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Review on Failures, Design and Material Optimization Techniques in Aircraft Landing Gear Mechanism

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Abstract: Landing Gear is proved to be the most critical subsystems in aircraft. It is a crucial part in all ground operations, take-off and landing of aeroplane. Landing gear operates as dead weight after an aircraft is in the air, burning more fuel and taking up room which can be used for other safety measures. When taking into account all the legal and safety standards, it is vital to shorten the time needed for the landing gear design and its development cycle. All aerospace sectors strive for attributes such as minimal weight and volume, great performance, and reduced life cycle costs. Our objective was to create a landing gear with the least amount of weight and volume while maintaining maximum structural integrity. To achieve this goal, we designed landing gear links using generative design. In addition to this, we also studied different parameters considered for landing gear design.

Keywords: Landing gear mechanism, generative design, finite element analysis, design optimization, 3D Printing.

I. INTRODUCTION

Aircraft landing gear mechanism is most critical subsystem of entire aircraft, moreover it has most substantial influence on structural configuration of aircraft. Landing gear is the undercarriage that is used for take-off and landing. The main purpose of landing gear in aircraft is to provide a suspension system during taxi, take-off and landing.[14]

Absorption and dissipation of kinetic energy are key elements considered while designing landing gear, which ultimately reduces impact loads transmitted to aircraft frame. It also helps in directional control of the aircraft on ground.[10] In latest design of aircraft, Landing gears are kept retractable to minimize aerodynamic drag during flight.

The landing gear integration and design process includes knowledge of many engineering disciplines such as structures, dynamics, kinematics, fluid mechanics and runway flotation.

The geometry, flotation requirements, mission requirements and operational requirements of the aircraft govern the landing gear configuration. The configuration design includes choice of number of wheels, tire sizes, pressures, type of shock absorbers, landing gear layout, retraction kinematics and bay geometry design.[14]

The landing gear design also accounts various requirements of strength, stability, stiffness and ground clearance and damping under all possible ground altitudes of aircraft.[14] There are three types of landing gear arrangements: tail wheel- type landing gear (also known as conventional gear), tandem landing gear, and tricycle-type landing gear.

Tail wheel-type landing gear is also known as conventional gear, because many early aircraft use this type of arrangement. Today, aircraft are manufactured with conventional gear for the weight savings accompanying the relatively light tail wheel assembly. The main gear is located forward of the centre of gravity, causing the tail to require support from a third wheel assembly. A few early aircraft designs use a skid rather than a tail wheel. This helps slow the aircraft upon landing and provides directional stability.

Few aircraft are designed with tandem landing gear. As the name implies, this type of landing gear has the main gear and tail gear aligned on the longitudinal axis of the aircraft. A few military bombers, such as the B47 and the B-52, have tandem gear, as does the U2 spy plane. Sailplanes commonly use tandem gear; many only have one actual gear forward on the fuselage with a skid under the tail.

The most commonly used landing gear arrangement is the tricycle-type landing gear. It is comprised of main gear and nose gear. The nose gear of an aircraft simply casters as steering is accomplished with differential braking during taxi. The main gear on a tricycle-type landing gear arrangement is attached to reinforced wing structure or fuselage structure. Many main gears have two or more wheels. The tricycle-type landing gear arrangement consists of many parts and assemblies. These include air/oil shock struts, wheel and brake assemblies, gear alignment units, support units, retraction and safety devices, steering systems, etc. It also provides better visibility from the flight deck, especially during landing and ground maneuvering and prevents ground-looping of the aircraft.

3D printing is making a significant contribution in aerospace industry. It allows engines with sophisticated geometries, defined aerodynamic and fluid dynamic properties to be produced, as well as lightweight structures whose individual parts weigh up to 60 % less. Processing superalloys is also more cost-effective with 3D printing, since the material usage rate is lower. The results significantly reduced environmental pollution over the lifetime of the aircraft. Parts made from a single piece are also more resilient and less susceptible to damage.

The increased speed of design is perhaps the most obvious benefit generative design provides, and one that will prove crucial to the entire product lifecycle. When a generative design algorithm receives the requirements, it needs for a part or system, it will create many even hundreds of different options in a short span of time for engineers to work from. These requirements include geometric constraints and allowances, but can also include non-geometric concerns like materials, fuel efficiency, and emissions.

