Design Optimization of Aircraft Landing Gear's Torsion Link Using Generative Design

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Abstract- *The paper proposes a design optimization of aircraft landing gear torsion link using Generative design on one of the most used aircraft in general aviation. Generative design is a new method of product development and innovation. This approach to torsion link innovation leads to reduce in the time spent developing prototypes along with reduced weight, improved performance, and part consolidation. Catia V5 and Fusion 360 software are used for 3D modeling and generative design of the landing gear torsion link. This academic research comprises a CAD design of Airbus a380-800's main landing gear torsion link. The aim used for this paper is to research the functionalities of the main landing gear torsion link for the defined shimmy for underlying condition and to execute structural, fatigue, modal and multibody analysis. The model is analyzed in ANSYS and Mathworks with different designs obtained from generative design and further discussion on the optimization is done.*

Keywords- Generative Design, Aircraft Landing Gear, Design Optimization

I. INTRODUCTION

The development of aircraft is recognized as one of humanity's greatest inventions. In the modern era, demand for aircraft is strong by serving as a mode of transportation for the defense sectors and commercial purposes. As our global interactions continue to expand, there will be an increase in demand for aviation as the mode of transportation.Different structures and parts are mounted in an aircraft to make it operable. Some of the main parts are fuselage, wings, cockpit, landing gear, engine, etc. these parts play a significant role in various stages of flight like takeoff, maneuvering, landing, etc.To design these parts, it is important to take into consideration the loads, stresses, forces, etc. that acts on each component and systems employed. The selection of material has to be done wisely so that it meets the essentials of a component. To make an aircraft tough, strong and light nowadays, design and analysis were done in software. Before manufacturing each component and subsystems were designed and analyzed to get better results and it is much easier to be rectified.Landing is one of the crucial systems which supports the aircraft on the ground, helps in ground operations like takeoff, landing, taxiing without causing any damage to the aircraft.Primarily wheels are being used but alternative metho ds such as skids, skis, floats or a combination of these are used depending on the terrain. High-speed airplanes comprise of retractable undercarriages that fold upon take-off to decrease air resistance or drag Landing gear wheels are designed to land on rough terrain with oil shock absorbers or more modern air / oil struts. Many airplanes in their landing gear systems are comprised of skis for water or snow floats. The undercarriage is a heavy part of the aircraft and can account for up to 7% of the takeoff weight.

Torsion link: It is a component which couples upper and lower cylinders of a landing gear. This is used to avoid twisting or torsion of components in the system between the cylinder and the piston. This connection helps in preventing shimmy vibrations throughout the landing gear process. Shimmy is a self-excited oscillation occurring in the lateral and torsional direction of landing gears. This kind of excitation is triggered by the contact of the tires with the ground. These shimmy oscillations are not catastrophic but it reduces the stability of the landing gear and causes serious problems like the shortened life cycle of gear parts, safety concerns, etc. and finally triggering an accident.

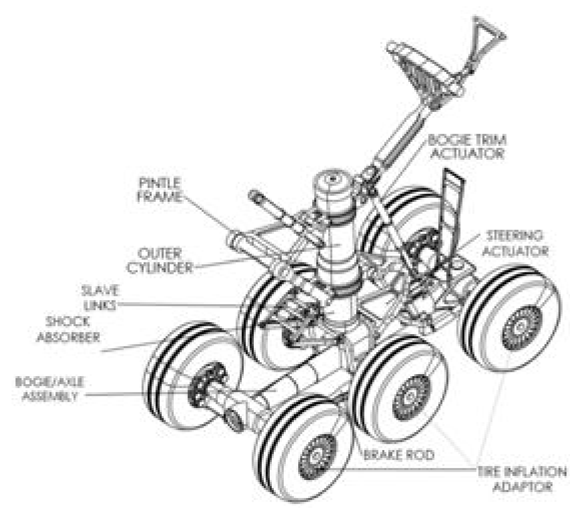

Figure 1Airbus A380 Landing Gear

Generative Design: The resources to manufacture the aircraft has to be utilized efficiently as it needs great expenditure. So, to meet this criterion many aviation industries choose to reduce the cost by optimizing the weight by keeping the performance intact. There areseveral ways to optimize the weight of an aircraft. One such method in the modern world is the use of generative designs. Generative design is a revolutionary technology, it's an approach to use machine learning and cloud computing to construct various design choices. It is a central element in the Fourth Industrial Revolution.

