OPTIMIZATION PROJECT – AIRCRAFT DOOR HINGE ARM

Finite Element Optimization

TFMASA Course

Under Professor

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1. INTRODUCTION

An aircraft door Is a part of an aircraft for mobility of people or objects for their mobility inside or outside the aircraft. The importance is more of doors in aircrafts as many people are seated inside and safety is a concern to take them out safely. Also, in high altitude due to high pressure difference it is very difficult to operate. So, understanding the working is very important. An aircraft door is of many types such as: Passenger door (type I exit), Galley service door (type I exit), Two over wing emergency exits (type III exit), Flight compartment overhead escape hatch, Cargo door, Avionics compartment door, Aft equipment compartment door. But working is similar with parts like: hinge, actuator, sensors, electronic equipment or signals and much more smaller parts.

In order to construct a five joint link mechanism, a vehicle door opening/closing hinge device consists of an outer link with one end connected to a first pillar pin and the other end connected to a first door pin, an inner link positioned longitudinally apart from the outer link and having one end connected to a second pillar pin, and a connecting link with one end connected to the other end of the inner link and the other end connected to a second door pin. To manage door opening positions, the inner link is made of a guide member with a slot that can be engaged by a third door pin. Since the inner link and connecting link in the door hinge device above occupy a small portion at the door fully closed position, it is possible to enlarge the passenger getting in-or-out space at the passenger's feet at the beginning door open position, and smoothly and widely open the door to the door fully open position to provide a wider passenger's space. In general, an aviation door arm hinge serves as the door arm's pivot point, enabling the door to open and close securely and smoothly while also preserving the aircraft's structural integrity.

Topology optimization is a mathematical method that can optimize the material layout in each design space for a set of given loads, boundary conditions, and constraints, and then let the design meet the given conditions (loads, boundary conditions, constraints) for the optimized performances. The difference between topology optimization and shape optimization or size optimization is that the design can obtain any shape in the design space. Topological optimization typically employs the finite element method to evaluate design performance. Topology optimization objectives might be to minimize the compliance of the part, i.e. to maximize the stiffness of the part, as compliance is the inverse of the stiffness; the constraints could be the maximum allowable deformation, the maximum mass fraction and so on. The topology optimization tools generate a complex natural shape that shows the removal of materials based on the objectives and constraints set in the design problem. The design is then finalized on CAD software to get smooth and manufacturable part following the shape generated from the topology optimization process.

In this research the analysis and optimization of the aircraft door arm hinge and actuator has been performed. The model used already designed and provided for research to be done. This will result in providing very good functions and will also reduce the weight of the hinge making it more efficient.

2. MODELLING

The design and mesh of the aircraft door arm hinge has been already performed. The Fig. 1 represents the hinge arm with the mesh. Also, the nodes of mesh are joined for the arm near the holes at the ends.

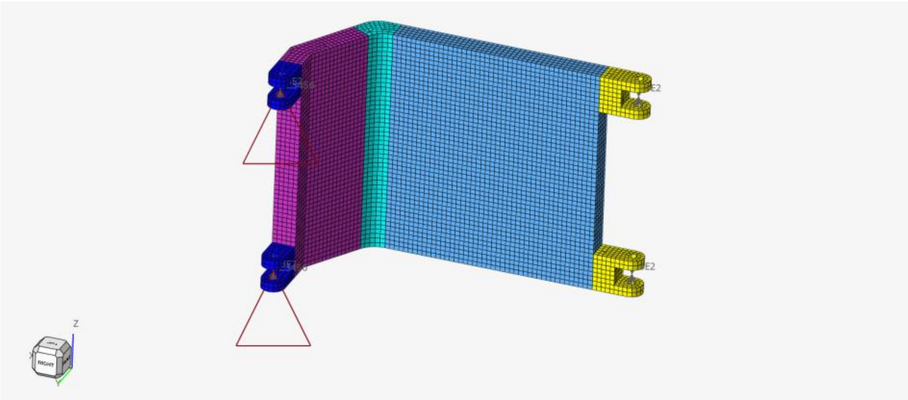

Fig. 1: Aircraft hinge arm design with a mesh

2.1 MATERIALS

The hinge arm has been assigned material properties of an aluminium. The properties of aluminium are defined in the table 1.