Paper is organized as follows; Section II describes the Material selection and requirements in landing gear. The design and failure optimization techniques are discussed in Section III. Section IV presents a detailed Methodology. Finally, Section V presents conclusion.

II. MATERIAL SELECTION

Material selection plays an important role in designing of landing gear; with can reduce failures up to large extent. Failure analysis of checking of material composition, manufacturing processes, heat treatment methods, loads, nature of cracks. Material used for landing gear should have high specific strength and fracture toughness and excellent fatigue properties. Ayan Dutta [2] presented various material trends for landing gear. Ti 6Al-4V accounts around 60% of whole production volume. Aerospace industry is moving towards new materials such as AerMet100 and AF1410 for steel replacements. Ti 10-2-3 and Ti 5-5-5-3 are gaining more attention for wide body aircraft. CATIA V5 R21 software is used for designing of various elements, such as: cylinder brace, upper torsion link, wheel hub, strut, lower torsion link and tyre. A detailed comparison of all major material properties is shown between Ferrium s53, Ti 10-2-3 and Al 2030. Experimental results shows, 52MPa maximum stress is induced on whole assembly having material Aluminium alloy. Using steel alloy, maximum stress increases up to 67.5MPa, additionally to this, Titanium alloy offers Maximum stress up to 52.2 MPa. As a result, Strut has highest amount of stress allocation should be made of steel alloy [Ferrium s53] and Titanium alloy [Ti 10-2-3] has good material stiffness which reduces deformation, so upper and lower torsion links should be made of titanium alloy.

Mr. Pavankumar Hebsur, et al, [13] shares, work analysis using three different materials; like SAE 1035 steel, 7075-76 Aluminium alloy and Ti-6Al-4V Titanium alloy with detailed comparison of their physical properties. Landing of aircraft may be roughly or smoothly hence different loads acts upon it they are drag load, vertical load and side load etc. so the landing gear must be designed in such a way that it must withstand these loads in static and dynamic conditions. A 3d model of the landing gear in CATIA software is created and ANSYS is used to determine the variation in the displacement and von misses stress behaviour for three different materials, which is subjected to static loading for the same loading condition. The maximum stress of three alloys are plotted 7075-76 Al has 324.64 MPa, whereas Ti-6Al-4V has 278.26 MPa and SAE 1035 steel 231.88 MPa. In Conclusion, the SAE 1035 steel has less stress concentration and less deformation of material which makes SAE 1035 steel best suitable for any type of landing. Aditya Armaan, et al [10] demonstrated all Landing gear failures can be occurred due to various reasons; such as metallurgical, environmental, design, processing and overload failure. The paper discuss landing gear application in various aircrafts and their failure causes. Study says, Corrosion and contact stresses initiate the fatigue cracking. Heat treatment process also decreases fatigue endurance limit. Recrystallization also initiates the fracture; mostly aluminium alloy has grain boundary precipitation and recrystallization. Failure fractographic analysis is done using visual examination, non-destructive testing, fractography and micro-analysis which predicts crack growth behaviour.

Divakaran V.N; et al, [14] presents that manufacturing of landing gear involves processes like; closed die forgings, machined components from ultra-high strength steels, titanium and aluminium alloys. Structural strength tests and environmental tests including vibration, acceleration, temperature, altitude, salt spray, sand and dust etc. are performed on the landing gear. For some components in the landing gear Composites are being used because of their superior specific strength and stiffness properties.