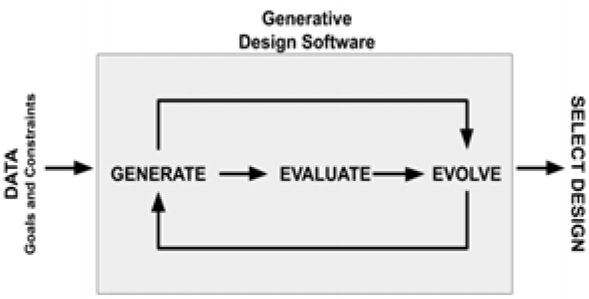

Figure 2 Generative Design Process

II. LITERATURE REVIEW

A vast majority of research and experimentation has been done on reducing the weight of various aircraft components of landing gear, fuselage, and wings structure. Many such research papers related to the above-mentioned subject were studied as part of the research for this project.

A torsion link subassembly is selected by Jonathan Y.B. Wong's [1] research paper as a candidate for design optimization of commercial aircraft landing gear components for weight, cos, and performance by considering structural and dynamic behaviors. Detailed drawings for the upper slave link and lower slave link were provided by Safran LandingSystems and a CAD model was recreated using SolidWorks. The finished CAD assembly was then exported into Altair's Hypermesh to create the finite element model. The research presented, successfully demonstrated an effective and efficient methodology to computationally characterize, analyze, and optimize components of a landing gear assembly. According to a report published by Lars Krog [2] in 2011, To design the aircraft components such as leading-edge ribs and wing box ribs, Airbus used the topology optimization process. Paper also addressed the difficulties of the finite- approach in achieving the correct loading and boundary conditions. The work shows how methods are used in the technical design of aircraft components for topology, sizing and shape optimization. This method was widely used in an industrial environment.

The paper written by A.M. Elsaie [3], provides the design engineers with basic understanding and confidence of the Starstruck design tool for structural optimization. This tool is used for effective weight optimization of landing gear components. Analysis of stresses, buckling, deflections, and frequencies of vibration is done for a landing gear assembly.According to Bagassi, F. Lucchi, F. De Crescenzio, F. Persian [4], Generative Design is a method for capturing the design engineer's intent, generating new solutions. A set of parameters and rules is considered as the DNA of the design process. Airbus and Autodesk have developed one of the most effective examples of Generative Design inaeronautics. Cabin partitions are designed to be manufactured by a 3D additive manufacturing process. Generative Design principles are not yet explored enough. Some examples have been considered in small component design, but only a few cases and tests are proposed in aeronautics.

The stress contours and modal analysis of the upper torsion link are compared with the paper by Krishnan [5]. Six natural frequencies of the optimized model are obtained and mode of shape is discussed. The analysis is done on Motion View and HyperMesh tools. It is required to minimize the stresses by changing hole positions and geometry. The effects of giving multiple holes and combining holes are studied.

Ashwin[6] contrasts the fatigue evaluation from the limit stresses obtained to find out the fatigue life of landing gear with specific load spectra. When determining durability and fatigue, both static and fatigue loads are taken into account.
MSC Nastran is used as a solver for the analysis. The value of force and the limiting factors are taken from[7]. The weight reduction after using the composite material for the torsion link is being discussed and compared with aluminum alloy. RTM mold for fabrication of the composite torque links was designed.

III. METHODOLOGY

Design

Catia V5 is used to design the main landing gear. The design consists of all the intricate parts with up to scale dimensions. The figure below shows a 2D diagram of the model designed.

Generative Design Software

Autodesk Generative Design is used for the research paper. The resulting product appears organic and natural. The algorithms of Generative Design use a process called shape synthesis that takes signs from nature and effectively grows new forms that imitate bone and sinew. GD is introduced with the Autodesk Fusion 360 platform.

