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Conceptual Design and Analysis of Link for Arresting Slat actuator Play in Tejas Aircraft

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Abstract: **TEJAS – The world's number one light combat supersonic aircraft which is built by Hindustan Aeronautical Limited (HAL), experienced a major drawback in the leading edge slat assembly. The problem was sorted out after twenty five cycles of flight and due to this the factor of safety of the flight was drastically reduced. Due to continuous load acting on the aircraft the leading edge slats were prone to experience a play. This was because the lugs which were the primary structural elements in airframe structure, that were widely used in connecting slat actuator and the strut with the help of bolt, experienced a wear of material. Because of this wear in the lug the slat actuator loses its plane of motion and vibrates in different direction(play).In order to avoid this play, a separate link was installed between the actuator and the bolt so that it can hold them together and part of the load transmitted to the lugs was taken by this link. This setup drastically reduced the forces acting on the lugs thereby controlling the wear of the same and hence the vibration of the actuator was controlled. The forces acting on the link were calculated and analyzed using software [ANSYS] and the results were compared with those without the usage of link. It was found that the results with the presence of link were found to be satisfactory. The stress was reduced by 48%.**

1. INTRODUCTION

Tejas is the smallest and lightest Multi-Role Supersonic Fighter Aircraft of its class. This is the indigenous product developed in India. Technical demonstrator is the first LCA aircraft produced in India. Since the first flight, Tejas aircraft has been constantly developed and improved consistently to increase the performance and life of the flight. The Series Production of Tejas has been started but still development is required in increasing life cycle of aircraft. So the research and design is still in progress.

Slats are aerodynamic surfaces on the leading edge of the wings of fixed-wing aircraft which, when deployed, allow the wing to operate at a higher angle of attack. A higher coefficient of lift is produced as a result of angle of attack and speed, so by deploying slats an aircraft can fly at slower speeds, or take off and land in shorter distances. They are usually used while landing or performing manoeuvres which take the aircraft close to the stall, but are usually retracted in normal flight to minimize drag.

Problem definition

The main problem revolves around leading edge slat system – Tejas aircraft. The slat system consists of actuator which is bounded to nose box assembly of the wing. One end of the actuator is attached to the slat and the other end is connected to the strut with the help of the bolt. The bushes act as an interface between the bolt and the actuator. It is found that after the use of slats for about 25 flights, the lug which is present in the actuator-strut hinge point is wearing out due to the high load which is transferred from the base plate. Due to this wear, the actuator is subjected to the moment causing the displacement which is referred to as play and this play is undesirable. This play should be arrested in order to have safe flight. There should not be made any major changes in the actuator LRU because it has space constraints. It also should be cost effective and easy to produce

Aim

To design the lug in such a way that the failure of lug is prolonged, meeting the space constraints and also without much changes in the manufacturing process.

Solution

The above problem can be solved by using a better material, special dimensions, bushes or reducing the load acting in the lug by any ways[1,2,3,4]. For the above mention problem, **the concept of redundant structures** is implemented[5]. The use of mechanical link is suggested by us to reduce the load acting in it. Play which is happening in the transverse direction is mainly due to the high load transferred to the lugs. So in order to avoid that, a mechanical linkage is placed near the actuator hinge point and this mechanical linkage will reduce the load acting in the lugs. As the link takes a part of the load, the lug is not subjected to too much stress and the reaction moment that acts on the lug is minimized[6]. The load acting on the lug before and after the employment of the link is calculated and the solution is justified as follows.

