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Development and Static Structural Finite Element Evaluation of a Main Landing Gear Assembly for Multi-Body Aircraft

KUMMARI ANIL KUMAR[1], Mr.D. PRABHAKAR[2], Dr.B. SANDHYA RANI[3]
[1]PG Student, CAD/CAM, Ellenki College of Engineering and Technology.
[2]Asst. Prof., Department of Mechanical Engineering, Ellenki College of Engineering and Technology.
[3]Head of the Dept., Department of Mechanical Engineering, Ellenki College of Engineering and Technology.

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Abstract - As one of the most stressed structural subsystems in an airplane, the landing gear must absorb the impact of landing, support the whole airframe's weight on the ground, and transfer the stresses of taxiing, braking, and turning—all within a small and weight-limited space. A twin-wheel main landing gear leg with an oleo-pneumatic strut (cylinder and piston), upper and lower drag/side-stay arms, a central pivot joint, an axle, twin tyres, and wheel-retention bolts is illustrated in this paper through three-dimensional solid modeling and static-structural finite element analysis. The nine-body assembly was imported into ANSYS Workbench after being modeled in CATIA V5. Titanium Alloy, Structural Steel, and Aluminium Alloy properties were assigned to the various bodies. At the mating interfaces, forty-eight bonded contact regions were defined. The geometry was then discretized into a tetrahedral mesh with 14,793 nodes and 11,140 elements. An upper strut trunnion was used as a permanent support, and the axle/wheel contact was subjected to a static ground reaction force of about 1000 N. The pivot-joint and stay-arm clevis fillets experience a concentration of approximately 2.10 MPa equivalent (von Mises) stress, a maximum equivalent elastic strain of 3.13×10^{-5} mm/mm, and a maximum total deformation of 0.0277 mm. This corresponds to a static factor of safety of about 119 against the lowest material yield strength (250 MPa, Structural Steel). Using a simplified reference load instead of certificated FAR/CS ground-load factors and a fully bonded representation of sliding and rotating joints in the physical assembly, this paper analyzes the limitations of the baseline result. It then identifies the extensions—certified load cases, non-bonded contact, and dynamic drop-test simulation—needed to advance the model toward a certification-representative structural substantiation.

Index Terms - Topics covered include aircraft landing gear, oleo-pneumatic struts, CATIA V5, ANSYS static structural, finite element analysis, von Mises stress, bonded contact, and factor of safety.

I. INTRODUCTION

As an unusual airframe structure, the landing gear must dissipate the kinetic energy of the vertical sink rate at touchdown, react to drag, side, and braking loads, and support the aircraft during taxiing, takeoff, landing, and ground maneuvering—all while being lightweight and, often, retractable [1], [2]. An oleo-pneumatic shock-absorber strut, a wheel axle, drag or side stays to keep the strut from rotating, and trunnion and pivot fittings to join it to the main airframe structure make up a typical main leg.

Limit and ultimate ground-load circumstances, including level landing, tail-down landing, one-wheel landing, side load, and braked roll, are defined in the applicable parts of FAR/CS-23 or FAR/CS-25, which control the structural substantiation of landing gear for airworthiness purposes [3]-[5]. Landing gear design relies on the tight relationship between CAD geometry and finite element structural analysis. It is one of the more demanding and iterative tasks in airframe engineering due to the large dynamic load factors that must be maintained on a structure while keeping it as light as possible.

This paper details the CAD-to-FEA relationship for a typical twin-wheel main landing gear leg. The whole geometry, including the strut, stay arms, pivot joint, axle, tyres, and fasteners, was modeled in CATIA V5. Then, the ANSYS Static

Structural solver was used to calculate the deformation, strain, and stress distribution that resulted from the static ground reaction load. The purpose of this validation was to create a baseline model that could be used for future, more thorough certification-oriented analysis.