On other hand, Ultra-high strength steels are used due to its high strength to weight ratio and size advantage. Moreover, with improved manufacturing techniques, cost factor is now being over-come. Depending upon the applications of landing gear components, the choice of material is done, and this requires trade off studies of strength, stiffness and cost to arrive at the optimal choice. Fatigue and fracture toughness properties and aspects like protection against stress corrosion, wear, reliability in service etc. are other considerations in the selection of material for the landing gear. Good corrosion protection is important for the landing gear components as they are susceptible for easy environment attack. Reduced weight, longer life and maintenance free wheel brakes are the key advantages of Carbon composite brake disc which ultimately reduces the cost per landing. Use of corrosion resistant materials is also becoming increasingly popular. Apart from normal electrolytic finishes like cadmium plating, hard chromium plating, HVOF etc. epoxy or polyurethane primer and polyurethane top coats are applied for the exposed landing gear parts. P. I. Pradeep; et al, [15] have studied the additive manufacturing using AISI 316L material. Recognition of 3D printing as a revolutionary type of processing to replace fabricated components, including castings, wrought products and multiple piece assemblies, it produces parts with minimum material wastage and allowing higher level of design optimization. For the studied, two brackets of type -1 and 2 was identified and material chosen was an austenitic grade stainless steel; which is majorly used for wrought products, with molybdenum addition to increase the corrosion resistance, hardenability, normally used as toughness, tensile strength and carbon content restricted to improve immunity against sensitization (grain boundary carbide precipitation). In comparison with conventional manufacturing, a reduction of lead time and cost for components are the characteristics of Additive Manufacturing; short lead time from design to manufacturing, adaptability to design changes, complex geometries at no extra cost and considerably less post-processing are other features. Laser powder bed fusion was selected to 3D print the brackets. Brackets are tested in a Zwick Universal Testing Machine for evaluating the tensile properties. Charpy test with V-notch, Microstructural Evaluation and Computed Metro Tomography (CT) Inspection were conducted for properties evaluation. In non-destructive testing, brackets were found free from the defects. Type-1 bracket were observed with Minor warpage on the thin and unsupported edges, and causes of these problems were identified as thermal stresses during 3D printing leads to distortion of the thickness with slender edges and supports were not adequate to resist the distortion. The root cause for the lower deviation of Type-2 bracket is improper spreading of powder at the layer. The Soundness of brackets produced by 3D printing is confirmed by Computed metro tomography analysis. The parts produced with 3D printing has higher level of porosity than that of wrought products; however, this will not affect the functionality of the products. Structural testing results showed that the strain observed is negligible even at four times the actual load experienced in service. As a result, there is huge scope for design optimization for these brackets utilizing the potential of additive manufacturing and weight reduction can be achieved using topology optimization.

Zhongji Sun; et al [16] conducted study with selective laser melting and Stainless steel 316L. The study aims to prove how to build SLM based parts without any loss of parts density and mechanical properties. For this, Authors choose to fabricate high density stainless steel 316L parts using selective laser melting, to improve production rate by reducing the primary process timing; while maintaining a low porosity. At some places, detection of vertical cracks was found. Due to uneven suspended powder inside the build chamber during melting, these cracks are generated. It was observed that fine cellular size was the reason to have high strength and high hardness in SLM build parts. The study resulted in approximately 72% enhanced overall build rates as compared to commonly used processing parameters. Moreover, the microhardness of the build parts has also increased, as compared to standard annealed counterparts.

Aluminium alloys have grain boundary precipitation and recrystallization which is responsible for intergranular corrosion and pit cavities ultimately reducing the load carrying strength. Also, aluminium alloy goes under maximum deformation during impact loading. For preventing such precipitations material undergoes heat treatment process. Sometimes, faculty heat treatment process leads to decrease in endurance limit and grain boundaries, so it is very crucial to assess conditions during process.

It is understood that, Strut has highest stress values imparted over it and it should be strong enough all the loads so, should be made of steel alloy, although steel weight is more but it has better mechanical strength and Titanium alloy has good material stiffness which reduces deformation, so upper and lower torsion links should be made of titanium alloy. As compared to titanium alloy, steel has 66% more weight. Aluminium alloy is best suited for Wheel hubs, while bolts and nuts are made of stronger material i.e., steel. SAE 1035 steel proves to be the best suitable material for the landing gear, as it has less stress concentration and less deformation occurrence when load is applied over it. Excellent stress distribution in steel alloys is the key advantage of this material. Study also resulted that stainless steel 316L material is used for different components in aerospace industry, it has good structural strength and handle thermal stresses without affecting functionality of component. SS 316L can processes using additive manufacturing process to produce aerospace parts, which results in less defective errors in parts.