The steps involved –

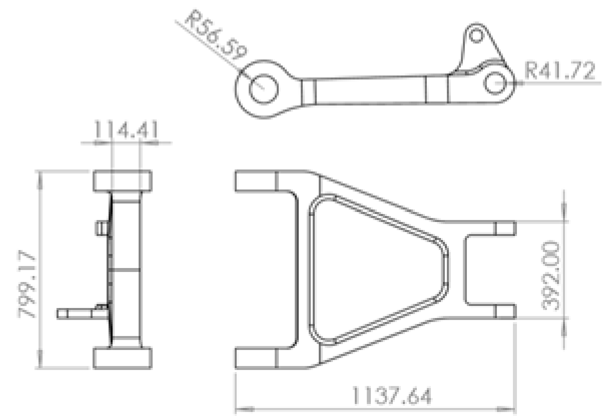

Figure 3 Torsion Link

- *Creating preserve geometry*

This form of design space implores the application not to differ from the specified shape/geometry, although the same shape parameters are already part of the starting form. The chosen geometry "preserve" often describes the strains and constraints that are associated with the case study. The green textured pieces show the geometry retained.

- *Creating obstacle geometry*

This leaves the machine restricted not to put any substance in between. Generative Design can work around it, if needed, beyond the obstacle. In some designs, the surrounding design parameters that overlap or interfere with the stated preserve geometry and will, therefore, be regarded as both preservation and obstacle.

When that occurs, one must create separate geometry representing those design space requirements. The red textured part in the figure shows an obstacle for the torsion link.

The geometry that is classified as preserve or obstacle (in Generative Design) must be modeled in Fusion 360 as separate structures, components or solids or in some other acceptable CAD format. It can not be part of or connected to our mounting bracket or the actual portion one can use.

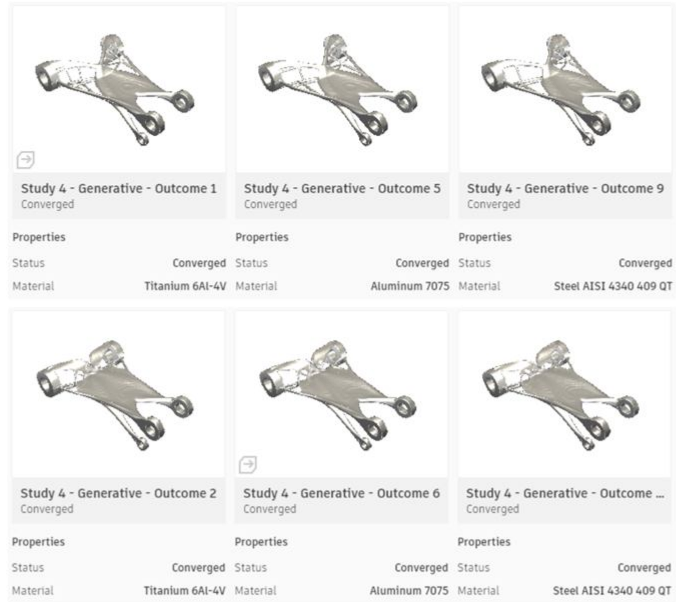

Figure 4 Generative Design Outcomes

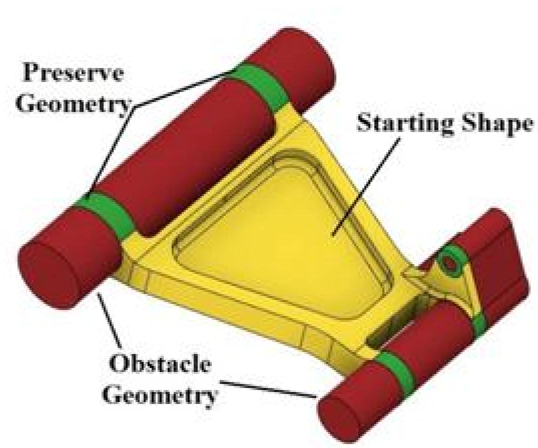

Figure 5 Generative Design Steps

- *Define a design space or starting shape*

A starting shape may or may not be included in the design workspace. The more data assigned to the program the more predictable the design will be. The original geometry has been considered as Starting shape for the analysis.

- *Setting up a design problem*

Use the constraints to define interfaces between design and the surrounding environment. Apply structural loads to simulate pushing, pulling and twisting forces that the design should withstand. Along with one can specify the optimization objectives such as a factor of safety, stiffness, mass target, manufacturing process. A load of 4.48 KN [5] is acting axially on the torsion link.

- *Explore outcomes*

Figure 4 Generative Design Outcomes

The software generates outcomes that satisfy the design requirement specified in the generative study. Once the processing is done design alternatives called outcomes can be explored along with their properties.