Table 1: Material properties of Aluminium

Young's Modulus (E)	Poisson's Ratio (ν)	Density (ρ)
70000 MPa	0.27	2.7×10^{-9} tonne/m^3

2.2 BOUNDARY CONDITIONS AND LOADS

The hinge arm before being analysed it has to fixed at small length end as a hinge is going to be supported for the movement of an aircraft door which will act as our boundary conditions for the entire problem.

The hinge arm needs to be analysed for different loads for giving an optimum method to finalize the model. The arm is undergoing through a load of 1000N. Considering different cases where loads can be applied, we consider 7 types of load variation. These loads are applied at the end where the nodes have been joined near the hole. The load variation is:

1. 500 N at both top and bottom of the arm. (Load Case 1)
2. 1000 N at the top of the arm. (Load Case 2)
3. 1000 N at the bottom of the arm. (Load Case 3)

Next cases are for lateral bending

4. 500 N acting at the top and bottom in opposite direction and laterally. (Load Case 4)
5. 500 N acting at top and bottom in opposite direction and laterally opposite to case 4. (Load Case 5)

Next cases are for torque

6. 500 N acting at top and bottom in shear direction. (Load Case 6)
7. 500 N acting at top and bottom in shear direction opposite to case 6. (Load Case 7)

Fig. 2 represents the boundary conditions and all the other loads acting as in the cases mentioned above.

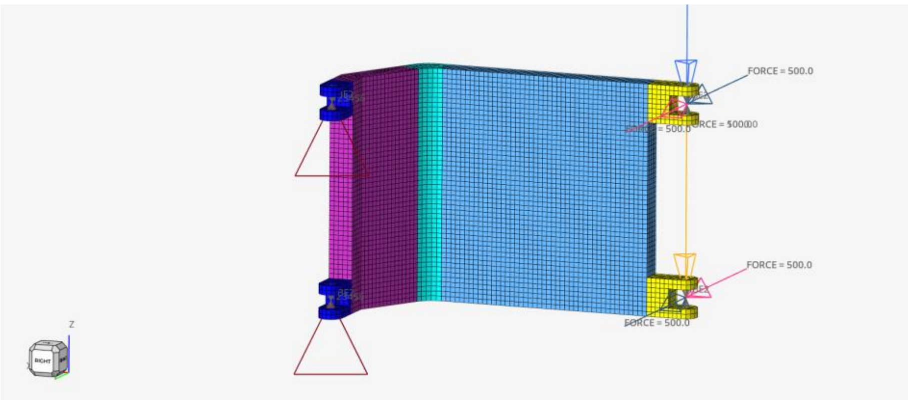

Fig. 2: Door arm hinge with loads and boundary conditions acting

3. ANALYSIS & RESULTS

Hypermesh has an option to run the results for all the load cases available at one simulation. We simulate for static analysis and number of elements for this analysis is found to be 19451 elements. Hence for each load case the model has been simulated giving the results for stress and displacement as shown in table 2. The Fig. 3 represents the stress and displacement for load case 1. The Fig. 4 represents the stress and displacement for load case 2. The Fig. 5 represents the stress and displacement for load case 3. The Fig. 6 represents the stress and displacement for load case 4. The Fig. 7 represents the stress and displacement for load case 5. The Fig. 8 represents the stress and displacement for load case 6. The Fig. 9 represents the stress and displacement for load case 7.

Table 2: Maximum stress and displacement for different load cases

Load Case	Max. Von Mises Stress (MPa)	Max. Displacement (mm)
Load Case 1	6.591	0.1565
Load Case 2	6.592	0.1605
Load Case 3	6.591	0.1606
Load Case 4	21.02	1.1780
Load Case 5	21.02	1.1780
Load Case 6	1.634	0.07821
Load Case 7	1.634	0.07821