2. GEOMETRY OF THE COMPONENT AND MATERIAL DATA:

The leading edge slat actuator is shown below

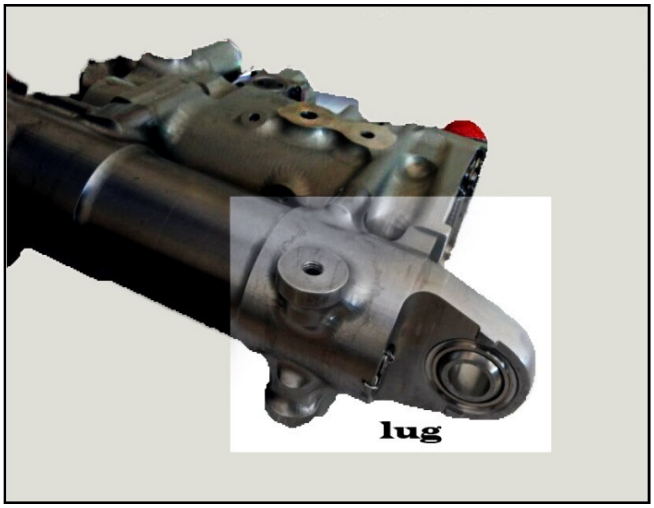


Figure 1. Leading edge slat actuator

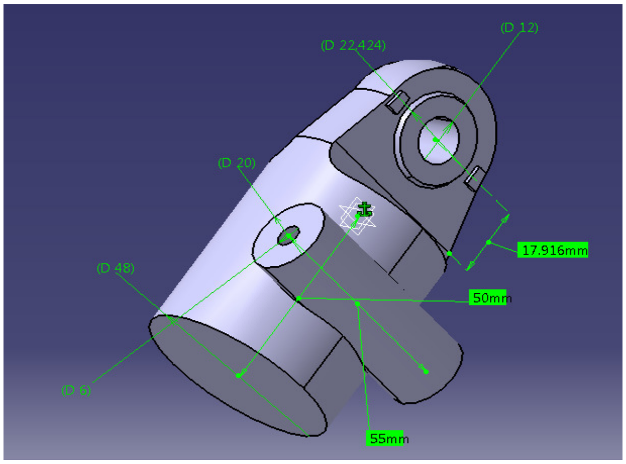


Figure 2.Slat lug geometry

The geometrical configuration and dimensions of the lug are shown in the figure. The lug was with the hole diameter of 12 mm (Ri = 13) and the outer diameter of 22.42 mm (Ro = 35). A steel bushing was installed between the lug and the pin.

3. CALCULATION

When any structure is loaded , stresses are induced in the various parts in the structure, and in order to calculate the stresses, where the structure is supported at a number of points, the bending and shearing force acting must be considered to consists of series of beams, linked together in some way and further the complete structure may be treated as a beam with an elaborate cross section calculations can be made progressively first on the structure as a whole and then on the individual parts.

Assumptions:

1. The leading edge slat system is a cantilever beam which coincides with the actuator cylinder axis.
2. The reaction force is due to pressure force that act in the base plate and the weight of the actuator
3. The pressure force acting in the base plate is transferred to the CG of the actuator as point load.
4. The slat system with mechanical link is considered as propped cantilever beam with overhanging moment.
5. The mechanical link provides frictional support to the actuator.
6. The moment acts on the midpoint of the actuator cylinder.

Given Parameters:

1. The pressure acting in the base plate= $30\,psi = 207\frac{KN}{m^2} or Kpa$.
2. Area of the base plate= $0.0601m^2$.
3. The coordinate point of the C.G of the actuator is given in rectangular co-ordinate system (x,y,z) as C (9683.895, -3262.805, 115.642).
4. The coordinate points of two ends of the actuator lug is given as A (9781.061, -3187.275, 137.9965) and B (9655.2655, -3410.8165, 101.031)
5. Friction coefficient , $\mu = 0.3$

Note: Negative sign indicates the opposite direction.

In the design of the lug the dimensions and material of the lug are not modified. During production the slat actuator LRU can be installed directly along with the link. So the production is made easier with increase lug life. So the reaction moment at the lug part before and after the installation of the link are to be calculated.

Load acting in the actuator **F**= 22 KN

Moment acting at the midpoint actuator cylinder
M= 416193.22i
Length of the beam is 129.17 mm

Free body diagram:

The slat actuator assembly is converted to the cantilever problem. It is given that 30psi of force acts on the base plate connected to the actuator.