II. LITERATURE REVIEW

While the FAA and EASA standards formally define the limit and ultimate ground-load factors applicable to normal- and transport-category aircraft, foundational landing gear design references outline the strut, stay, and joint sizing philosophy and certification load cases that govern gear structural design [1], [2]. The larger context for the aircraft structural design, as provided by Niu [6], is used to size the landing gear attachment fittings. The basic system-dynamics framework of Ogata [8] is used to address the oleo-pneumatic damping behavior that controls the strut's load-stroke characteristic and, by extension, the peak load transferred into the surrounding stay-arm structure.

While Cook et al. [12] covers general finite element formulation and meshing technique, the particular pre-processing, contact-definition, and solution processes employed for a multi-body assembly of the sort investigated here are documented in the ANSYS Mechanical and Meshing user manuals [9]-[11]. When it comes to creating and restricting multi-part mechanisms like landing gear legs before transferring them to a finite element package, the aerospace industry often uses CATIA V5 Part Design and Assembly Design [13], [14].

Several published research have used landing gear constructions and a CATIA/ANSYS methodology that is quite comparable. Stress, deformation, and fatigue findings that are in line with the basic materials-selection pattern used here were reported by Aftab et al. [15] after modeling a nose landing gear similar to that of a Boeing-737 and comparing alloy-steel, titanium, and aluminum candidates under a design ground load. The importance of comparing computational gear models with physical test data was highlighted in the work of Lin et al. [16], who conducted a combined finite element and modal-test structural strength assessment of a commercial nose landing gear under towing taxi-out loading. This type of validation was also identified as future work in Section V. In contrast, Skorupka [17] reported dynamic fatigue testing of landing gear structures, highlighting how a static reference load captures only a fraction of the cyclic loading that a gear leg encounters in service. The unique contribution of this research is the documentation of a completely built nine-body gear leg as a single bonded-contact system with three simultaneously assigned materials. No other study has done so with the same amount of mesh, contact, and boundary-condition information as this one.

III. METHODOLOGY

A. Design Details and Parts Catalogue

The gear leg examined is a twin-wheel main landing gear assembly built around an oleo-pneumatic strut. Table I provides a concise overview of the main design and load constraints. The assembly was decomposed, for modelling purposes, into nine functional bodies: the outer cylinder (housing the strut and providing the upper trunnion and stay-arm clevis attachments), the inner piston (telescoping within the cylinder and carrying the lower clevis and axle attachment), the upper and lower drag/side-stay arms, the central pivot joint connecting them, the axle carrying the twin wheels, the twin tyres, and the wheel-retention bolts.

Parameter	Value / Description
Gear type	Twin-wheel main leg, oleo-pneumatic strut
Bodies in assembly	9 (cylinder, piston, upper arm, lower arm, pivot joint, axle, 2 × tyre, wheel bolts)
Assembly envelope	≈ 700 mm bounding diagonal
Contact regions	48 bonded, at all mating interfaces
Fixed support	Upper strut / airframe trunnion
Applied load	Static ground-reaction force, resultant ≈ 1000 N, at axle/wheel interface

Table I. Design and Load Parameters of the Landing Gear

B. Supply items

The main strut and linkage members required a high strength-to-weight ratio, so Titanium Alloy was assigned to them. On the other hand, Structural Steel and Aluminium Alloy were assigned to certain secondary bodies and fasteners, in line with common practice for landing gear materials [1], [6]. The three materials' critical mechanical parameters are shown in Table II; Section IV's factor-of-safety calculation is based on Structural Steel's lowest yield strength of 250 MPa, which is taken from the ANSYS Engineering Data repository.