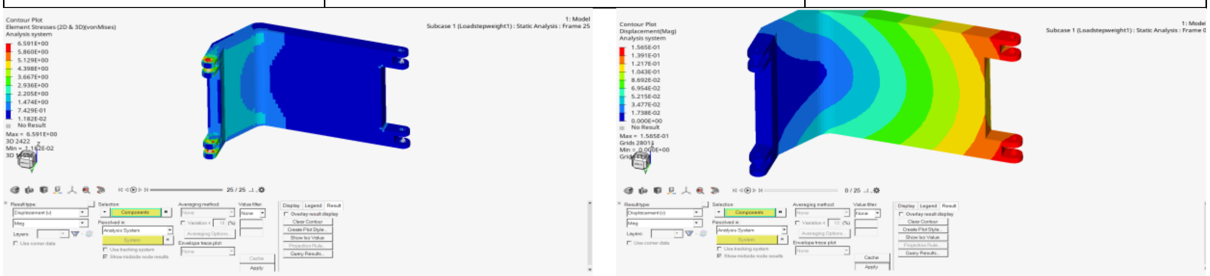

Fig. 3: Stress and displacement contour for load case 1 respectively

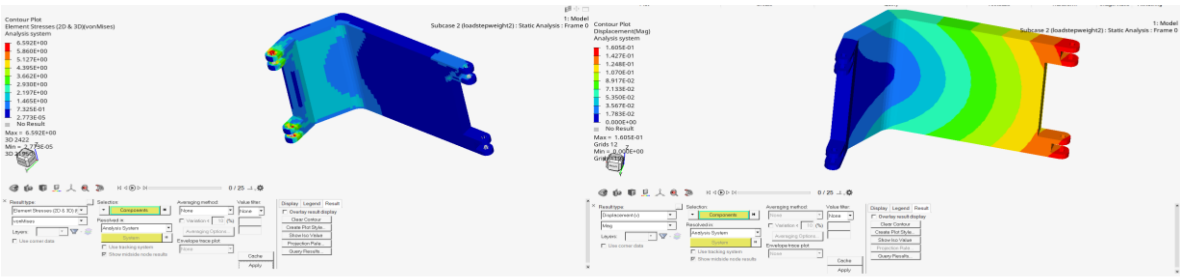

Fig. 4: Stress and displacement contour for load case 2 respectively

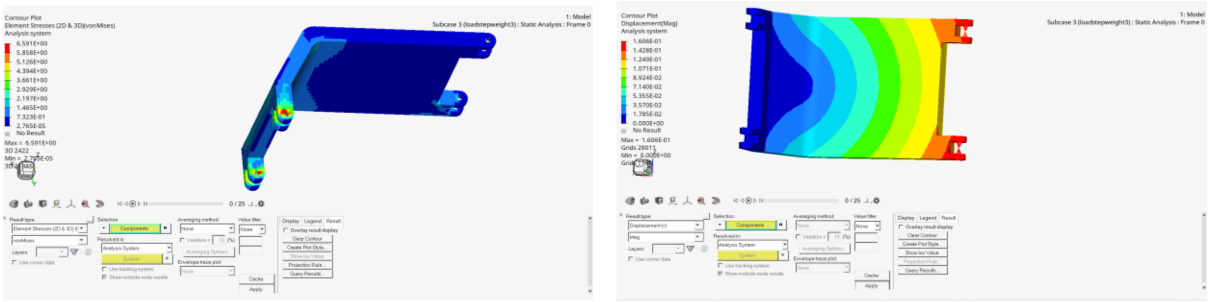

Fig. 5: Stress and displacement contour for load case 3 respectively

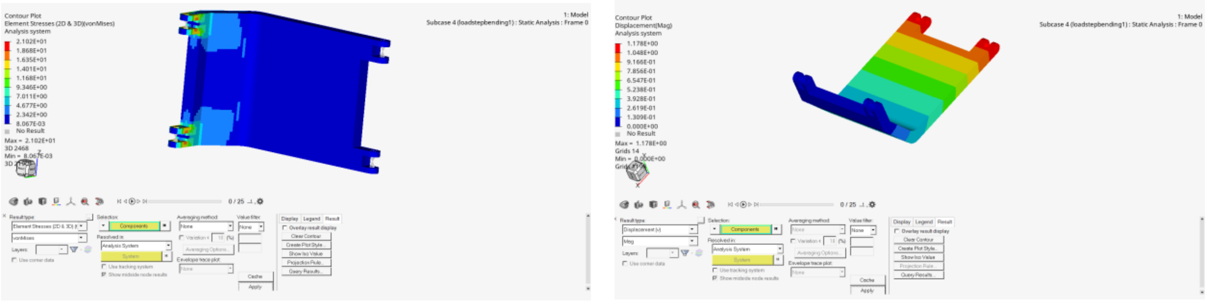

Fig. 6: Stress and displacement contour for load case 4 respectively

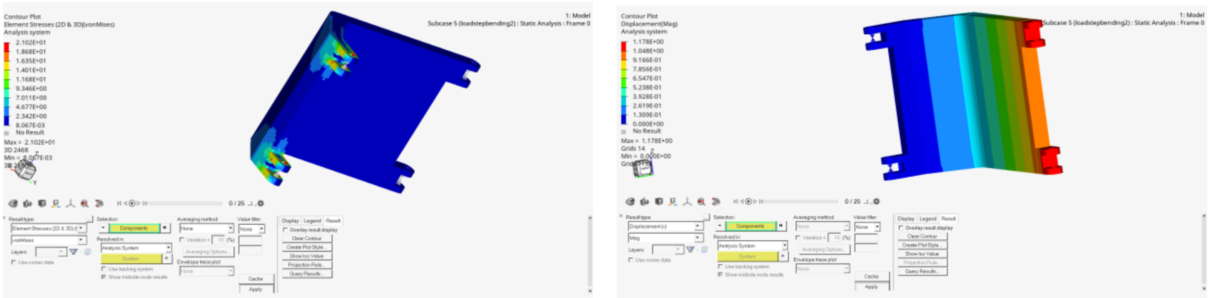

Fig. 7: Stress and displacement contour for load case 5 respectively

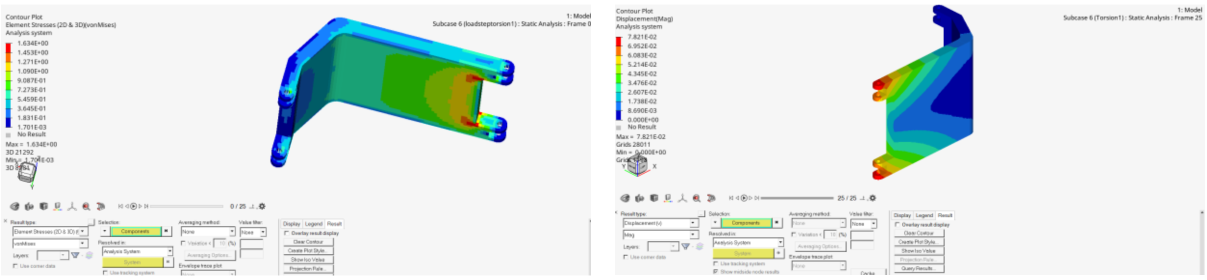

Fig. 8: Stress and displacement contour for load case 6 respectively

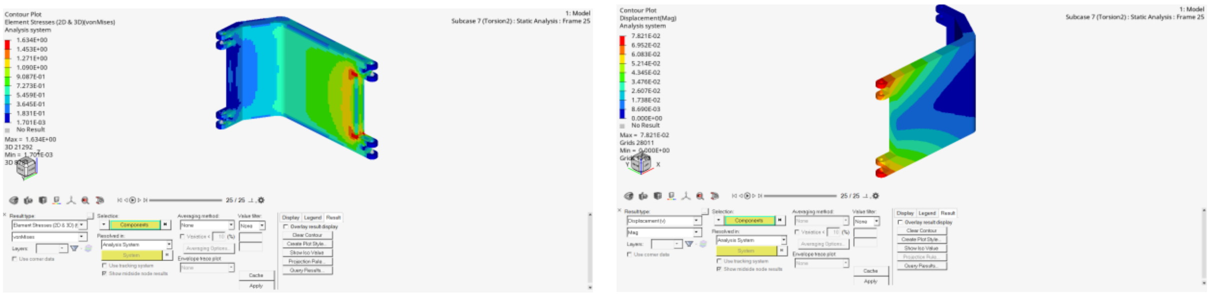

Fig. 9: Stress and displacement contour for load case 7 respectively

4. OPTIMIZATION & RESULTS

Optimization is a process of simulating the structure to find the parts of mass that can be removed to reduce the mass without much change happening to the system due to this change. The optimization technique used is topology optimization.

The optimization in this research is going to go through 3 methods such as:

- No parameters,
- Mindim with 45 and
- Mindim with 45 and anchor points

The topology optimization option is chosen from the optimize ribbon. Then design variables are created in which properties are selected and based on that we optimize for all 3 methods one by one. Then we create response and create a response of mass fraction. Mass fraction is the ratio of optimized mass to original mass. Another response is created for volume fraction. Then constraints are created for volume fraction to assign the upper bound as 0.3, which allows maximum volume retention of 30% of the total volume. And an objective is assigned to minimize the weight.

