIDE EDGE ST8 modelling software. Since, the model which has been designed can be imported to any analysis software for further iterations of analysis need to be conducted over the specimen this software for drafting will be used.

The dimensions of spar beam are considers from the literature survey. It consists of tapered I-cross section and the length of beam is 3.25m. Stiffeners are added to account for Ribs across the beam.

DIMENSIONS

- Beam length = 3250 mm
- Beam height = 162 mm
- Beam height at tapered end = 40 mm
- Web thickness = 8 mm
- Flange thickness = 8 mm
- Flange width = 20 mm

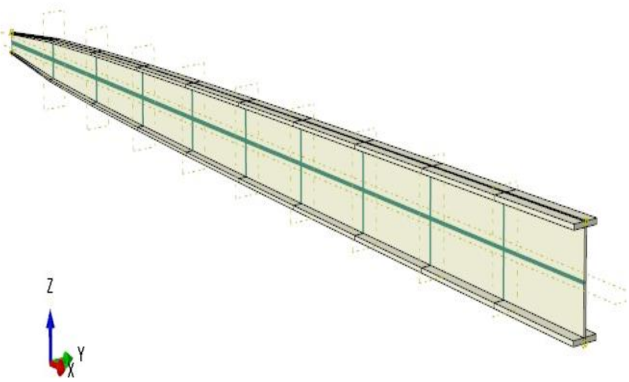

Figure 4.1: Geometric modeling of Spar beam

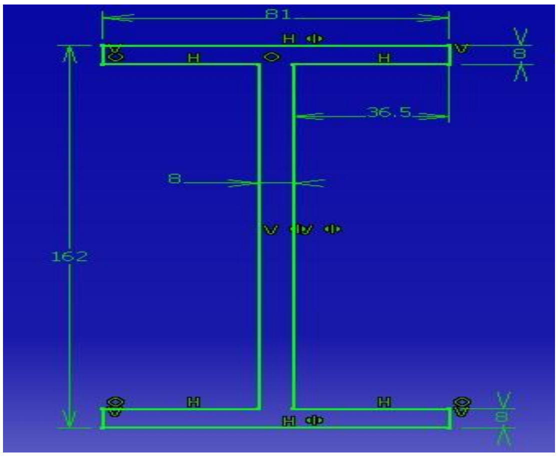

Figure 4.2: Section of a wing spar

4.1. Meshing

These elements are selected because the quadratic result interpolation at the integration point. Table 3.1 gives the count of number of elements and nodes.

Here the meshing is done by two kind of elements like linear line elements of type B31 and linear hexahedral element of type C3D8R in order to increase the details and to study the response of each individual element and behavior under standard boundary conditions.

The simplest solid element of the Iso-parametric hexahedral family is the 8-node hexahedron, often abbreviated to Hex8. It is often referred to as “brick” in the FEM literature. The following developments assume linear elasticity.

Alongside there is a need for the linear line elements of type B31 for the stiffeners which are added on to account of ribs.

Figure 4.3: Mesh model of Tapered Spar Beam

4.2. Loads and Boundary Conditions

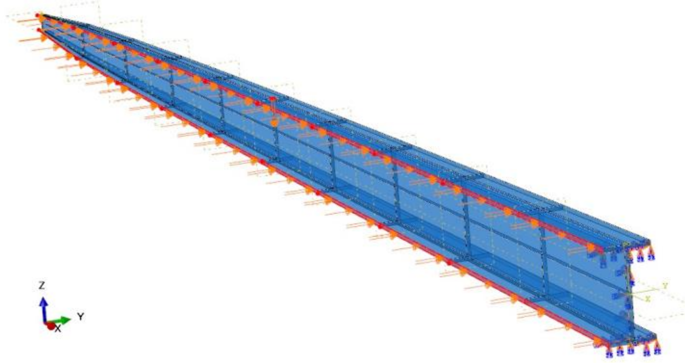

Figure 4.4: Loads acting on the spar beam

Wing pressure load data is calculated based on available standards for typical civil airlines with a cruise altitude of ~12 km. The area is marked in the figure. This gives us a reference pressure value of 4000 Pa. This is for a aero foil leading edge area. Assuming an equivalent of beam height cylindrical area, wing load is calculated as below. This load is distributed as pressure on beam.