III.DESIGN AND FAILURE OPTIMIZATION TECHNIQUES

Landing gear is given an immense significance of all other aircraft components; it is designed to provide suspension during taxi, take-off and landing segments of the flight. Performance, safety, time frame, cost, technology and resources are the key drivers of the landing gear design. The landing gear geometry is defined along with kinematics. Dynamic simulations for material selection and preliminary sizing of components are estimated from the ground loads. The actuation mechanism, loads and take-off studies are taken in account to enhance weight, volume and cost. Rajesh A, et al, [1] have described about the design and operational requirements of the nose of an aircraft. 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. Various analysis was conducted; from which (i) Flow analysis-pressure contour describes fluid flow with Mach number of 0.2 and angle of attack -5° results in pressure variation in range of -10742.89Pa to 3364.05Pa and maximum pressure goes up to 3333.33Pa. (ii) Flow analysis-temperature contour outcomes in slight temperature variation with changing angles is found and maximum temperature is seen at the tip of nose front cone. (iii) Mechanical analysis presents that, landing gear goes under deformation when impact load acts during aircraft landing and maximum load is transferred to axles and struts. With given loading condition, aluminium alloy goes under maximum deformation and maximum stress distribution is in steel for impact loads. G Krishnaveni, et al [3] This paper describes about the buckling analysis of nose landing gear. 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 post-processing MSC.NASTRAN as solver is used. For the analysis, Titanium Ti-5553 alloy is used, moreover for meshed elements Isotropic material properties of titanium is assigned. Around 15-20% of aircraft load acts on nose landing gear; so, the total static load applied on nose landing gear is 98590.5N and strut has point load acting of 1221.61N. As a result of analysis, landing gear will not buckle in the static condition before aircraft take-off. These studies resulted that maximum deformation in landing gear takes place when impact and high drag landing of aircraft occurs. During impact loading, maximum stresses are transferred to axles and struts of landing gear assembly. Buckling does not affect the landing gear assembly and components during static conditions and ground activities. Buckling is taken into account for dynamic loading and for impact and high drag conditions.

Chen Huang, et al, [6] has aimed towards kinematics of operating actuator is modified with geometric dimensions to achieve optimal actuating force during landing gear retraction. The primary purpose is to exploit the dynamics and develop optimization strategy with minimum computational cost. For the analysis, the mechanism is constrained fully and inverse dynamic analysis is applied. The result are verified using three different optimization techniques: multi-island genetic algorithm (MIGA), Design of Experiments (DOE) and Sequential Quadratic Programming (SQP) refinement. The main operating actuator stroke function equals the maximum power required during retraction of landing gear.

For weight reduction and cost saving in aircraft's landing gear, topology optimization approach is used; which reduces design and development cycle of landing gear and keeps its structural strength intact. J. Wong, et al, [4] have presented an efficient methodology that applies high-fidelity multidisciplinary design optimization techniques to commercial landing gear assemblies, for weight reduction, cost savings, and structural performance dynamic loading. Specifically, a slave link subassembly was selected as the candidate to explore the feasibility of this methodology. The design optimization process utilized in this research was sectioned into three main stages: setup, optimization, and redesign. Different input motions are considered for multi-body dynamics; Translational motion for lower strut due to compression of shock absorber during landing and vibrational loads on the system during landing. To replicate these motions, rotational motions about Y and Z axis to lower strut and upper strut are prescribed respectively. The topology optimization algorithm chosen for analysis was dual optimizer. Iso-surfaces were used to revise and create light weight designs. The utilization of Equivalent static load method [ESLM] for Multi-body dynamics [MBD] analysis can enable users to do optimization considering various parameters. The final outcome of topology optimization was of 36% of overall weight saving, 6% of peak stress increase and 60% of cost saving. Milad Zarchi, et al, [5] studied the traditional landing gear system and its performance on ground maneuvering with extreme forces and vibration absorption under normal conditions, whereas with varying condition of landing and situation of the runway for the airplane, performance of this system decreases noticeably. For overcoming this problem, the parameters of hydraulic nonlinear actuator added to the traditional shock absorber system, and the vibration absorber are optimized simultaneously. This paper also presents the sensitivity analysis of three-point landing due to the additional payload and the touchdown speed and the robustness analysis of one- and two-point landings due to the wind conditions as emergency situation for an Airbus 320-200. The Bee Swarm-based algorithm is used for optimization in this research, which is inspired from natural foraging behaviour of honey bees. The algorithm requires many numbers of parameters, and differential recruitment is a key operation of this algorithm. In this research, this algorithm is applied to active vibration system having high and low pressure, damping and stiffness coefficients.