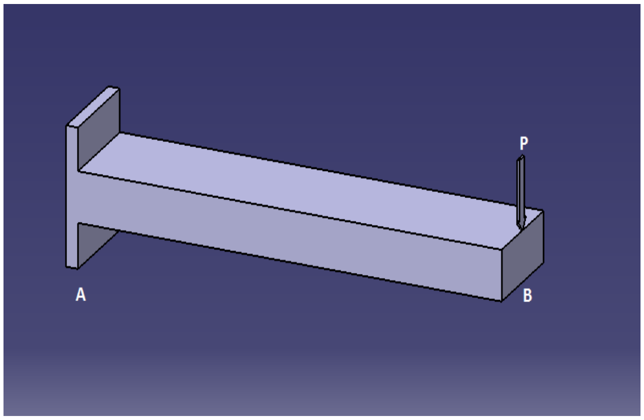


Figure 3. cantilever beam without link

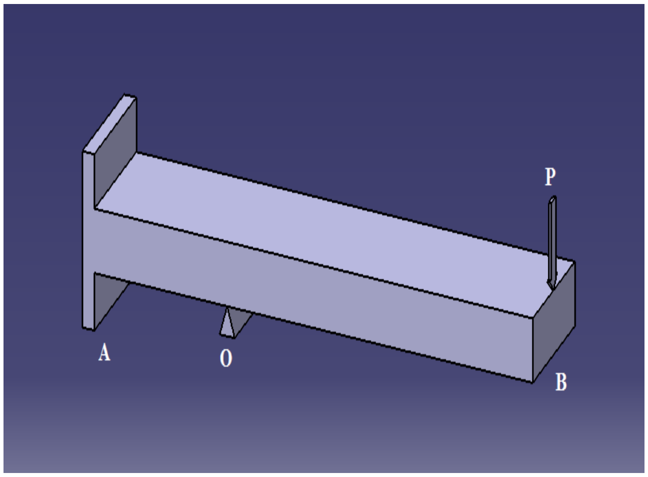
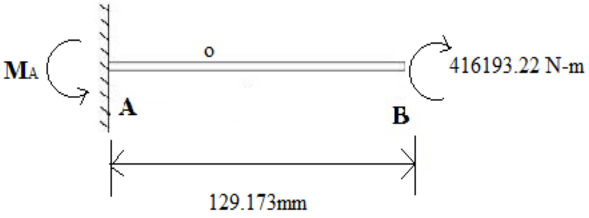


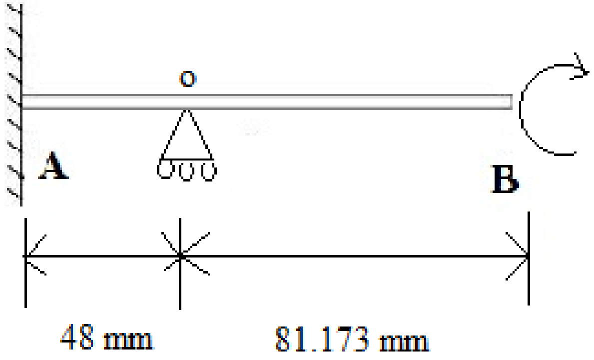
Figure 4. cantilever beam with link

Cantilever without redundant structure:

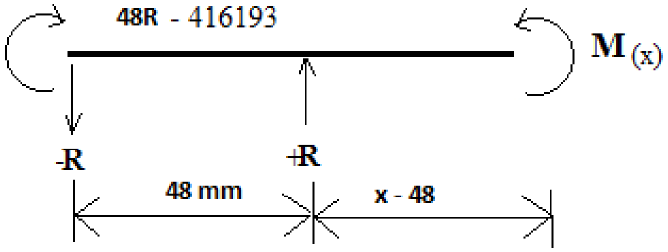


$$ReactionmomentM_A = 416193.22\,Nmm$$

Propped cantilever with overhang(with link):



Draw the free body diagram for Macaulay's method.