CAD-ready solutions with multiple manufacturing constraints-Generative design has the ability to pick several manufacturing methods at once, from additives to 3 or 5 axes and more, to rapidly explore various approaches to your design and engineering challenges.Providing you with a variety of solutions to achieve your goals, this generative design software gives you the opportunity to explore the various outcomes and even return the solutions to your CAD system to improve the design.

- *Materials*

The materials used for the torsion links in the aircraft industry are Titanium alloy Ti6Al 4V, whose properties are shown in table 3.1. Ti-6AL – refers to the chemical composition of approximately 90% titanium, 6% aluminum, 4% vanadium, 0.25% (max) iron and 0.2% (max) oxygen, respectively..It has exceptional strength, small elasticity modulus, high resistance to corrosion, good weldability and is heat treatable.

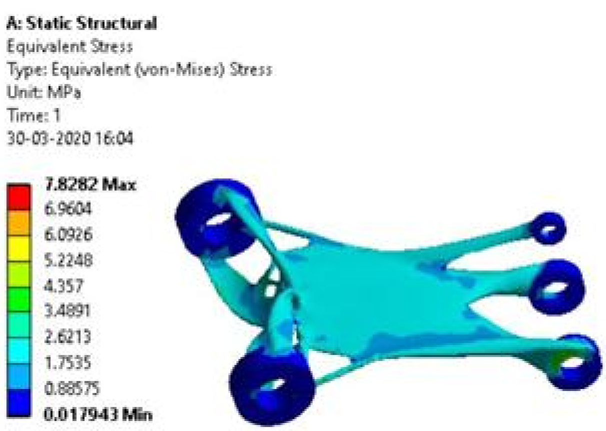

Figure 6 Conventional Design

Table 1 Ti-6Al-4V

Property	Ti6Al 4V
Young's Modulus (MPa)	113800
Shear Modulus (MPa)	42782
Density (kg/m³)	4430
Poisson's Ratio	0.33
Bulk Modulus (MPa)	111570

Ti-6Al-4V (UNS designation R56400), also sometimes called TC4 or Ti64,[1] is an alpha-beta titanium alloy with a high strength to weight ratio and outstanding abrasion resistance. This is one of the most frequently used titanium alloys used in a variety of industries requiring low density and superior corrosion resistance, such as aerospace.

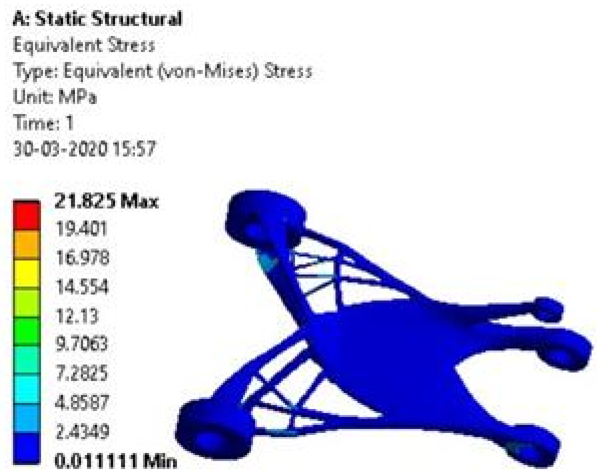

Figure 7 Generative Design Iteration 1

3.4 MESH

Ansys workbench is used to perform various static and dynamic analysis. The mesh is generated using Ansys Design Modular. The minimum element size for the analysis is taken 5 mm.

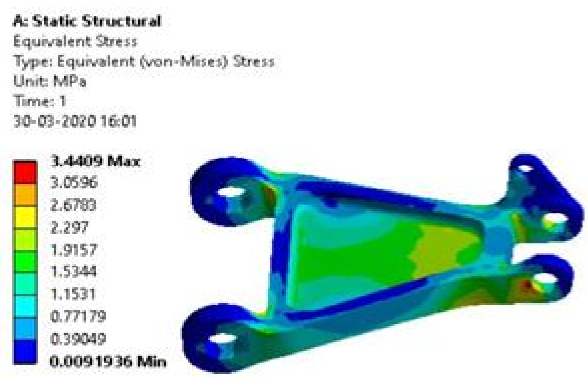

Figure 8 Generative Design Iteration 2

Table 2 Mesh nodes and elements

	Elements	Nodes
Conventional Design	2076070	2921854
Generative Design Iteration 1	1097621	1604103
Generative Design Iteration 2	1092078	1579567

IV. RESULTS AND DISCUSSIONS

Static Structural

The Failure theory offers instructions for determining an analogous parameter such as stress, strain, energy under combined load that can be contrasted with related parameters from the uniaxial study. The ultimate energy distortion principle (Von Mises) applies to ductile materials since they are weaker. Von Mises stress is more efficient in accordance withthe maximum shear stress theory. Fig 6, 7 and 8display static structural analysis performed using Ansys.

