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Design and Analysis of Rudder Hinges of an Aircraft

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ABSTRACT

On an aircraft, the Rudder is one of the important directional control surface along with the rudder-like elevator (attached to the vertical stabilizer) and ailerons (attached to the wings) that control pitch and roll, respectively. The rudder is usually attached to the fin (vertical stabilizer) through HINGES which allows the pilot to control yaw about the vertical axis, i.e. change horizontal direction. The components of hinge assembly are hinge Arms, Fork Head, Spar and Panel, hinge Arms are to be designed to take loads from rudder. One end of the hinge arms are attached to Spar (composite) and Panels (Top and Bottom Skin) through fasteners. Other end is connected to Fork head (metallic) through riveting. The scope of the present work is to detailed design of Rudder hinge assembly to meet strength and stability requirements and modelling done by using Unigraphics V10 software. The static stress analysis carried out to find the stresses like Von misses, Maximum Principal, shear stresses for both Metallic and composite materials and also Lug strength check, Linear static analysis, Normal mode analysis, and buckling analysis are covered in the justification of Hinge assembly for the rudder using finite element approach with help of MSC/PATRAN and MSC/NASTRAN software. From the analysis found that maximum von-Misses stress for the critical load is 347MPa is within the allowable yield strength of 350MPa of AL material. The maximum principal stress is 165MPa and is within the allowable ultimate strength of the material 470MPa. Maximum principal stresses for the composite materials (CFRP) are within the allowable limits. FEA of static and hand calculation results are compared and deviation is less than 2%..

Key Words: *Vertical tail, Rudder Hinge, Unigraphics V10, Hyper mesh, MSC PATRAN, MSC NASTRAN*

1. INTRODUCTION

Balanced rudders are used by both ships and aircraft. Both may indicate a portion of the rudder surface ahead of the hinge, placed to lower the control loads needed to turn the rudder. For aircraft the method can also be applied to elevators and ailerons; all three aircraft control surfaces may also be mass balanced, chiefly to avoid aerodynamic flutter. The principle is used on rudders, elevators and ailerons, with methods refined over the years. Two illustrations of aircraft rudders, published by Flight Magazine in 1920,[3] illustrate early forms, both with curved leading and trailing edges. Both are mounted so that the area of the balancing surface ahead of the hinge is less than that of the rudder behind. Various layouts have been tried over the years, generally with smaller balance/rudder areas. Most fall into one of two categories: horn balanced, with small extensions of the control surfaces ahead of the hinge lines at their tips, or inset balanced with extension(s) of the control surface into cut-outs in their supporting fixed surface. The rudder is usually attached to the fin (or vertical stabilizer) which allows the pilot to control yaw about the vertical axis, i.e. change the horizontal direction in which the nose is pointing. The rudder's direction in aircraft since the "Golden Age" of flight between the two World Wars into the 21st century has been manipulated with the movement of a pair of foot pedals by the pilot, while during the pre-1919 era rudder control was most often operated with by a center-pivoted, solid "rudder bar" which usually had pedal and/or stirrup-like hardware on its ends to allow the pilot's feet to stay close to the ends of the bar's rear surface.

In practice, both aileron and rudder control input are used together to turn an aircraft, the ailerons imparting roll, the rudder imparting yaw, and also compensating for a phenomenon called adverse yaw. A rudder alone will turn a conventional fixed-wing aircraft, but much more slowly than if ailerons are also used in conjunction. Use of rudder and ailerons together produces co-ordinated turns, in which the longitudinal axis of the aircraft is in line with the arc of the turn, neither slipping (under-rudder), nor skidding (over-rudder). Improperly rudder turns at low speed can precipitate a spin which can be dangerous at low altitudes.