Proceeding as usual, we take moments about the cut, being careful to properly locate the moment reaction at A using the correct discontinuity function format.

$$M(x)-(48R-416193)(x)-(-Rx)-(R(x—48))=0$$

Since x will always be positive, we can remove the Maccaulay's brackets for the moment reaction at the A, and then we have

$$M(x)=EI\frac{d^2y}{dx^2}=(48R-416193)-Rx+R(x-48)$$

Applying boundary conditions,the reaction force is obtained as,

$$\boxed{R= 6503}$$

The above reaction force is obtained in the redundant support when it is considered as fixed.

If it is frictional support, then, $\mu= 0.3$
$R= \mu R$

$$R = 0.3 \times 6503$$

$$\boxed{R = 1950.9\,N}$$

Reaction moment,

$$M = 48R - 416193$$

$$M = 48 \times 1950.9 - 416193$$

$$\boxed{\text{Reaction moment}\, M_A = 322549.8\,Nmm}$$

Therefore it is seen that, by using Mechanical linkage as redundant structure, reaction moment at lug **is reduced by 93640 N mm.**

The above calculations conclude that the reaction moment is reduced by **22.95%** after the implantation of link. This evidently proves that the load transferred to the lugs portion is drastically reduced and hence therefore the displacement in the transverse direction [PLAY] is arrested.

4. MODELLING

The slat actuator assembly in which the problem is found is shown in the figure. Here the base plate is subjected to aerodynamic pressure of 30psi and the load is transmitted to the actuator through four bolts. The stress in the actuator lug is due to the weight of the base plate, actuator and the pressure force. the mechanical link is introduced to reduce the stress acting in the lug as well as to arrest the play which is explained already in the problem statement. Based on the calculations the link is designed, and the material is chosen from the standards. The part modelling of the link and other components of the actuator assembly are drawn using CATIA Part design.

