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Optimization of Landing Gear Mechanism using Generative Design

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Abstract: Combining evolutionary algorithms with additive manufacturing (AM) techniques, new material approaches, in aerospace and industrial applications can result in advanced design procedures. This combination adds extra degrees of flexibility to the final design concept, enabling multifunctional designs. Aerospace, which is heavily focused on customised production, is a perfect fit for AM due to its effects on economies of scale and scope. These technologies are prepared to be included within the generative design process for safety-critical contexts, including the aerospace, thanks to novel structural materials and advanced AM processes. The three primary phases of conventional aircraft design are conceptual design, preliminary design, and detailed design. Multidisciplinary optimization processes are currently being developed to support designer in assessing the optimal solution. Generative Design is a novel form-finding process that takes into account structural performance, material properties and ergonomic demand. Evolutionary design approaches limits to numerical optimization, while Topology Optimization seeks to find an optimal structural configuration within a given design domain for specified objectives, constraints, loads and boundary conditions. This paper focuses on creating appropriate generative design models which can sustain same amount of stresses as of the original model. In the current study the optimization of Boeing 747's nose landing gear is depicted using solidworks and fusion 360. Static structural analysis is utilized to evaluate the effects of stresses and failure mode produced by various materials, in order to figure out a materials characteristic as well as for material selection. Additionally, this paper examines original and generative design models.
Keywords: Landing gear, Generative design, Fusion 360, 3D printing, Additive manufacturing.

I. INTRODUCTION

Aircrafts are a highly complex product that is used in multiple ways, such as commercial and military purposes. They have lots of sub-systems and components, such as fuselage, landing gears, cockpit, wings, engine, ailerons, rudder etc. To make an aircraft tough, strong, and light, design and analysis are done in software to get better results. The future and challenges of aviation involve a balance between costs, environmental aspects, regulations, airliners' requirements and aircraft performance.

The aircraft's landing gear system is one of its most important components since it sustains the craft when it is not in flight, enabling it to take off, land, and taxi without suffering any damage. They are made up of a variety of mechanical and structural parts that enable movement when on the ground and are stowed away inside the aircraft when in flight to minimise drag and increase aerodynamic efficiency. Aviation landing gear, which typically consists of wheels with shock absorbers or more sophisticated air/oil oleo-struts for runway and rough terrain landing, makes up a significant portion of the vehicle. Landing gear is a component used in modern aviation, and is composed of a single nose landing gear (NLG) and two sets of main landing gears (MLG) located in line with the wings of an aircraft. There are various configurations of landing gear layouts, but the tricycle layout is one of the most common. Faster aircraft usually have retractable undercarriages, which fold away during flight to reduce air resistance or drag.

The shock absorber connected to the main strut acts as a spring-damper mechanism to soften vertical loading experienced during landing, the torque-link subassembly provides the landing gear with torsional stiffness to prevent twisting between the main strut and the lower wheel assembly, and the landing gear retraction mechanism allows for storage within the fuselage or wing.

Due to weight and space limitations, few redundancy systems exist within landing gear systems, and they must endure the extreme impact and vibrational loading experienced during landing and braking. The two primary loading cases that are typically considered are vertical loading induced when the tire comes into contact with the ground during landing and fore/aft loading; when brakes are applied to decelerate an aircraft upon landing. However, there are also induced vibrational loads as a result of the loading and can be classified by two possible phenomena: "shimmy" and "gear walk". Shimmy is a type of vibrational loading that can occur in various conditions such as taxiing, take-off, and landings, while gear walk is another phenomenon that is used to describe oscillations in the fore/aft direction of the landing gear strut.