2. PROBLEM DEFINITIONS

The objective of the study is to design and develop Hinge Assembly to support Rudder of an aircraft. Individual components of hinge assembly are designed and analyzed for their strength and stability. Design and analysis of Hinge assembly involve Finite Element Modeling of Hinge arms, Fork Head, Spar and Panels. The Spar and Top and Bottom Panels are Composite materials and require composite definition and modeling. Only a part of spar and Panels attaching to Hinge arm are modeled which attaches with Hinge Arm. Analysis involve Loads evaluation and Boundary Conditions (BCs) applied on the Hinge structures, Finite Element Analysis (FEA) and hand calculation results to substantiate FEA results. Design modifications and evaluation to meet strength and stability requirements.

3. METHODOLOGY

- Suitable elements are used for metallic and composite parts of rudder hinge assembly in FEA.
- Aircraft loads and loads arising from rudder rotation are according to aircraft standards.
- Stress-Strain and Stiffness based approach are used for the design of individual parts of rudder hinge assembly.
- Aircraft standard methodologies like ESDU (Engineering Sciences Data Unit) calculations, Bruhn approach and Roark's formulas for stress and strains are extensively adopted in design guidelines and calculation of metallic and composite parts.
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4. DESIGN SPECIFICATIONS

Length of Hinge arms = 831.11mm

Thickness of hinge arms = 10.2mm

Radius of Fork head R1 = 25.05mm

Radius of fork head R2= 25.95mm

Skin thickness (t) = 3.5mm

Two hinge arms Angle=35^0

3D Modeling of Rudder Hinge Assembly design by using UG V10 software as shown below figure 1