Below all the catia parts of link-actuator- strut assembly is shown

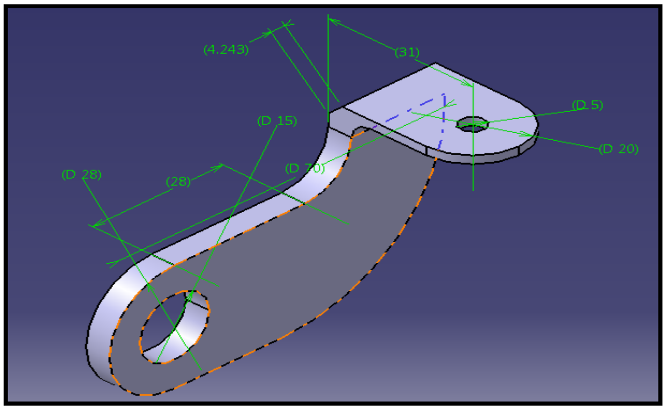


Figure 5. CATIA part drawing- Link

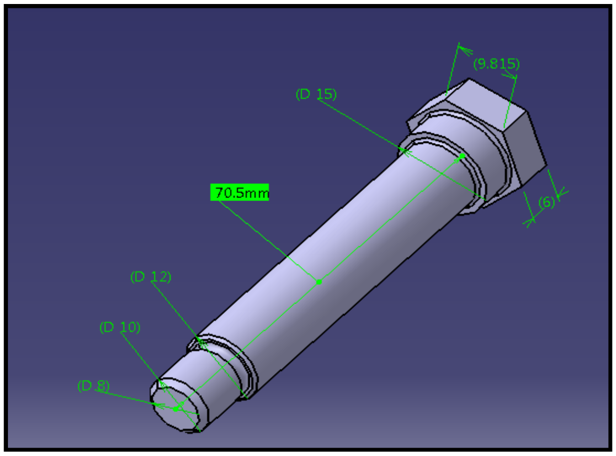


Figure 6. CATIA part drawing- Bolt

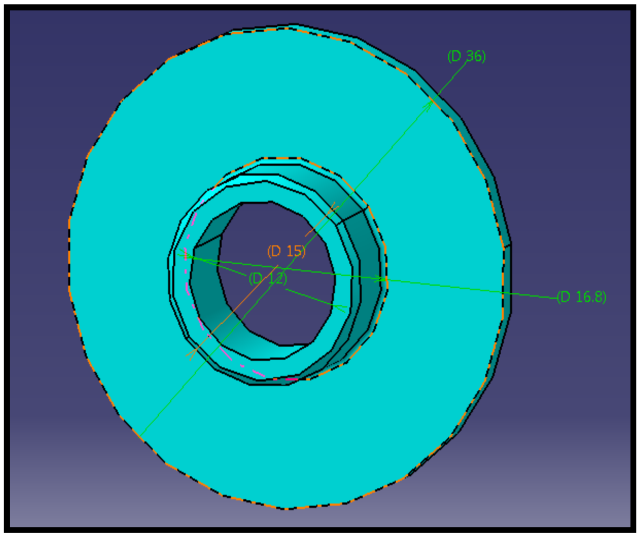


Figure 7. CATIA part drawing- Bush

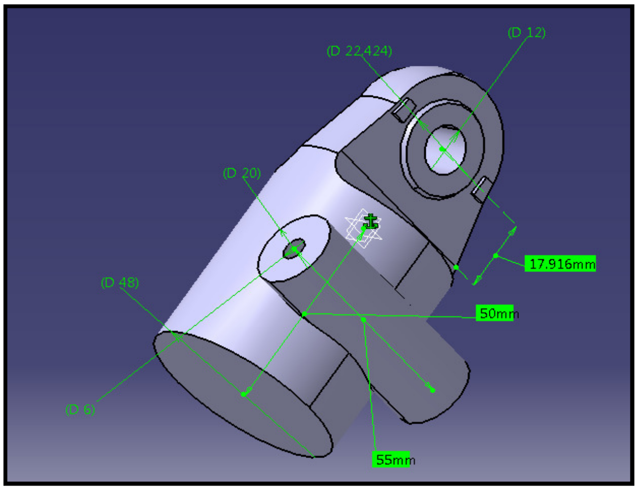


Figure 8.CATIA part drawing -Actuator

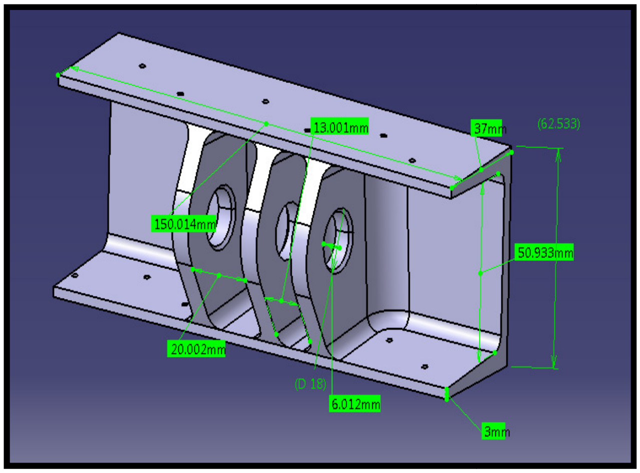


Figure 9.CATIA part drawing Struct portion

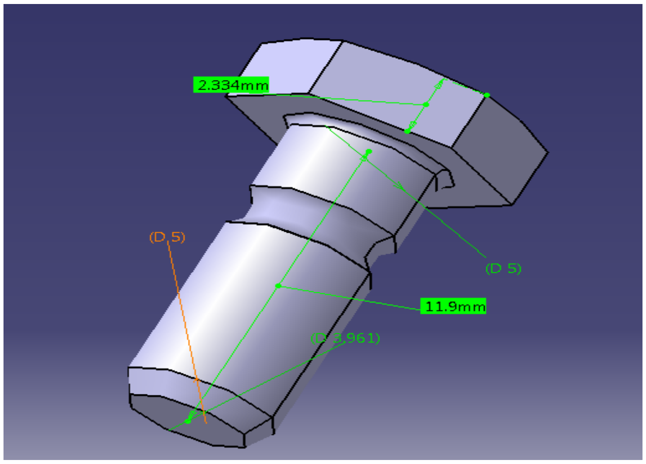


Figure 10. CATIA part drawing- Bolt for link

5. ASSEMBLY DRAWING

The part drawings drawn with the help of CATIA part design tool is assembled using CATIA assembly tool.