Structural performance is a crucial aspect to consider in the design of landing gears to ensure components are able to withstand various time-dependent loading conditions. Once this behavior has been accurately characterized, various optimization techniques can be used to improve weight, cost, and performance of the part. Advanced design procedures can be combined with Additive Manufacturing techniques to create multi-functional concepts. AM's adoption has increased across industries, with the aerospace industry contributing 10.2% of AM's global revenues in 2012. AM provides the flexibility to create complex part geometries that are difficult to build using traditional manufacturing. Generative Design is a design method for capturing the designer's intent, generating new solutions. Rule-based design-construction programs define the design-programming tool and techniques exploits the principle of database amplification, the identification of rules, and generating complex forms and patterns from simple specifications. Advanced Generative Design System and Tools should include key aspects such as modularity, regularity and hierarchy. The final achieved design is optimized in accordance with the proposed requirements and limits and consists of a "family of designs" according to different parameters.

Tri-cycle arrangement landing gear is an advantageous configuration, but it has its own drawbacks such as weight drag, sudden application of load, acoustics, fatigue, and noise. This work examines the implementation of computer aided generative design using the Fusion 360 by Autodesk. It compares the generative design results of a specific manufacturing procedure and material with a standard engineering approach that uses simple methods according to the Strength of Materials. The main focus is on the design of the three strut links and the two torsion links, which start with the same concept and preliminary design parameters. The standard approach requires a loop between the analytical and finite element analysis (FEA) to design, improve and validate the arms. The generative approach is more straightforward than the standard one, as it produces organic-shaped, optimised solutions. Static structural analysis is carried out for designed geometry of original model and generative models, and primary results of acoustics are compared with available data. Paper is organized as follows; Section II describes the contributions of various researchers in optimization of landing gear. A detailed Methodology is given in Section III. Section IV presents design phase of original model. Generative design approach for landing gear is discussed in Section V. Study of stresses induced in links is studied in Section VI. Finally, Section VII and VIII presents results and conclusion respectively.

II. LITERATURE REVIEW

The contributions made by many authors and researchers in the subject of aircraft landing gear were briefly listed in the current chapter. It comprises generative design approach used for landing gear optimization, also various analysis done on nose landing gear. The literature is based on numerous methods and procedures used to optimise the failure modes and causes of the landing gear system.

The paper by I Zaimis proposes to revise the improvements brought by Generative Design principles within the traditional design procedure in aeronautics, considering Additive Manufacturing technology [7]. Generative Design is a novel procedure to support designer in widely explore the design space, combining several optimization modules to topology definition within a CAD environment. The solution space is generally developed considering freeform shapes, and the selected shape is designed to be manufacture by an Additive Manufacturing process. Low weight and structure's strength used to be the main objectives of aircraft component design, and the development of a robust design procedure that includes Generative design principles would bring great improvements both in components' feature and design results and in design time reduction as well as aircraft operational costs. The study by S. Bagassi, et al presents the different approaches of standard engineering design and the generative design methods [8]. It outlines a design path for the structural design of components using CAD generative design, which is compared with a simple standard engineering approach. The generative design method reduces the design time significantly, while also investigating many different concepts and providing lighter designs. The results are based on linear FEA, providing efficient material distribution, only limited by the manufacturing capabilities. This study shows the potential of this technology and the benefit of the design procedure.

Several material trends for landing gear were presented by Ayan Dutta [2]. Around 60% of the total production volume is Ti 6Al-4V. For steel alternatives, the aerospace industry is looking towards novel materials like AerMet100 and AF1410. Wide body aircraft are paying more attention to Ti 10-2-3 and Ti 5-5-5-3. Several components, including the cylinder brace, upper torsion link, wheel hub, strut, lower torsion link, and tyre, are designed using the CATIA V5 R21 software. Ferrium s53, Ti 10-2-3, and Al 2030 are thoroughly compared in terms of all significant material parameters. The findings of the experiment indicate that the aluminium alloy-containing complete assembly is subjected to a maximum stress of 52 MPa. Maximum stress can be increased using steel alloy up to 67.5 MPa; in addition, titanium alloy gives maximum stress up to 52.2 MPa. Since titanium alloy [Ti 10-2-3] has good material stiffness and reduces deformation, upper and lower torsion links should be built of titanium alloy; since the strut has the maximum amount of stress allocation and should be made of steel alloy [Ferrium s53].