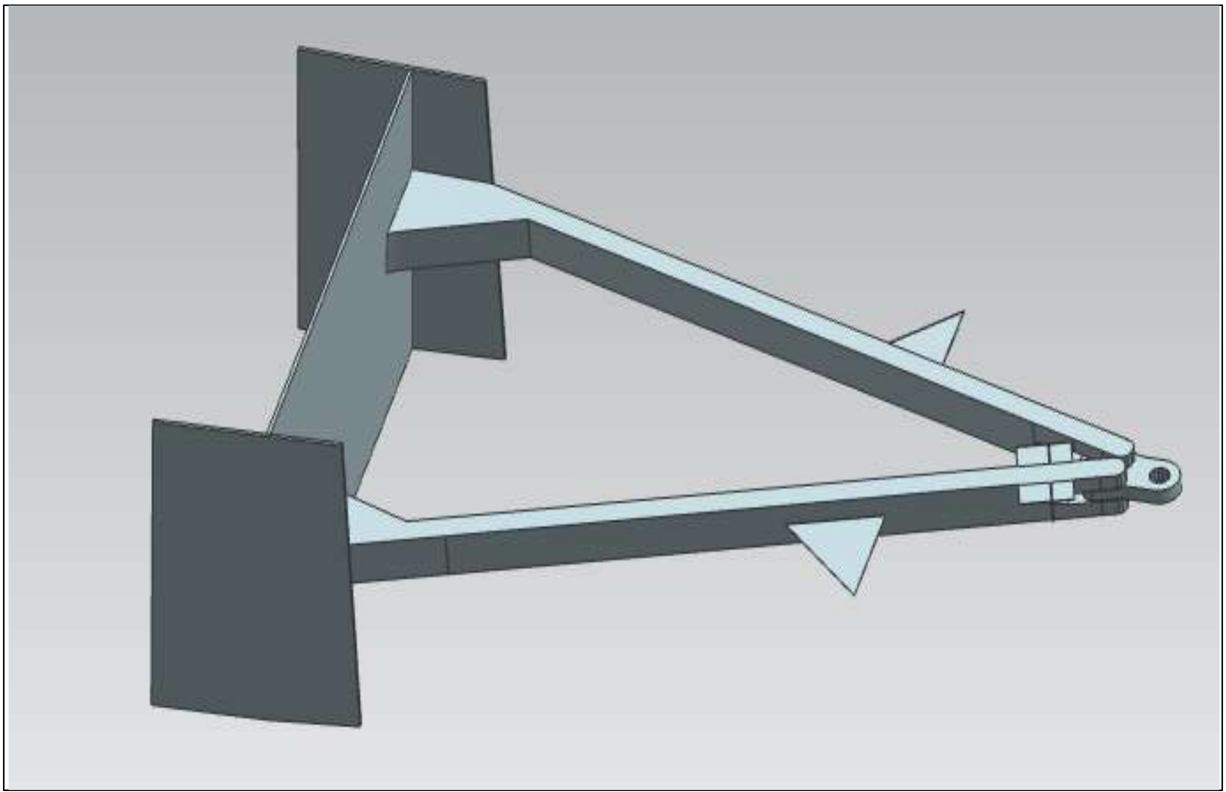

Figure1. 3D modelling of Rudder hinge Assembly of an Aircraft

5. FINITE ELEMENT ANALYSIS

A Meshing Model (FE model)

The rudder hinges consists of 1D and 2D element. The FE model is performed in Hyper mesh software, this Hyper mesh software is a powerful tool in FEA for meshing with simple and complex geometry models are easily mesh using this software. Fine mesh will get from hyper mesh software and big advantage of this software is you can import this model to any pre/post processing software's.