The two multi-objective function deducts the error in sprung mass due to additional payload and touchdown speed due to environmental conditions. As a result, the impact force during landing phase is significantly limited by active suspension. The root mean square (RMS) is reduced by 35% for level loads and the value of power spectral density (PSD) is also reduced compared to common passive shock absorber subsystem. The different approaches of the generative design methods was investigated by I Zaimis, et al, [7]. The case study of a nose landing gear for a prototype tactical unmanned aerial vehicle, intended for low volume production was undertaken. Firstly, the stresses were calculated, then the generative design study is carried out using Fusion 360. Both concepts are studied with finite element analysis to validate the strength requirements according to the STANAG 4671. The arms are manufacturing using Al7075-T6, with endurance limit of 175MPa and yield limit of 503MPa. The results are based on the linear FEA and provides efficient material distribution with the view of iso-geometric analysis. The final structure will be manufactured with 3-axis CNC machining, while providing about 36% weight reduction without compromising the structural functionality.

From the above reviews, Bee-swarm based optimization algorithm is a multi-objective function with differential recruitment is also widely used for landing gear's mathematical analysis and also helps in detection of errors of small components like sprung masses which can lead to major accidents in landing gear. With help of this algorithm, suspension system of landing gear is redesigned with bounce momentum decreased up to 52%. The optimization strategy sometimes exploits the dynamical characteristics of landing gear retraction, which ultimately reduces computational cost. With topology optimization, generative design is gaining huge significance in aerospace industry. With iso-geometric analysis, around 36-54% lighter design in terms of weight and volume can be produced with simpler geometries.

Landing gear failure is a very sensitive issue, as a failure can led to loss of control of the aircraft. Asad Hameed, et al, [8] have studied the failure study with the analysis of a nose landing gear support strut of an aircraft that failed during landing within 2 sec after nose wheel touchdown. Finite element method was used to find the (overload failure) stress in the eye-end bolt during landing. The failure occurred during the fourth landing of the aircraft. Visual inspection revealed that the threaded portion of an eye-end bolt of the support strut was fractured. During detailed fractography, no indication of progressive failure was observed; on the contrary, clear signatures of overload failure were found. The pin had damage marks on the adjacent brackets. The stress at the fractured region was within the yield limit for all cases of normal operation. However, the stress rose to well beyond UTS when one pin connection was dislodged from the housing, owing to a likely improper installation. The fractured area had dulled visible morphology of around 87%. The landing was very rough and hard in which approximately 20% of aircraft weight acted over nose landing gear. The landing gear was under safe condition in all normal operational parameters. It was recommended to have independent 'quality assurance' check after every take-off and landing. Yanpeng Feng, et al, [9] investigated, A MLG sliding tube from one airline operated A320 aircraft, was diagnosed with a crack indication at one end of the axle arm. The part had completed about 25,000 cycles and 8,000 cycles since overhaul. The part was sent to different inspection test like; acid etch inspection, magnetic particle inspection, and Barkhausen noise inspection. The mode of crack propagation across the whole surface was intergranular, the crack surface was heavily corroded. A region on the outer diameter encompassing the crack had been blended prior to the receipt. Deformation was observed on the unblended inner diameter, suggesting that this location suffered a significant impact which imparted residual stress into the component. Aditya Armaan, et al [10] demonstrated all Landing gear failures can be occurred due to various reasons; such as metallurgical, environmental, design, processing and overload failure. The paper discuss landing gear application in various aircrafts and their failure causes. In commercial aircrafts, the major portion of impact energy is absorbed by landing gears, thus MRF (Magneto Rheological Fluids) dampers are gaining huge significance. These dampers have faster responses and maneuverability at the same time with same structures. Dynamic loads affects the main landing gear, due to aerodynamic excitation which ultimately results in performance decrease. The passive momentum exchange impact damper (PMEID) helps in increase of payloads and prevent tipping. In military aircrafts, it is studied that crack propagation starts from areas where fatigue cracks are already present. Corrosion and contact stresses initiate the fatigue cracking. Heat treatment process also decreases fatigue endurance limit. In Space vehicles, in order to convert vertical motions into horizontal motions liquid spring damper is made, which make use of buoyant force in underwater gliders. Recrystallization also initiates the fracture; mostly aluminium alloy have grain boundary precipitation and recrystallization. Failure fractographic analysis is done using visual examination, non-destructive testing, fractography and micro-analysis which predicts crack growth behaviour. Luís Fernandes [11] did a detailed analysis of a nose landing gear failure. In the aviation industry, Nose gear failures are a high concern. In average 55% of aircraft failures occur during take-off and landing. In order to determine the causes of the accident, a detailed study of the fracture's surface both visually and using optic and scanning electron microscopy. This cracking is characteristic of the existence of areas of stress concentration.