Rajesh A, et al have described about the design and operational requirements of the nose of an aircraft [1]. CATIA V5 R19 is used for this study to create the structure of front nose, moreover various analysis are conducted over the nose. For the study, material properties of steel and aluminium alloy are considered. The results of several analyses include (i) Flow analysis-pressure contour, which represents fluid flow with a Mach number of 0.2 and an angle of attack of -5°, which results in pressure fluctuation in the range of -10742.89Pa to 3364.05Pa and a maximum pressure that rises to 3333.33Pa. (ii) The flow analysis-temperature contour shows that the temperature varies somewhat with varying angles and reaches its highest point at the tip of the nose front cone. (iii) According to mechanical study, landing gear deforms when an impact load occurs during aircraft landing and the axles and struts receive the most load. The most deformation of the aluminium alloy occurs under the specified loading conditions, and the greatest distribution of stress for impact loads is in the steel. The paper by G Krishnaveni, et al describes about the buckling analysis of nose landing gear [3]. It is predicted around 50% of accidents of aircraft are occurred due to failures of landing gear. For buckling analysis MSC.PATRAN software is used for pre-processing and postprocessing MSC.NASTRAN as solver is used. Titanium Ti-5553 alloy is employed for the analysis, and mesh elements are also utilised. Titanium has been given its isotropic material characteristics. The nose landing gear receives around 15% of the aircraft's load; as a result, the total static load applied to the nose landing gear is 98590.5N, and the strut receives a point load acting of 1221.61N. Analysis has shown that the landing gear won't budge in the static situation just before takeoff. According to the findings of these investigations, an aircraft's landing gear deforms most when it makes an impact and experiences heavy drag. Maximum stresses are transferred to the axles and struts of the landing gear assembly during impact loading. When there is no movement or static activity on the ground, buckling has no impact on the landing gear assembly and its components. Buckling is taken into account for dynamic loading and for impact and high drag conditions.

III.METHODOLOGY

Study of landing gear arrangements and its all components
- Choosing arrangment for generative design

Selection of Appropriate material
- Using Ti 10-2-3 and SS316L for manufacturing parts

Study of Stresses, loads and failures in landing gear
- Considering all Safety requirements and mechanical properties for design

Design of Structural and Aerodynamic elements
- Using CREO and ANSYS CFX solver

Selection of links to be optimized in the mechanism
- Considering the weight, volume and the necessity of the parts optimization is decided

Testing and Analysis of the Initial Design
- Using Matlab and ANSYS liner dynamic solver

Creating generative designs of different links
- Using Fusion 360 to create low weight and volume design

Testing and Analysis of the New Design
- Using Matlab and ansys liner dynamic solver

Manufacturing Both Initial and Generative design models Using 3D printing method
- Using low cost alternatives Final manufacturing of the product using DMLS

Comparison of both the designs (original and generative)
- Ex: original & optimized weight, stress induced, deformation

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IV. DESIGN PHASE

The conceptual traits of a CAD model are described in this section. The location is significantly impacted by different driving stability restrictions. The load is at its greatest intensity during the level landing scenario, whereas the structure is susceptible to diverse load directions during the side and forward loading situations. The nose landing gear bears 3-5% of the entire load. The maximum take-off weight of an aircraft is 440,000 kg, and the nose landing gear bears 5% of the total weight, around 22,000 kg. A static load of 215600 N has been selected for the nose landing gear (assuming minimum F.O.S = 7.5) taking into consideration maximum take-off weight. The nose landing gear weighs about 4500 kg. The landing gear components' average weight distribution is-

Table 1: Weight distribution of components in landing gear

Component name	***Material***	***Number of parts***	***Total weight***
Oleo strut shock absorber	Annealed steel	Cylinder and piston	580.47 kg.
Mounts	Annealed Steel	03	50.6 Kg.
Secondary shock absorber	Annealed steel	Cylinder and piston	62.5 kg.
Strut links	Stainless Steel 316L	03 x 107	322 Kg.
Torsion links	Stainless steel	02 x 62	125 kg.
Wheel axle	Annealed Steel	01	2952 Kg.
Wheel hub	Titanium alloy	01	90.86 kg.
Tyres	Rubber	02	--

For the optimization using generative design, we selected strut links and torsion links; Strut has highest amount of stress allocation should be made of steel alloy [Stainless Steel 316L] and Titanium alloy [Ti 6Al 4V] has good material stiffness which reduces deformation, so upper and lower torsion links should be made of titanium alloy.