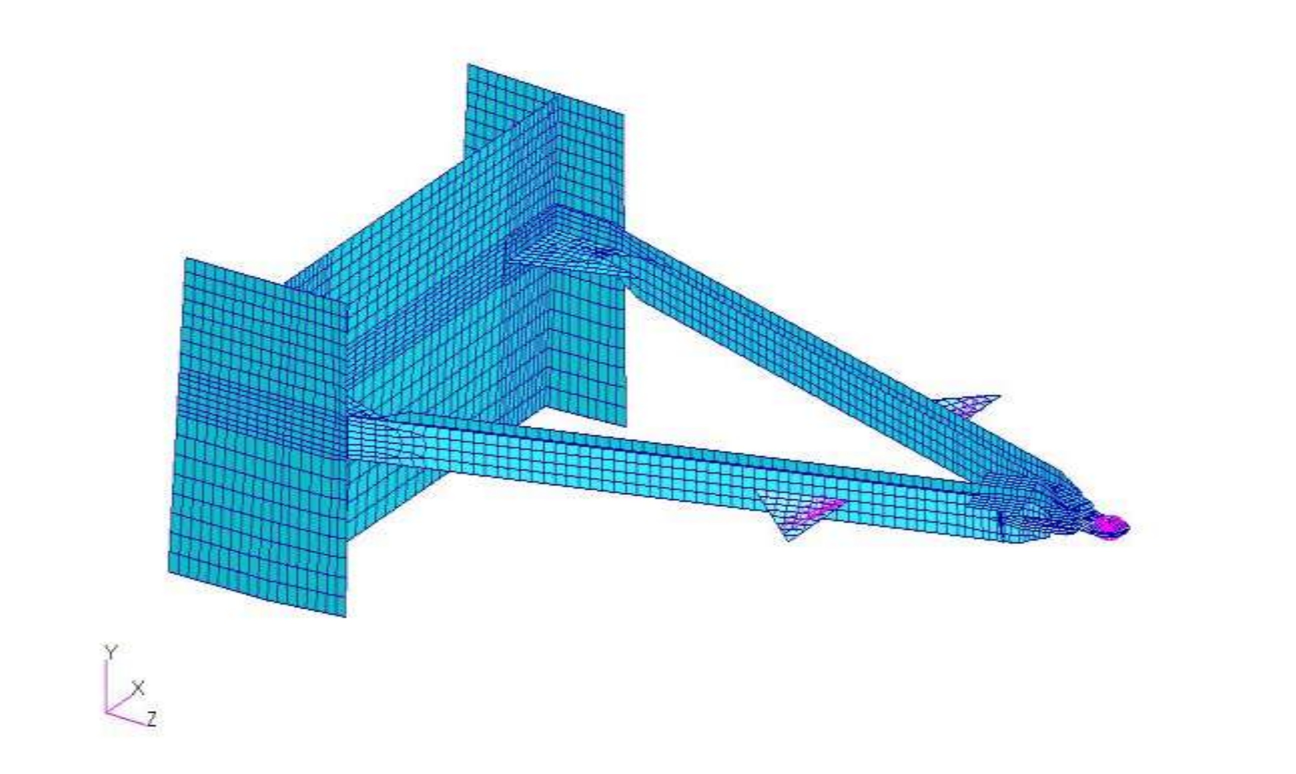

Figure2. Finite Element model of Rudder Hinge

Model Summary

Total elements in Rudder hinge = 4537

Number of GRID points = 4884

Number of CBEAM elements = 32

Number of cquad4 elements = 4434

Number of CTRIA3 elements = 71

Number of RBE2 elements = 3

B Applying Load and Boundary conditions:

The Rudder hinge of an aircraft free edges are constrained with boundary conditions as shown above figure 3 and only five worst load case are applying on rudder hinge arm. It's difficult to show all loads on Rudder hinge of an Aircraft.

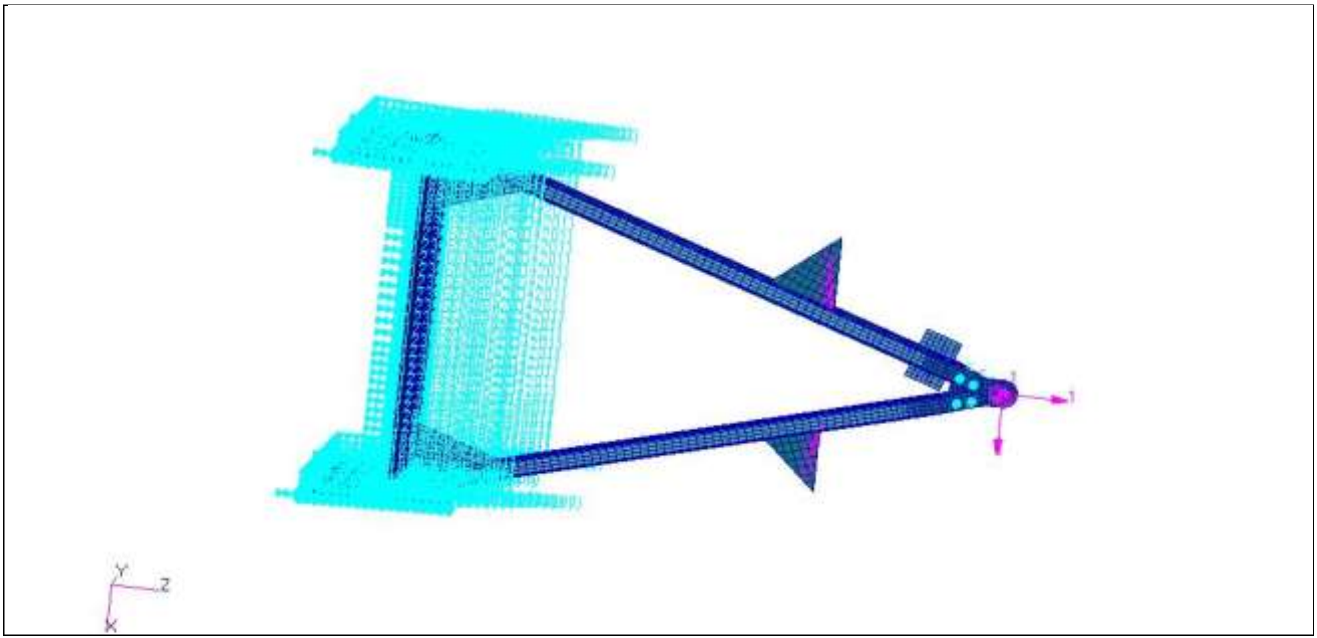

Figure 3: Boundary constraints of Rudder Hing

Material Properties		
E	71000	Mpa
Ftu	470	Mpa
Fty	380	Mpa
Fsu	215	Mpa
mu	0.33	
π	3.141592654	