The conventional component experiences maximum stress of 3.4409 MPa and the generative design iteration 1 & 2 experiences maximum stress of 7.8282 MPa and 21.825 MPa respectively. The yield strength of the Ti-6Al-4V is 970 MPa which means all the designs including generative designs are safer to design.

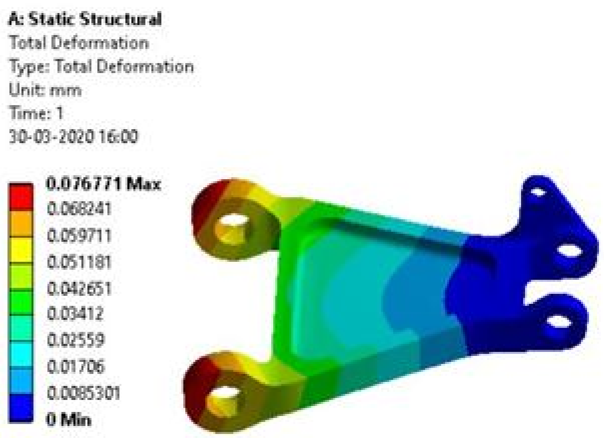

Figure 9 Conventional Design

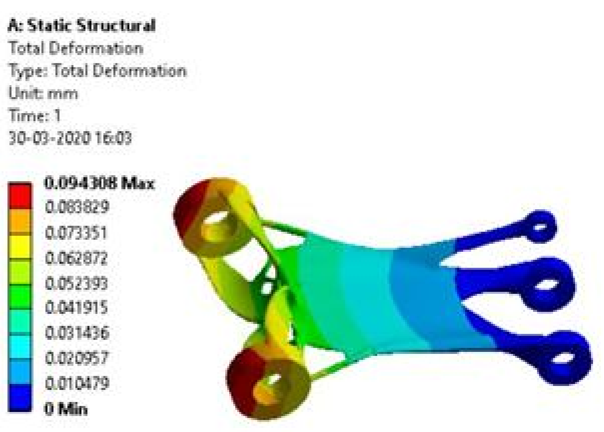

Figure 10 Generative Design Iteration 1

Deformation

Fig 9, 10 and 11 shows total deformation under static loading. Conventional component experiences 0.076771 mm deformation whereas generative designs iteration 1 & 2 experiences 0.094308 mm & 0.089805 mm deformation respectively.

Modal analysis

For shimmy to occur, a force must be applied to the landing gear which excites torsional vibration in Torsion Link. The A380 has around 15 Hertz (Hz) vibration levels [9],so the natural frequency of the generated design should not be around this value to avoid *resonance*. Engineers have hypothesized that an alternating drag force is possibly the force required to start shimmy. As when one tire hits the ground, the internal cylinder twists in one direction and the second tire hits the ground a fraction of a second later, causing the inner cylinder to twist in the opposite direction. In shimmy mode, if the time between the first and second tires connecting the runway is close to the shimmy frequency, the gear can oscillate. Based on the analysis, the body's natural frequency is not near the external vibration of the excitation, so the design assumes to be safe for use.