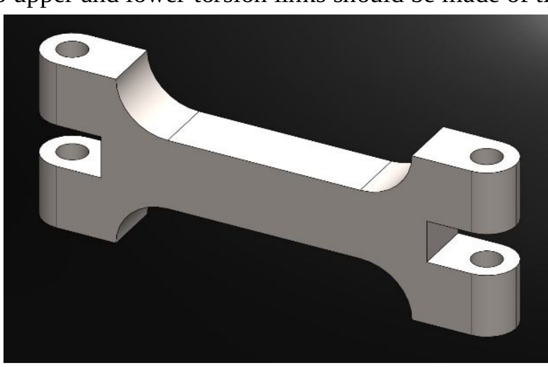

Fig 1 Oleo strut link

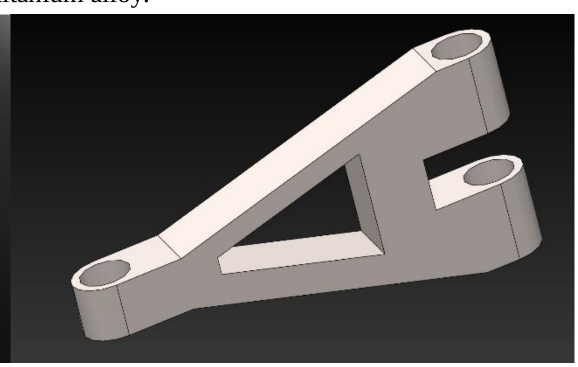

Fig 2 Torsion link

V. GENERATIVE DESIGN

Fusion 360 is used to perform the generative design for each part separately. The design space should first be specified, as seen in Figures 3 and 4. The areas that should be preserved for future use or need not to be optimized are identified by the green shapes. Based on linear FEA simulations and the level set method, the algorithm effectively links these locations with material routes. The red shapes serve as obstacles in areas where material paths shouldn't cross them. The different components will have the desired clearance and particular mounting locations due to the clearly specified obstacles. The various load scenarios are then described. The parts should be arranged parallel to the manufacturing directions. The component gets converged till the last iterations.

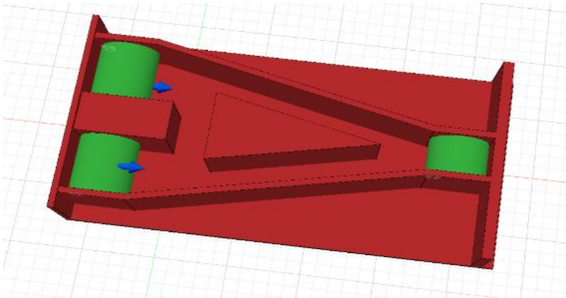

Fig 3 Obstacle geometry - Torsion link

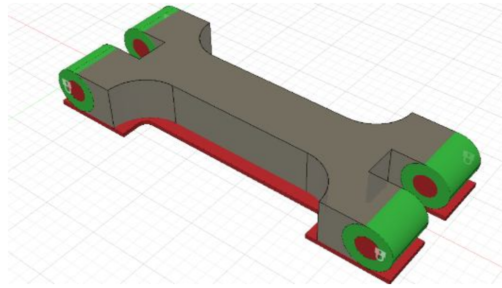

Fig 4 Obstacle geometry – Oleo Strut link

Fig 5 Generative design – Torsion link (Front)

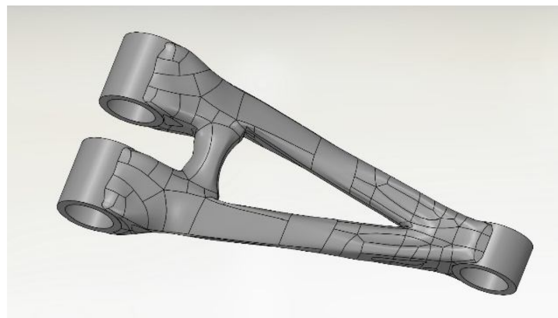

Fig 6 Generative design – Torsion link (Back)