Where

E=Young's modulus

Ftu=Ultimate stress

Fty=Yield stress

Fsu=Shear stress

6. RESULTS OF RUDDER HINGE ASSEMBLY

Linear static Analysis Results:

It specified the most basic analysis of the structure means Displacement, stresses etc, Force are not vary with time called static analysis,

From MSC NASTRAN software Von misses stress and maximum and minimum principal stress, shear stress are obtained and plotted for the only second load case without considering the composite material. Among five worst load cases second load case is critical for this load cases all Displacements and stresses are plotted and as shown below

Displacements plot for deformation for load case two values is 6.63Mpa as shown below figure4

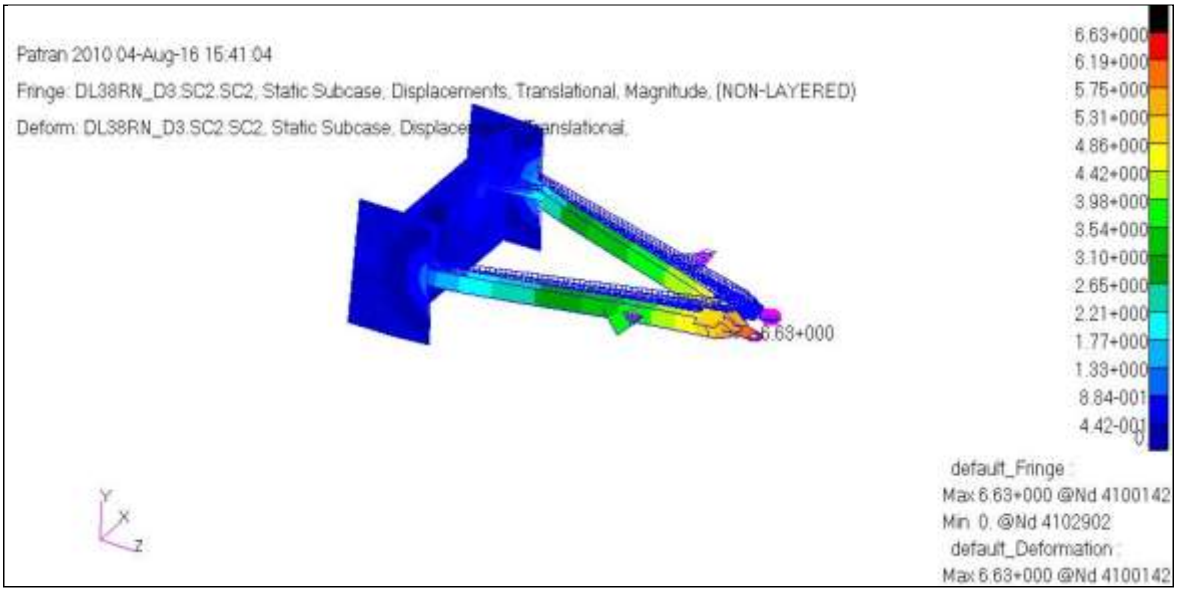

Figure4 Displacement plot for Rudder hinge

Von misses stress

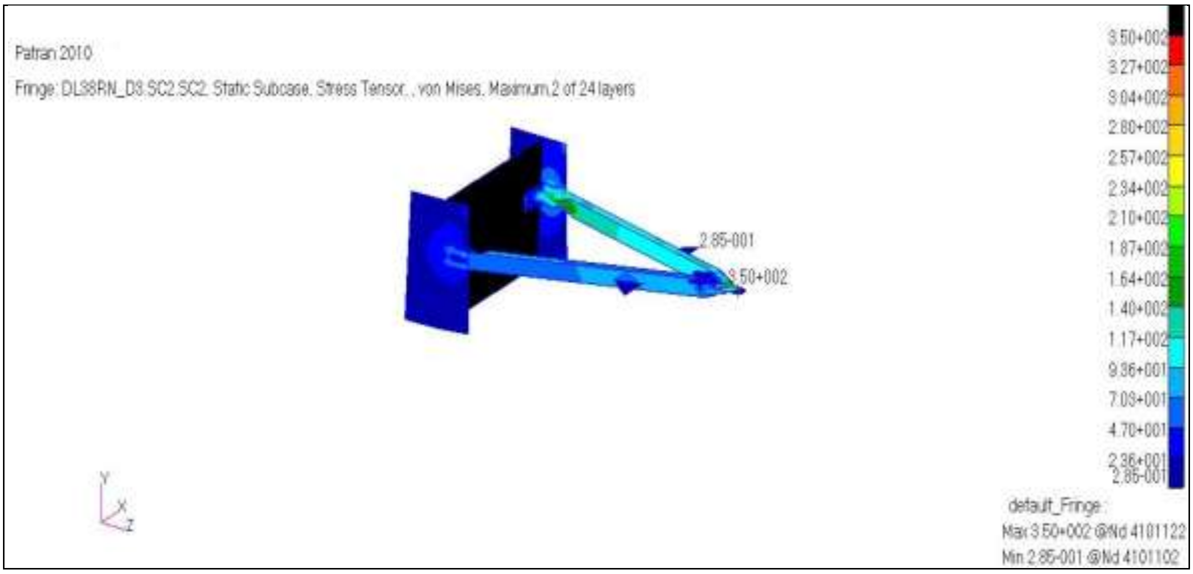

Figure 5 Von misses stress of Rudder Hinge

Von misses stresses Maximum value is obtained maximum stress 350Mpa and minimum stress is 28Mpa values show in below figure5