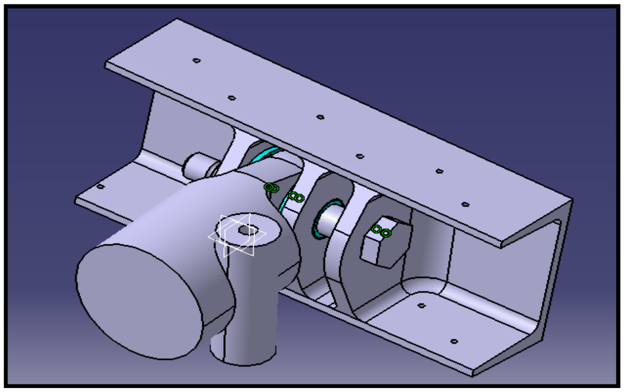


Figure 11. Actuator assembly without link

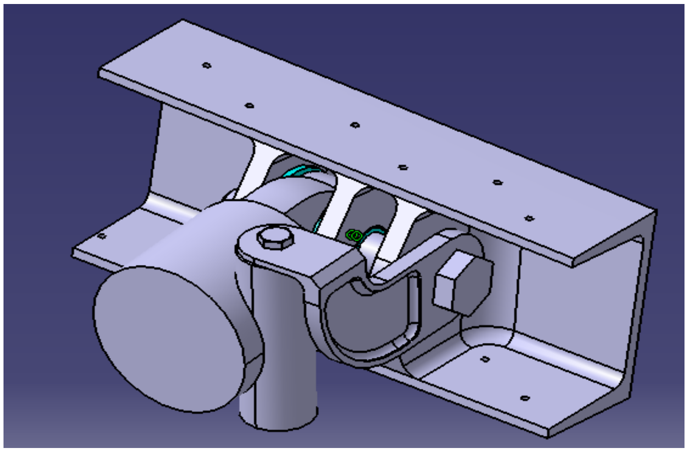


Figure 12. Actuator assembly with link

6. ANALYSIS

The CATIA assembly drawings are imported to ANSYS 13 and analysis is done

Preprocessing: Meshing

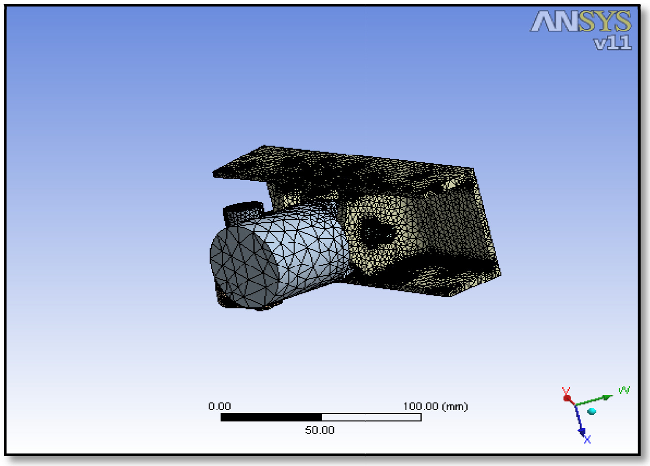


Figure 13. Meshing

Table 1. Materials used in Actuator Assembly

SNo	Components	Material used
1	Strut (front spar)	Aluminium alloy
2	Lug	Steel
3	Bushes	Steel
4	Bolt for connect lugs with strut	Steel
5	Link	Stainless steel (H 1025)
6	Bolt for connect link with lug	Steel

7. POST PROCESSING

Equivalent stress:

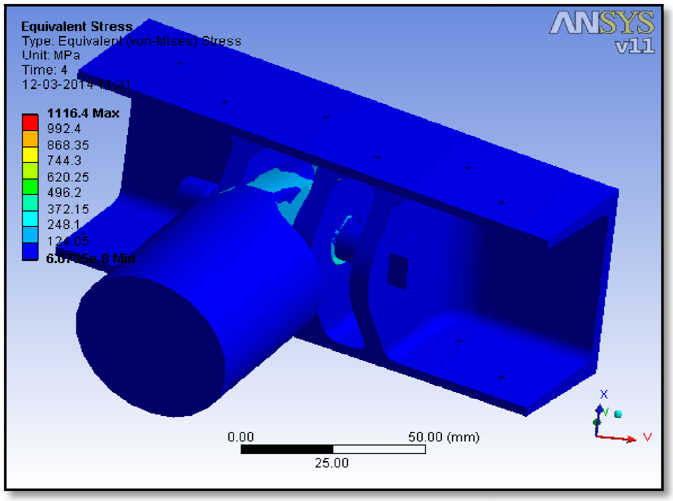


Figure 14. Equivalent stess (without link)

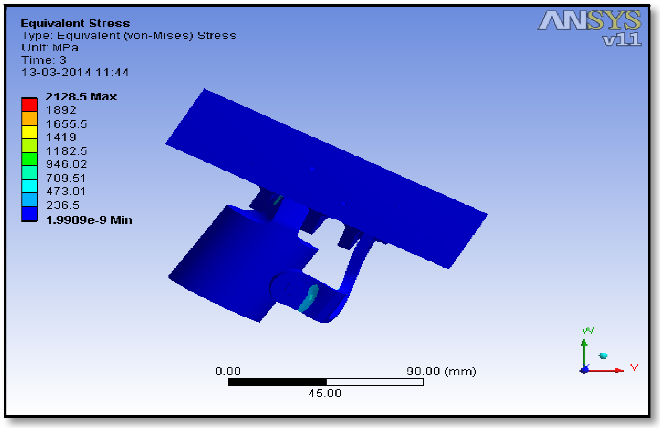


Figure 15. Equivalent stress (with link)

Table 2. Post processing results

Parameters	Values	Without link	With link
Normal stress	Maximum	139.89 m pa	119.18 m pa
	Minimum	-525.78 m pa	-628.32m pa
Shear stress	Maximum	160.05	88.771
	Minimum	-115.36	-212.31
Equivalent Stress	Maximum	248.1m pa	236.5m pa
	Minimum	6.073 e^{-8} m pa	2 e^{-9} m pa
Total deformation	Maximum	0.16449 mm	0.13863mm
	Minimum	0.036554mm	0.023104mm

8. CONCLUSION

The link takes a part of the load, the lug is not subjected to much stress and the reaction moment that acts on the lug is minimized. The load acting on the lug before and after the employment of the link is calculated and the solution is justified as follows.

The calculations conclude that the reaction moment is reduced by 22.95% after the implantation of link. This evidently proves that the load transferred to the lugs portion is drastically reduced and hence therefore the displacement in the transverse direction with respect to strut [PLAY] is arrested.

The slat actuator assembly is drawn in CATIA V5 and it is imported to ANSYS 13 workbench in stp format. The model is meshed and the input values are given. From the table of comparison it is clear that after the implementation of mechanical link the stress at the lug part is drastically reduced. Though the deformation is seem to be happen at the point of application of load, there will not be any deflection in real case. This is because; in real-time the support due to slat track is neglected. The problem is analysed for maximum load condition considering factor of safety. When it is taken into consideration, the stress is further reduced. As the play is arrested the adverse effects of slat play such as Aerodynamic flutter and vibrations are controlled.From the analysis, it is clear that the equivalent stress in the lug part is reduced by 48%.

The implementation of the mechanical link provides the following advantages.

- The stress is drastically reduced by 48 %
- The wear of the attachment lug is prolonged.
- The link supports the actuator and avoids the play even if the wear occurs.
- There is no need of change in actuator LRU (Line Replaceable Unit). So it is more economical.

9. ACKNOWLEDGEMENT

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