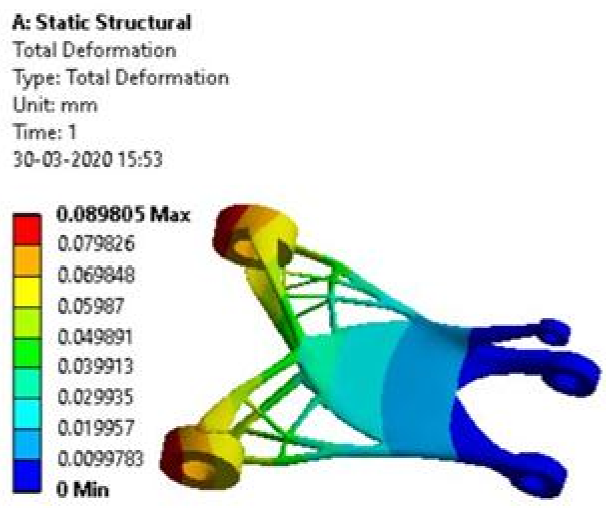

Figure 11 Generative Design Iteration 2

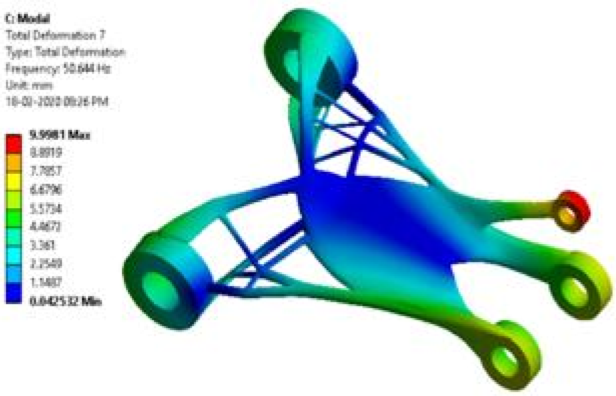

Figure 12 Modal Analysis

Table 3 Mode of Vibration

Mode	Frequency [Hz]
1	3.78e-4
2	5.45e-4
3	1.03e-3
4	50.644
5	71.241
6	107.79

Fatigue Analysis

The objective of design for fatigue loading is to estimate the number of cycles to failure. The physical sign offatigue failure is a minuscule crack initiation on the surface of the component. An S-N curve is a graph between alternating stress (MPa) and the number of cycles (N) to the failure of a material. Fatigue occurs through cracks in metal over time. A lot of investment is done by companies in the experimentation of fatigue analysis because there are a lot of reasons for the cause like component size and shape, loading (axial bending, torsion), surface treatments (thermal treatment, mechanical treatment), surface finish (ground, machines/colddrums, hot rolling, as-forged)

Steps to be followed to asses fatigue life are

1. Estimate the endurance limit of the material
2. Calculate endurance limit correction factors
3. Estimate endurance strength of the component
4. Consider the effect of stress concentration in the calculation of variable stress it needed
5. Calculate variable stress for given fatigue loading
6. Compare variable stress ad endurance limit of a specimen to find infinite life or finite life

The behavior of metal under fatigue loading is the S-N curve.Figure 13 shows the S-N curve of the Ti-6Al-4V.

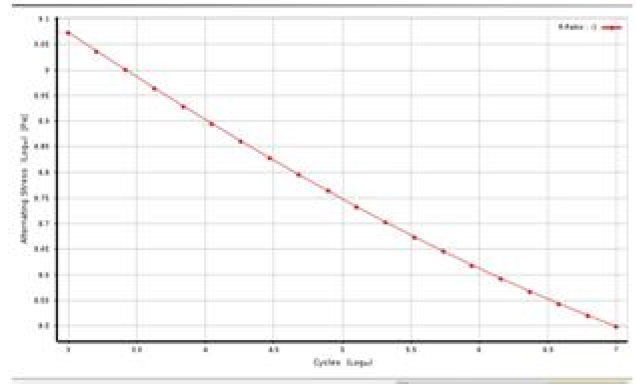

Figure 13S-N Curve of Ti-6Al-4V.

Table 3 S-N curve table

SL.NO	Cycles	Alternating Stress (MPa)
1	1000	1184.5
2	1624	1087.9
3	2637	1000.5
4	4281	921.25
5	6952	849.47
6	11288	784.44
7	18330	725.51
8	29764	672.13
9	48329	623.77
10	78476	579.95
11	127430	540.26
12	206910	504.29
13	335980	471.71
14	545560	442.19
15	885870	415.44
16	1438500	391.21
17	2335700	369.26
18	3792700	349.37
19	6158500	331.35
20	10000000	315.02

With this regard, aircraft have a High fatigue cycle of range 10^5. From Fatigue Life Analysis it is proven that all 3 design is above safety margin with approximate values of 10^7 cycle for al the design iterations

Completely reversed loading

A strictly reversing or cyclic stress means that the stress alternates sinusoidally between equivalent positive and negative peak stress during each operating cycle, as shown.