Maximum Principal Stress

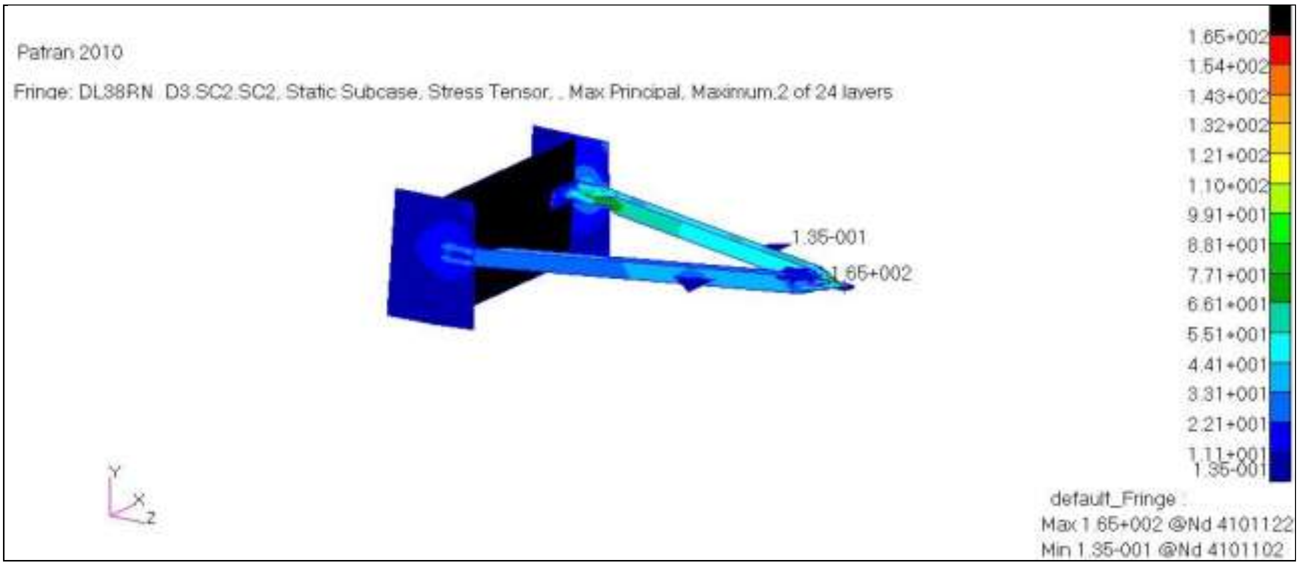

Figure 6 Maximum Principal Stresses of Rudder Hinge

The maximum stress found 165Mpa and minimum 13.5Mpa shown in above figure 6

Table 1 Stress results with considering the metallic materials

Load Case	Von misses stress	Maximum principal stress
2	350Mpa	165Mpa

Load case	Maximum principal stress	Maximum Shear stress
2	651Mpa	36.6Mpa

Table 2 stress results with considering the composite materials

Normal Mode analysis

- Normal mode is proved only when natural frequency is more than 15.81HZ
- The minimum natural frequency is greater than 15.8 Hz for any structures, below table shows the natural frequency are greater than 15.8Hz shows that structure is in safe mode condition.

Table3. Normal mode and Frequencies

SL

NO	NORMAL MODES N	FREQUENCIES HZ
1	1	22.40
2	2	101.39
3	3	108.71
4	4	148.33
5	5	149.83

Buckling Analysis:

Rudder hinge arms are subjected to compressive loads and are analyzed for Buckling. The critical mode is bending and Buckling Factor is 1.39 which is greater than 1.0.

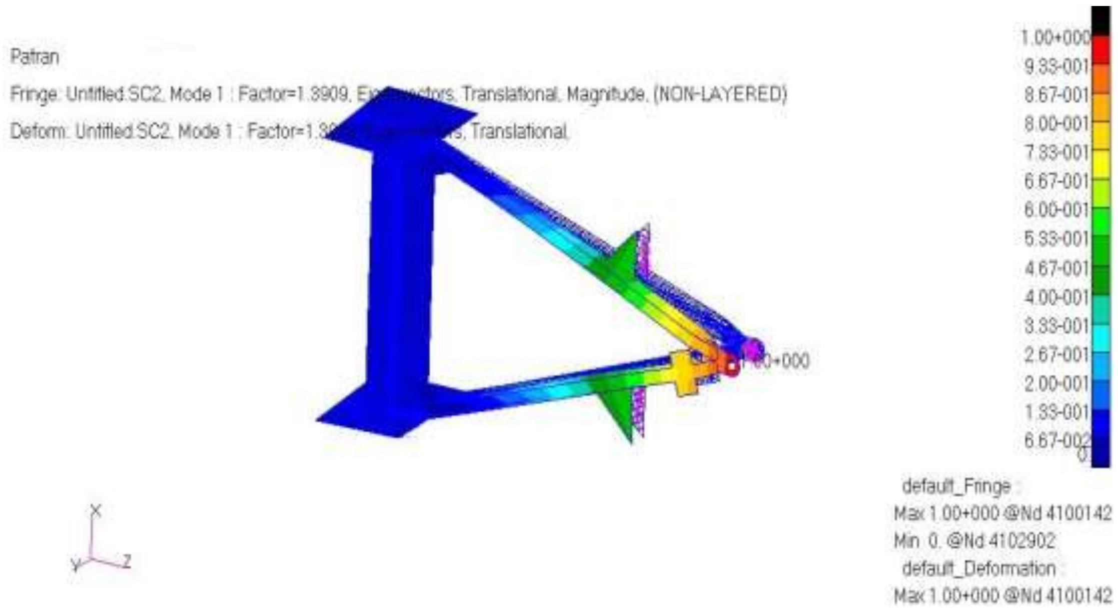

Figure 7 mode one buckling Analysis

Table 4: Buckling analysis results

MODE1	MODE2	MODE3	MODE4	MODE5
1.39	11.003	12.88	13.32	14.78

Table 5 stress values for all five load cases

Load cases	Von misses stress	Maximum Principal stress
1	240	113
2	**350**	**165**
3	319	150
4	148	70
5	319	150

ANALYTICAL CALCLUTIONS RESULTS

Table 6 Analytical calculations values

1	Von misses stress	350Mpa
2	Maximum principal stress	165Mpa
3	Buckling value	1.64

The Rudder hinge of an Aircraft results of FEM and Analytical calculations are discussed here as per the results got in FEA and Analytical Calculations from the above chapters already explained. From the table 7.6 for load case2 maximum stress is obtained according this load all results are plotted in FEA same for Analytical calculations. Following below tables gives the results of both FEA and Analytical calculations are compared both matches the results as show in below tables. Both von misses stress and Maximum Principal Stress are compared with Analytical calculations as shown below clearly .