The optimization is run and following results are obtained with changes in design variables for no parameters, mindim as 45 and mindim as 45 with anchor points. The following results are obtained for density as 0.2 for all the 3 cases. The table 3 represents elements, mass and volume for all the 3 methods of optimization.

Fig. 10 represents the topology optimization with no parameter for the hinge arm, Fig. 11 represents the topology optimization with mindim 45 for the hinge arm and Fig. 12 represents the topology optimization with mindim 45 and anchor points for the hinge arm.

After optimization the process OSsmooth is used to remove the excess material optimally and provide good design based on optimization made for the hinge arm. The Fig. 13, Fig. 14 and Fig. 15 represents the OSsmooth feature after topology optimization for no parameter’s, mindim 45 and mindim 45 with anchor points.

Mindim 45 is used based on the thickness the part generally a value to keep a fixed number of elements based on the part available for optimization. Anchor points generally define the vector in which direction should the structure be cut.

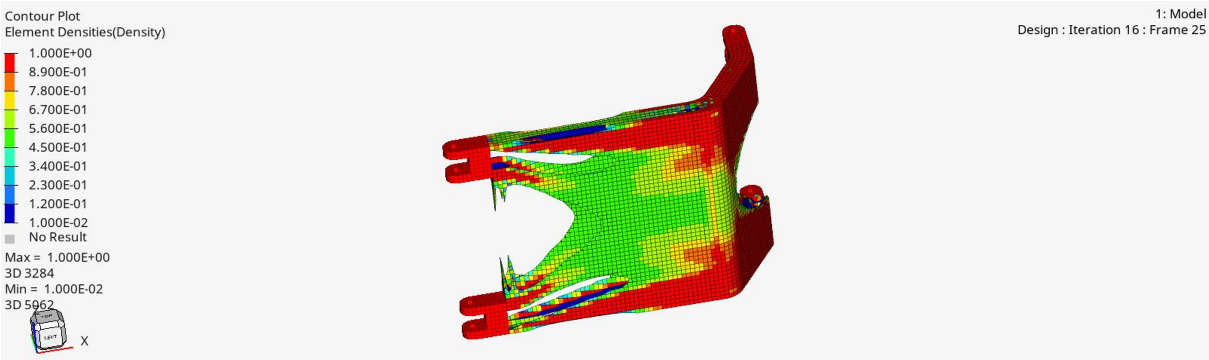

Fig. 10: Topology optimization with no parameter

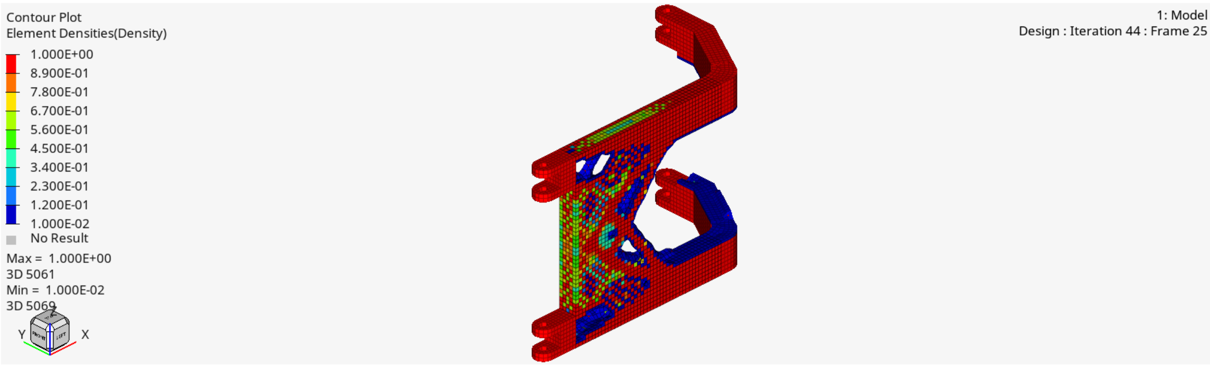

Fig. 11: Topology optimization with mindim 45