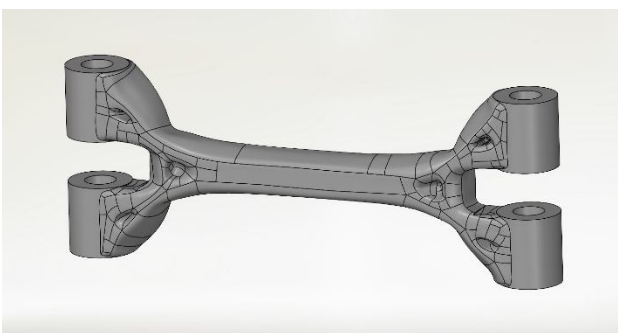

Fig 7 Generative design – Oleo Strut link (Front)

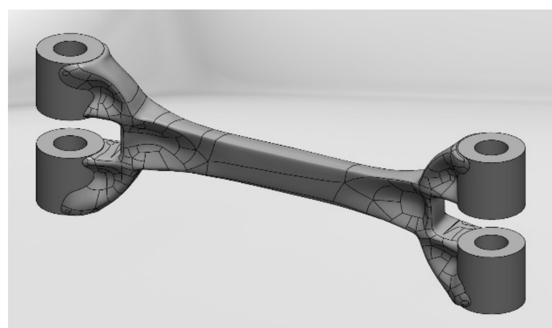

Fig 8 Generative design – Oleo Strut link (Back)

VI. DESIGN ANALYSIS

The components are exported as CAD files and examined by ANSYS software (Static structural) to verify the results. As the produced surfaces are quite complex, tetrahedral second order elements are produced by an automatic mesh generator. The connections between the components, the constraints and the loads are identical to the standard engineering approach.

For the analysis, in each link one side was considered as pin support and other side was elastic support. During landing, the Torsion link experiences a high vertical load and a significant bending moment. The approximate load acting on the Torsion link during landing can be around 140 KN to 200 KN.

During landing, the Oleo Strut Link experiences both compression and tension loads as the landing gear compresses and rebounds. The approximate load acting on the Oleo Strut Link during landing can be around 70 KN to 100 KN. For calculations, we have considered 100 KN load for Torsion link and 150 KN for Oleo Strut link. On the left side, static analysis of original model is shown, while on other side generative model analysis is depicted.

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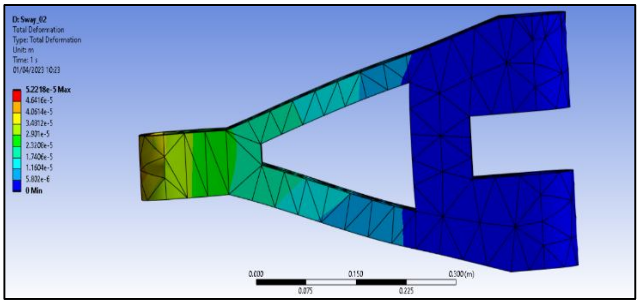

Fig 9 Total Deformation – Torsion link (Original)

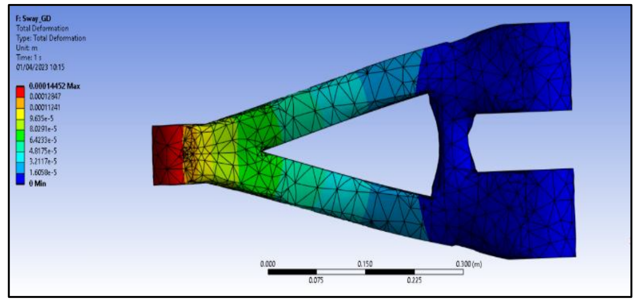

Fig10 Total Deformation–Torsion link (Generative design)