Von-Misses Stresses

Table 7 FEA vs. Hand calculations von misses stress

FEM Vs Analytical Calculation		
Von-Misses Stresses	FEM	Hand Calculation
Mpa	350	347

Maximum Principal Stress:

Table 8 FEA vs. Hand calculations Max principal

FEM Vs Analytical Calculation		
Max Principal	FEM	Hand Calculation
Mpa	165	165.4

The below following key points shows the possible outcomes of the Rudder hinge assembly of an aircraft

- Effective design of Hinge Assembly under various aircraft loads.
- Strength and Stability justification of individual components of Hinge Assembly
- Design modifications to meet weight optimization and optimum design
- Suitable Interacting methodology to connect metallic and composite components and Fastener modeling.
- Rivet connection in Fork head with optimum design.
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7. CONCLUSION

Rudder hinge arms and assembly parts are analyzed using Finite Element Analysis and substantiated by classical methods. FEM validation is to performed to ensure correction of FE model and accuracy of results. Static analysis of rudder hinge arm assembly is performed using static loads, analysis loads shows von-misses and principal stresses are within the yield and ultimate allowable limits of the material. The maximum von-Misses stress for the critical load is 347MPa is within the allowable yield strength of 350MPa of AL material. The maximum principal stress is 165MPa and is within the allowable ultimate strength of the material 470MPa. Maximum principal stresses for the composite materials are within the allowable limits. FEA of static and hand calculation results are compared and deviation is less than 2%. The lug analysis of rudder assembly is carried-out for all lug failures and result shows none of the lugs have failed.

Rudder hinge arms are subjected to compressive loads and are analyzed for Buckling. The critical mode is bending and Buckling Factor is 1.39 which is greater than 1.0.

Normal mode analysis is performed to know the dynamic behaviour of the structure. The natural frequency of the structure is 22.4 Hz which is above the required frequency of 15.81Hz to prevent it from resonance.

REFERENCES

[1] David F. Anderson and Scott Eberhardt, ‘Understanding Flight’, McGraw-Hill, USA

[2] IH Shames, ‘Energy and Finite Element Methods in Structural Mechanics’, New Age International Publishers Ltd.

3] R.S.Rawat , D.Karuppannan, B.L.Dharmappa., & M. Subba Rao “Development of co-cured Composite Torque Shaft for Rudder of High Speed Aircraft.”Advanced Composites Division, National Aerospace Laboratories, Bangalore, International Conference on Aerospace Science and Technology India June 2008.

4] Vinod S. Muchchandi, S.C Pilli “Design and Analysis of a Spar Beam for the Vertical Tail of a Transport Aircraft”**.** K L E Dr.MSS CET, Belgaum International Journal of Innovative Research in Science, Engineering & Technology, Vol. 2, Issue 7,July 2013

5] F. C. Campbell, ‘Manufacturing Technology for Aerospace Structural Materials’, Elsevier Ltd.

6] Horne DF, ‘Aircraft Production technology’, Cambridge University Press, London.

7] George F. Titterton, ‘Aircraft Materials and Manufacturing Process’, Himalayan books, New Delhi.

8] David J. Peery and J.J. Azar, ‘Aircraft structures’, 2nd Edition, McGraw-Hill, USA

9] R. D, Cook, D. S Malkus, Plesha, Witt, ‘Concepts and Applications of Finite Element Analysis’, 4th Edition, Wiley.

10] Robert M. Jones, ‘Mechanics of Composite Materials’, 2nd Edition, Taylor Francis.

11] Anderson T. L, ‘Fracture Mechanics-Fundamentals and Applications’, CRC Press, 3rd Edition.

12] ESDU (Engineering Sciences Data Unit) Standards.