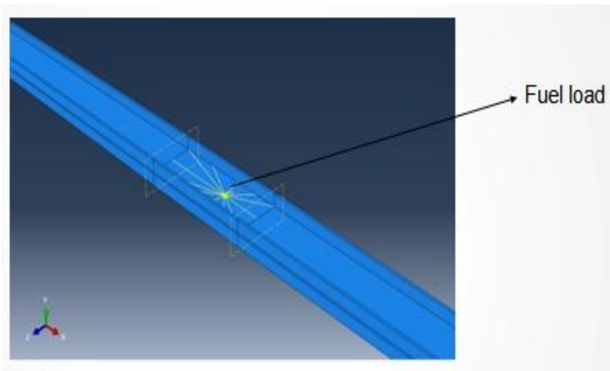

Figure 4.5: boundary conditions

we consider our plane to be as a typical passenger carrier private plane the fuel tank will be loaded on to the mid span of the spar beam as this will has a mass and occupies space it will have an effect of gravity on itself and tends to attract the ground at a force of 500 N. which can also be explained as a fuel load.

The load which is been applied here can also be of drop tanks which will be there present on the wings of an aircraft's.

Also in some cases there the turbine or the propellers will be there present on the wing surface which will be resulting a load on the spar beam.

5. Results & Discussion

The Finite Element model of tapered beam spar with loads and boundary conditions was run for analysis in ABAQUS software. After the consideration of all the physical and theoretical conditions of the beam the following figures give the results of dual condition of static analyses. For static analysis displacements and stresses which would be acting on the beam are obtained.

5.1. Linear Static Analysis

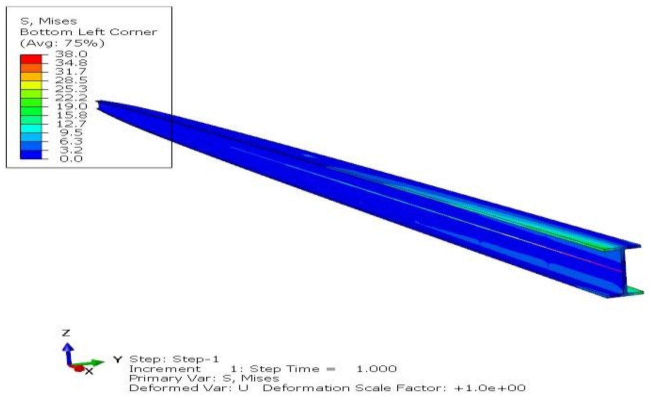

Figure 5.1: stress in the spar beam

From the figure above shows that the nonlinear analysis gives the Max stress of 38.0 MPa near the fixed side of the spar beam and the stress reduces along the length of the spar beam.

Theories suggests that the stress will be maximum at the fixed end and due to this reason the fixed end which will be larger when compared with the free end with respect to its cross-sectional area will be experiencing and higher stress value.

Henceforth, there this spar beam follows the hooks law and thus a maximum stress value of 38.00 Mpa can be developed at the fixed end.

The obtained value of stresses at the loading condition of the spar beam lies below the safety limit of operation in a passenger aircraft.

5.2. Displacement gradients

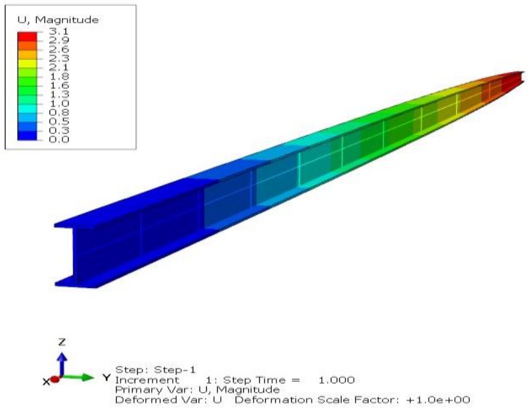

Figure 5.2: Displacement plot for static analysis

Figure 4.1 shows the displacement for the load applied on the tapered beam spar. It is clear from the above figure that the maximum displacement is seen at the free tip of the spar beam, which has the displacement of 3.1 mm.