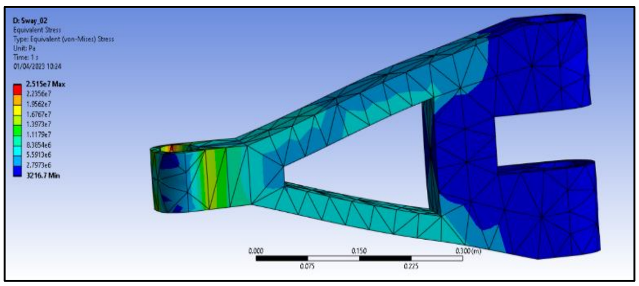

Fig 11 Equivalent stress – Torsion link (Original)

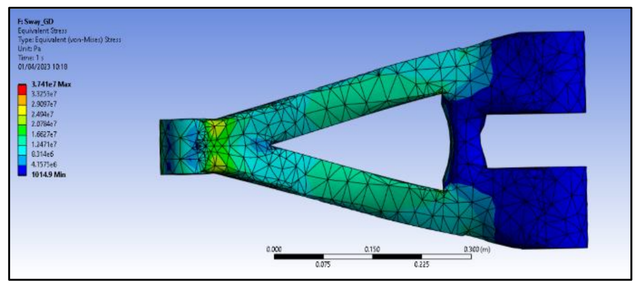

Fig12 Equivalent stress – Torsion link (Generative design)

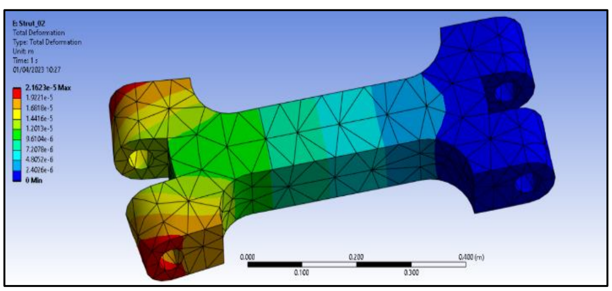

Fig 13 Total Deformation – Oleo strut link (Original)

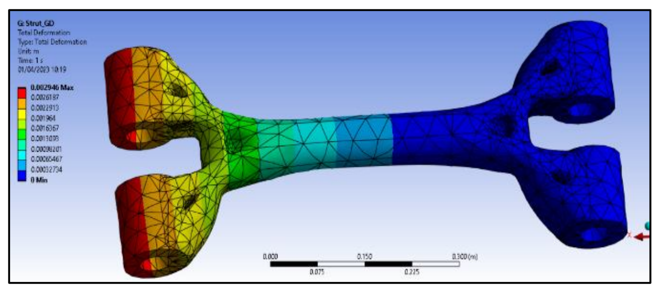

Fig14 Total Deformation–Oleo strut link (Generative design)

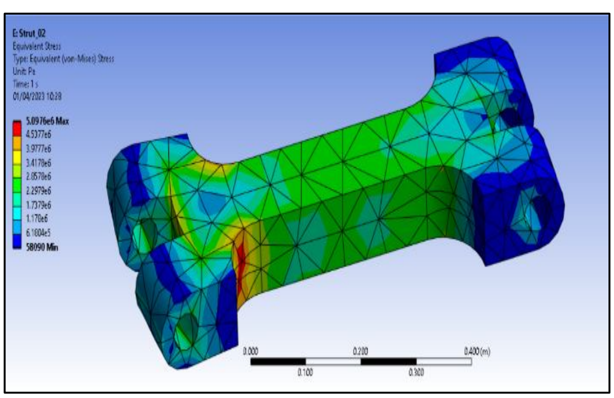

Fig 15 Equivalent stress – Oleo strut link (Original)