After having identified the crack initiation zone due to the beach marks near the origin of the crack, combined with the fact that the nose wheel fork was subjected to cyclic loading, leads to the conclusion that the component failed due to fatigue. Due to number of successive load cycles, bench marks or plastic deformation takes place. Cyclic bending stresses causes fatigue cracks. The vertical and drag loads are taken into account for analysis. The stress amplitude is much higher in plastic deformation areas and fatigue cracks are occurred in stress concentration zones. V. Infante, et al [12] aims at a detailed analysis of two in service failures concerning trunnions of landing gears of military aircrafts. The primary causes of failure were found out using, visual examination, chemical analysis and macroscopic, microscopic and microstructural examinations. The progress of the fatigue cracks was determined based on the observation of beach marks and cyclic plastic deformation. The stress system that produced failure, which is closely dependent on the mechanical behaviour of the material. The visual observation of the fractured surface immediately indicates that these failures occurred by a fatigue process. A main area of the fracture surfaces present high stress failure facies. The initiation zone does not have any metallurgical defects. The trunnion strut has fatigue fracture with slow cracking rate; and failed by overload. Failures in landing gears are caused due to several reasons; such as: Metallurgical failures (Material recrystallization and Grain boundary precipitation), Processing failures (High cycle fatigue [surface defects like oxides] and Low cycle fatigue with multiple cracks), Environmental failures (Change of temperature; corrosion), Design failures (Material properties, generated stresses, Fracture toughness and safety factors) and Overload failures (Local residual and mean stresses and Stress concentration).

Landing gear goes through number of inspection processes, namely, acid etch inspection, magnetic particle inspection, and Barkhausen noise inspection with helps in detecting intergranular cracks and micro-structure examination.

Failure analysis mostly starts with the visual examination and chemical analysis; but techniques like non-destructive testing (dye penetrating, radiography), Fractography, macroscopic and microstructural examinations, micro-analysis techniques like energy dispersive spectroscopy (EDS) are further used for detailed analysis. Fractography plays a vital role in predicting behaviour of crack growth. Fatigue crack failures, structural failures and noise production contributes the most in landing gear design.

Cyclic loads and bending Stress tend the components to undergo bench marks or plastic deformation, this happens because of higher stress amplitude and stress concentration at specific areas; ultimately crack propagation takes places in high stress zones resulting in failure.

IV. METHODOLOGY

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

Selection of Appropriate material
- Using Ti 10-2-3 or SS 316L for manufacturing parts

Study of 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

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

V. CONCLUSIONS

Landing gear being a crucial part in all types of aircraft; is to be designed with special requirements, this paper outlines, various research which contributed in the analysis and development of landing gear. The axles and struts should be designed to handle extreme loads while landing and take-off. Buckling analysis should be carried out for dynamic loading with high drag loading conditions. Operating actuator should have maximum impact load absorbing capacity acting during landing.

Topology optimization and generate design approach has got a great significance as decreases development cycles of landing gear mechanism. Generative design helps in reducing weight and volume, which ultimately does cost savings at larger extents. Bee-swarm based algorithm is a mathematical approach for analysis used to find errors. It requires number of parameters as input. Bee-swarm algorithm is applicable the adoptable landing gear vibration behavior and to design proportional integration derivative (PID) and for classical techniques for control of active hydraulic nonlinear actuator, damping performance of shock absorber at touchdown.

Failures in landing gears mostly occurs due to fatigue stresses, cyclic loads, impact and dynamic loading and careless overloading. Corrosion and contact stresses cause fatigue cracks development. Sometimes due to improper heat treatment processes, fatigue endurance limit of landing gear reduces. Grain boundary precipitation, stress concentration, recrystallization, poor inter-granular structure of material leads to component fractures.

Higher amount of stresses are developed in main frame, therefore strut and actuators should be made of steel alloys; whereas torsion links should have excellent material stiffness for less deformation, therefore it can be manufactured from titanium alloys. For corrosion protection cadmium plating, hard chromium plating, HVOF etc. epoxy or polyurethane primer and polyurethane top coats are applied for the exposed landing gear parts.

Stainless steel 316L material is used for different components in aerospace industry, it has good structural strength and handle thermal stresses without affecting functionality of component. SS 316L can processes using additive manufacturing process to produce aerospace parts, which results in less defective errors in parts.

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