Property	Steel	Aluminium	Titanium
Density (kg/mm^3)	$7.85 \times 10^{-}$[illegible]	$2.77 \times 10^{-}$[illegible]	$4.62 \times 10^{-}$[illegible]
Young's Modulus (MPa)	2.0 × 10[illegible]	71,000	96,000
Poisson's Ratio	0.30	0.33	0.36
Tensile Yield (MPa)	250	280	930
Tensile Ultimate (MPa)	460	310	1070

The table II. ANSYS Engineering Data for Assigned Material Properties

C. Finite Element Modeling and Solid Modeling

The gear leg was created as a multi-part CATIA Product. Each functional component was built as an independent Part using Part Design. The cylinder, piston, stay arms, pivot joint, axle, and tyres all had their own unique features. Then, Assembly Design was used to position the parts according to coincidence, concentricity, and angular constraints. This approach reflects how the components of a real gear leg are discrete and manufactured separately. Using the native CATIA-to-ANSYS geometry interface, the finished CATIA assembly was imported straight into ANSYS Workbench, with all nine bodies preserved.

For this first analysis, the assembly was treated as a single rigidly connected structure due to the forty-eight contact regions that were automatically identified at the mating interfaces (cylinder-to-upper-arm, piston-to-lower-arm, joint-to-arm, axle-to-wheel-bolt, etc.) due to the geometrical discreteness of the nine bodies. This is an intentional simplification made in the initial pass; it doesn't account for the piston's actual axial sliding freedom inside the cylinder bore or the pivot and clevis-pin joints' actual rotational flexibility, which is addressed in Section V. With the use of an unstructured, all-tetrahedral solid-element scheme that included additional contact elements at each bonded interface, the bonded assembly was discretized in ANSYS Meshing. Table III summarizes the results of the mesh statistics.

Mesh Statistic	Value
Total nodes	14,793
Total elements	11,140
Solid elements	6,452
Contact elements	4,688
Degrees of freedom	43,779
Total assembly mass	≈ 18.7 kg

The table Statistics for Finite Element Meshes III.

To validate the modeling workflow, a simplified ground-reaction load of about 22.4 N, 296.1 N, and −954.9 N (resultant ≈ 1000 N) was used, instead of a specific certificated FAR/CS load case, to represent the connection between the airframe and the trunnion pin. At the axle/wheel interface, a static surface force of about 1000 N was applied, with three orthogonal components. The direct sparse solver in ANSYS was used in a single load step across two parallel processor cores to solve the 43,779 equations that made up the resultant linear-elastic, small-deflection system.

IV. RESULTS

In this part, the converged static structural solution's total deformation, equivalent elastic strain, and equivalent (von Mises) stress fields are shown, together with the safety factor and a breakdown of peak findings per material.

A. Complete Deformity

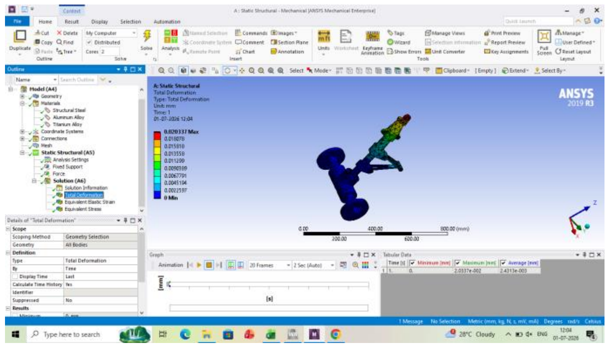
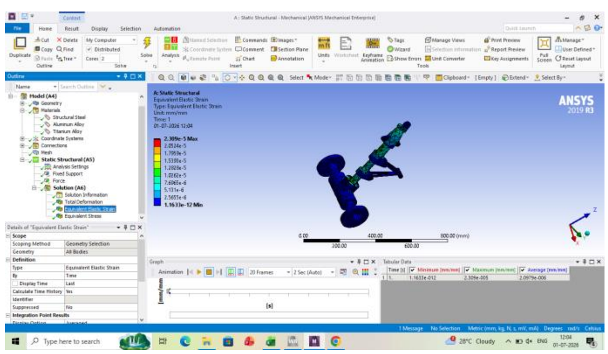


Fig. 1. The magnitude of the landing gear assembly's total deformation contour as a function of the reference load applied(mm).