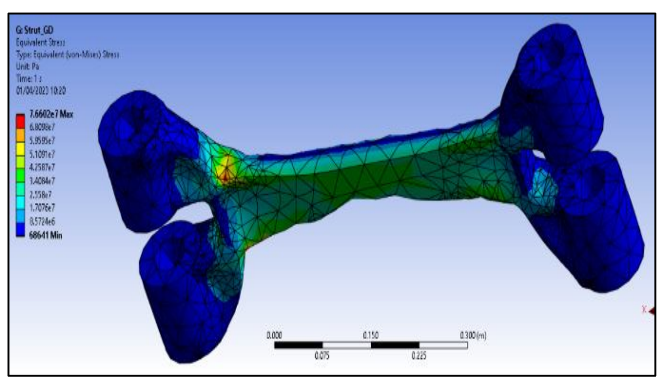

Fig16 Equivalent stress –Oleo strut link (Generative design)

VII. RESULTS

Table 2 Results of Oleo Strut link using AISI 316 Stainless Steel, Ti-6Al-4V and Aluminium AlSi10Mg

OLEO STRUT LINK

Factors	Original	Iteration 1	Iteration 2	Iteration 3
Material	Annealed Steel	AISI 316 Stainless Steel	Ti-6Al-4V	Aluminium AlSi10Mg
Manufactruing Method	Conventional method	Additive Manufacturing	Additive Manufacturing	Additive Manufacturing
Volume (mm^3)	13283528.24	5053535.865	5045646.054	4147154.5
Mass (kg)	106.27	50.297	22.35221202	11.07290252
Max von Mises stress (MPa)	40.0911	39.13765663	35.03098	37.53164515
Factor of safety limit	2	2	2	2
Min factor of safety	7.5	7.105	6.76	7.145
Max displacement global (mm)	0.0271907	0.026618217	0.041138994	0.071556518
Percentage of Reduction in mass	--	53 %	79 %	89 %

Table 3 Results of Torsion link using AISI 316 Stainless Steel, Ti-6Al-4V and Aluminium AlSi10Mg

TORSION LINK

Factors	Original	Iteration 1	Iteration 2	Iteration 3
Material	Annealed Steel	AISI 316 Stainless Steel	Ti-6Al-4V	Aluminium AlSi10Mg
Manufactruing Method	Conventional method	Additive Manufacturing	Additive Manufacturing	Additive Manufacturing
Volume (mm^3)	7609382.33	4461535.865	5052646.054	5243535.865
Mass (kg)	60.88	35.928	22.38221202	14.3578
Max von Mises stress (MPa)	70.448	66.186465663	55.73098	55.55465663
Factor of safety limit	2	2	2	2
Min factor of safety	8.5	8.557	8.712980356	7.04765445
Max displacement global (mm)	0.0587365	0.057618217	0.086138994	0.048618217
Percentage of Reduction in mass	--	41 %	64 %	77 %

VIII. CONCLUSIONS

The research concludes with a design approach for CAD generative design and structural design of components. The ANSYS software is used to validate both approaches. Results from the original model are based on standardized criteria. While the production time is shorter due to the simplified shape, the design time is longer. The generative design approach drastically minimises on design time while also exploring a wide range of ideas and producing lighter solutions. Three different materials—AISI 316 stainless steel, Ti-6Al-4V, and aluminium AlSi10Mg—are used to develop the results of generative design. Around 40 to 80 percent less mass than the mass of the real models is eliminated. For Oleo Strut link, Stainless Steel 316L is preferred which shows 50% reduction in mass and in torsion link 60% mass reduction is observed considering Titanium alloy is best for the component. The outcomes are based on the static structural approach, which offers effective material distribution and is only constrained by the production capabilities.

The present research shows the potential of this technology and the advantage of the design process as generative design evolves and in view of iso-geometric analysis and 3D printing establishing themselves in the industry. Reducing the weight of an aircraft's landing gear can provide several benefits, including: Airlines can save on fuel costs and reduce their carbon footprint; Increased payload capacity; A lighter aircraft can take off and land more quickly and require a shorter runway. This can enable airlines to operate in airports with shorter runways, and increase the number of available destinations; lower maintenance costs over the lifespan of the aircraft; In emergency situations, such as a forced landing or a crash, a lighter aircraft may experience less damage than a heavier one. This can potentially reduce the risk of injury or fatalities for passengers and crew.

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