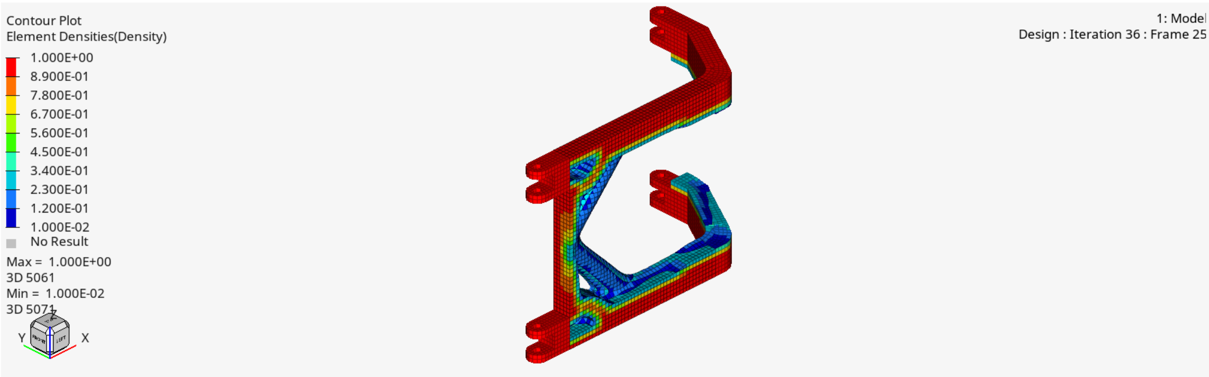

Fig. 12: Topology optimization with mindim 45 and anchor

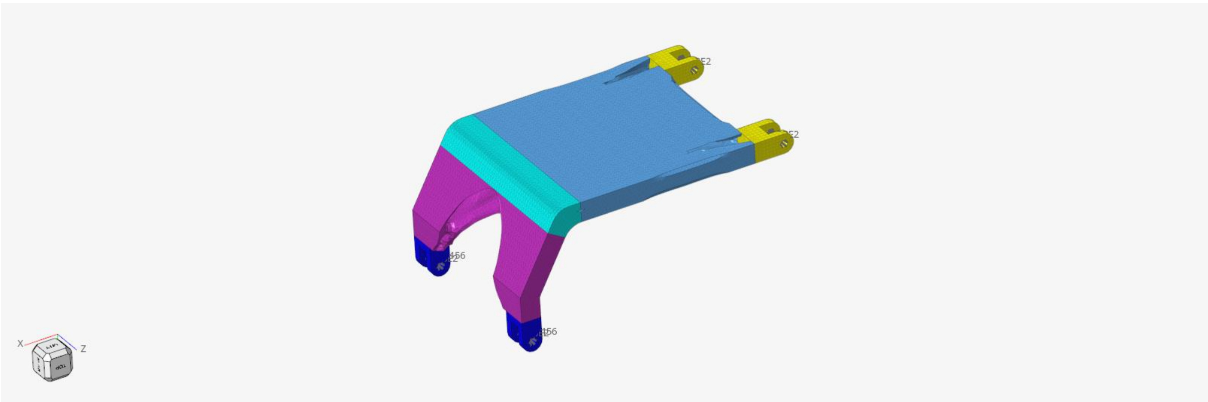

Fig. 13: Topology optimization with no parameter for OSsmooth parameter

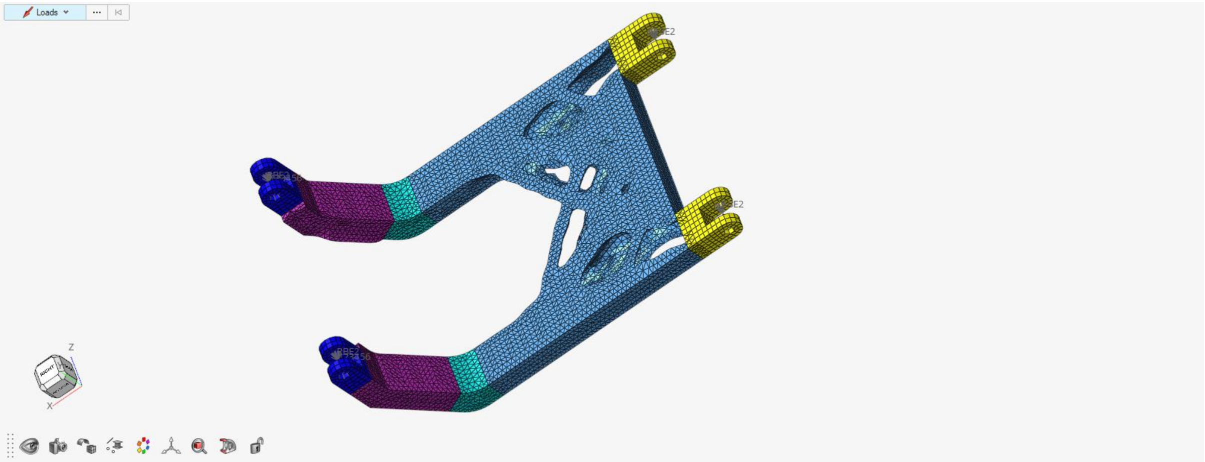

Fig. 14: Topology optimization with no mindim 45 for OSsmooth parameter

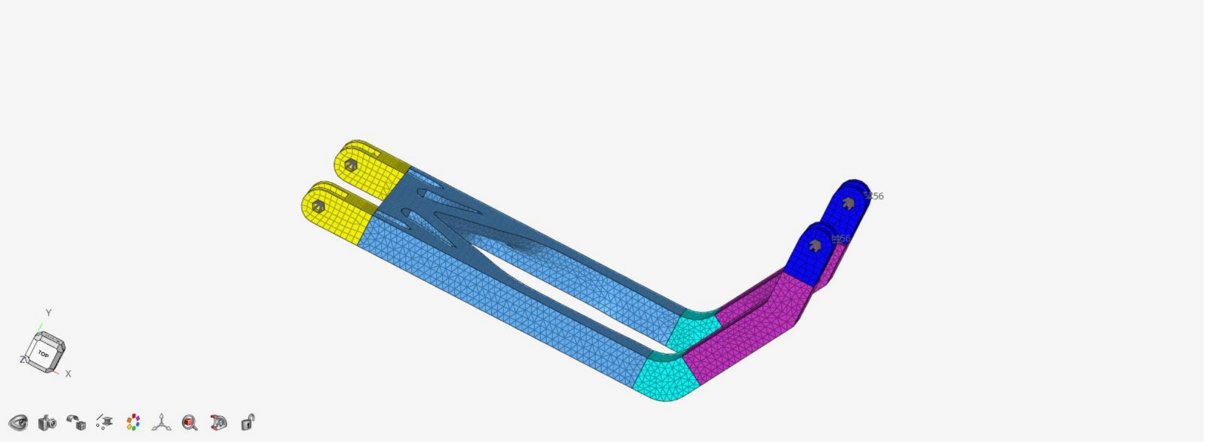

Fig. 15: Topology optimization with mindim 45 and anchor for OSsmooth parameter

Table 3: Optimization results with no. of elements, volume, mass and calculated mass

Optimization	No. of Elements	Volume (mm^3)	Mass (tonne)	Calculated Mass (tonne)= Density ($2.7e^{-9}$)✕ Volume
No Parameters	38902	8696403.38	0.02	0.02348028913
Mindim 45	44440	7841653.79	0.02	0.02117246523
Mindim 45 with anchor	37089	6937816.97	0.02	0.01873210582

5. CONCLUSION

The results obtained for static analysis for different load cases shows that maximum stress is obtained for bending which of magnitude 20MPa and also high values of displacement of magnitude 2 mm and is high compared to other modes. Based on the operation of the arm the bending with this stress for the material is in good agreement and will not affect the system functioning. Hence for analysis as we are aware of maximum failure mode is due to tension which appears in first 3 cases which is of less stress, so the arm can be analysed in good agreement and used for further steps of the production cycle.

The topology optimization performed is to reduce the mass/weight of the hinge arm to make light weight, less cost due to material reduction and will help to lift much more easily by the aircraft for less fuel comparatively. The optimization gave results for no parameters, mindim 45 and mindim 45 with anchor. These results show that maximum mass reduction is found in minim 45 with anchor. Based on manufacturing the type of design variables can be used. For using the manufacturing technique moulding we use the no parameters design, for additive manufacturing we can use mindim 45 and for CNC manufacturing process we can use mindim 45 with anchor. Hence for this research this operation is successfully agreeing with the results. In real life aircrafts have many other hinges attached so emptying so much material can lead to other problems which need to be considered further on.

6. FUTURE ASPECTS

Due to time constraint the following things need to be done to validate the structural analysis of the optimization

- Static analysis of optimized results
- CAD model using the optimized results
- Analysing the CAD model for stress and displacement
- Modal analysis
- Dynamic analysis