Since mild steel is elastic in nature it tends to elongate or undergo deformation under the loading conditions, as the result there is an elongation of spar beam up to 3.1mm in length at the free end which will opposite to the fixed end which exhibit nil deformation.

5.3. OPTIMIZATION USING TOSCA

We know that in an air craft industry the main preference which will be given is to for minimization of weight to volume ratio. Because lighter the weight more will be efficiency of the aircraft as well as the durability increases.

There will be many methods involved in development of new ideas wherein which we can minimize the use of extrinsic heavy gauge materials and one among which is the scooping out the unwanted materials from the topology of the spar beam and reduction of its overall volume which hence constitutes for the reduction in the mass.

At the same time care should be taken as to not to affect the structural design of airframe and also its essentials.

In today's highly time constrained product development environment, it is the need of hour for engineers to have equipped with latest technologies to make optimized products in the shortest development time possible. Light weight design, safety, comfort, performance, efficiency and durability are few parameters which are of paramount importance.

As leading technologies for structural optimization, TOSCA structure offer efficient optimization based on industry standard FEA software such as SIMULIA -ABAQUS/CAE.

The Tosca optimization suite built into ABAQUS/CAE platform takes full advantage of any improvement potential while leveraging advanced simulation capabilities. It creates optimized design concepts to achieve the highest performance and quality in shortest development time.

5.4. Topological variations results

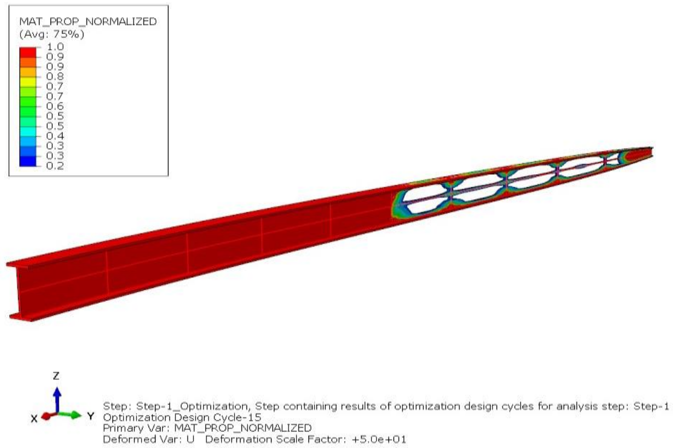

Figure 5.4: topological alterations

One can see a change in the topological features on the surface of the beam. Which is scooped out forming a web shaped structure.

The stiffeners which are added on to the beam are visible and are intact without any changes.

Overall there will be decrease in the volume and the mass of the beam decreases.

CONCLUSION

- Stresses and displacements for the given loads and boundary conditions are found. And these stresses and displacements are within the limits and safe for operation.
- The maximum stress in the beam is found to be 38 MPa which is well within the limits. After the topology optimization, the stress remained same.
- Displacement of 3.1 mm is found near the tapered end which follows the expected bending pattern in static analysis. Topology optimization ensured no change in displacements
- Modal analysis shows first five modes which follow the translation and twisting modes according to the cantilever beam modes
- Since most of the stress is towards the fixed end, the optimization results show material removal in the tapered end.
- Total 40 % of web weight is reduced by this topology optimization process.

SCOPE OF FUTURE WORK

- This experiment can also be conducted for various cross sectioned spar beams like T-section and L-section.
- The material considerations of the spar beam can also be different depends on the nature of the aircraft and its applications.
- By changing the loading and the boundary conditions of the given spar beam, the optimization results could vary

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