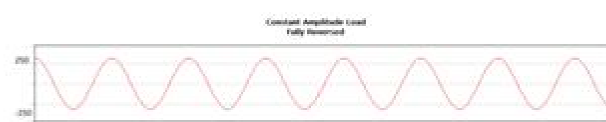

Figure 14 Completely reversed Loading

SODERBERG EQUATION = $\frac{1}{F.S.} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_v}{\sigma_e}$

Se'=0.5Sut , Sut ≤ 1400 MPa

Where,
S_e' = Material property (MPa)
S_e = Specimen property (MPa)
S_{ut} = Ultimate tensile strength(MPa)
K_a = Surface finish factor

Se'= 0.5×1064 = 532MPa
Se = Ka ×Kb ×Kc ×Kd ×Ke× Se'
Ka = c(Sut)d
For machines
C =4 .51, d = -0.265
Ka = 4.51(Sut)-0.265
= 0.71127
Kb = 1 (Axial load)
Kc = 0.85 (Axial load)
Kd = 1 T ≤ 4500C
Ke = 0.868(Reliability for 95%)
Se = 0.71127 ×1 ×0.85 ×1 ×0.86 ×532
= 279.1734 MPa
S = aNb
b =-1/3log(fSut/(Se))
a = ((fSut)^2)/Se
Calculation of f
For 103 cycles=550 MPa
f=550/1064=0.5169
b=-0.09815
a=1083.48
S = aNb=1083.48×105×-0.09815
=350.002MPa
S = aNb
=1083.48×107×-0.09815
=222.725MPa

The Graph between variable stress and mean stress tells the fatigue failure criteria.Goodman criteria are used for brittle materials whereas Soderberg is used for ductile materials, If the point lies inside the curve then it has an infinite life cycle and considered to be safe.

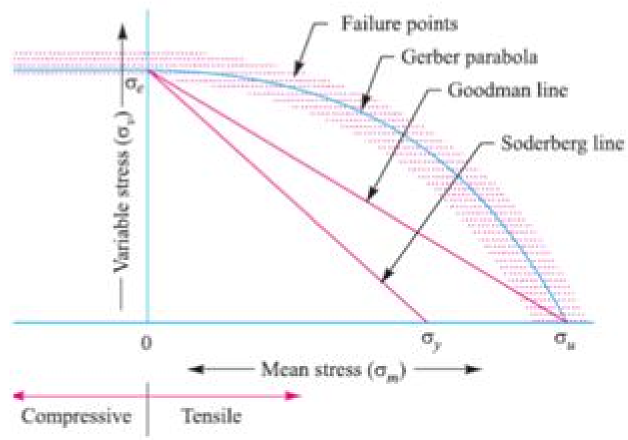

Table 15 Variable stress vs Fatigue stress

Sa*fety Factor*

The safety factor is the structural integrity of a structure above the true loads. The safety factor shows how much stronger the system is proportional to the load expected to be running on it.

The defined load is the standard load which is applied while the body is in operation. Along with other structural properties Autodesk Fusion 360 obtains the safety factor for the design produced. Except as otherwise stated, a FOS of 1.5 is applied to the given limit load which is called external loads on the structure.

V. CONCLUSION

This work is aimed at successfully demonstrating the ability to implement the Generative Design methodology for the assembly of aircraft landing gear, which undergoes various loading conditions. The cumulative weight, efficiency, product manufacturing time and cost of the component were considerably reduced through the use of this method.

The Torsion link is 48 percent lighter than the initial design with the same performance characteristics with the use of the Generative design process. Additives manufacturing is used for the manufacture of parts.

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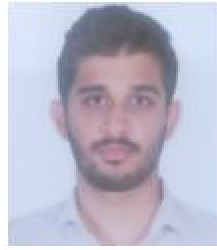

At Dayananda Sagar College of Engineering, Sonu Mathew is currently pursuing a B.Eng in Aeronautical Engineering. He has a particular interest in product optimization.

Dr. Rudresh M is an assistant professor at Dayananda Sagar Engineering College and has nine years of work experience. He did BE (mechanical), M.Tech (engineering design), Ph.D. (mechanical). He has written numerous articles and reviews in international conferences and journals.He has written several books on "Finite Element Analysis," "Cab roof optimisation design," "Split Blade design technique" and "Split Blade design and development".