Deformation starts at zero at the Fixed Support and gradually rises down the strut, reaching a maximum of 0.0277 mm at the free end, where the reference load is applied, as one would anticipate from a construction that is cantilevered at the top trunnion. There is no indication of local meshing artifacts, and the smooth, monotonic rise from the fixed to the loaded end is in agreement with the anticipated bending response of a cantilevered strut-and-linkage system. Due to the robust titanium strut and linkage parts as well as the relatively small magnitude of the imposed 1000 N reference load compared to real in-service landing loads, the peak deformation of just 27.7 microns is negligible in comparison to the approximately 700 mm assembly envelope.

B. The Same Elastic Strain Equivalent



The landing gear assembly's equivalent elastic strain contour under the reference load (mm/mm) is shown in Figure 2.

The stress distribution and strain field both concentrate at the pivot-joint and clevis-fillet areas, as seen in the following discussion. The assembly is confirmed to be well within the small-strain, linear-elastic regime under the reference load, as the maximum equivalent elastic strain of 3.13×10^{-5} mm/mm is over three orders of magnitude lower than any credible yield-strain threshold for the assigned materials. This is in line with the linear-elastic solver formulation that was used.

C. Stress Equivalent (von Mises) and Safety Factor

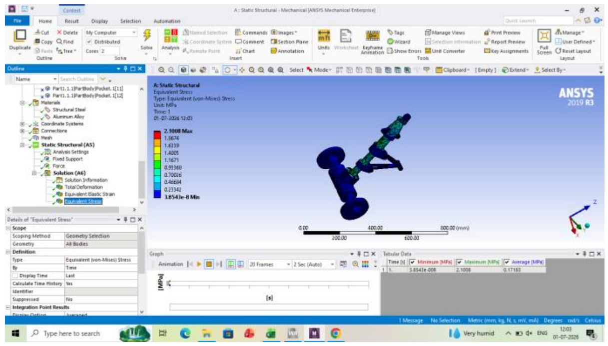


Figure 3 shows the landing gear assembly's equivalent (von Mises) stress curve under the reference load (MPa).

As mentioned in Section II, the most heavily loaded parts of a real stay-arm linkage are the central pivot joint and stay-arm clevis fillets, where the peak equivalent stress of 2.10 MPa is concentrated. The majority of the cylinder, piston, and axle bodies, on the other hand, experience stress at or below the average of 0.17 MPa. The static factor of safety is around 119 when comparing this peak stress to the lowest tensile yield strength in the assembly (250 MPa, Structural Steel). This means that, under the specific 1000 N reference load, there is a very substantial margin of safety in every body and material of the assembly.

D. Results for Each Material's Peak

Titanium alloy bodies exhibit the highest local deformation (as expected from their placement toward the free end of the assembly), according to Table IV's breakdown of deformation, strain, and stress results by material assigned to each body group. On the other hand, all three materials display very similar peak stress, in line with the geometry-governed stress pattern typical of a linear-elastic structure under fixed boundary conditions.

Material	Deform. Max (mm)	Strain Max (mm/mm)	Stress Max (MPa)
Structural Steel	9.892×10^{-3}	1.113×10^{-5}	2.1042
Aluminium Alloy	2.771×10^{-3}	3.129×10^{-5}	2.1008
Titanium Alloy	2.034×10^{-3}	2.309×10^{-5}	2.0970

The table IV. Maximal Outcomes from Delegated Tasks

V. DISCUSSION

There are two main reasons why the simulated gear leg should not be interpreted as physically acceptable for service only because the calculated factor of safety is quite high (≈ 119). To begin with, the reference load that was applied (approximately 1000 N resultant) is significantly lower than the certificated limit and ultimate ground-reaction loads that a real main landing gear leg is required to withstand according to the FAR/CS load factors [3]-[5]. These loads can be one to several orders of magnitude higher than the load that was utilized in this case, depending on the weight of the aircraft and the design sink speed. Rerunning the analysis at the actual FAR/CS-derived load factors for a target aircraft is the logical next step; the present result validates the CAD-to-FEA workflow, mesh, material assignment, and boundary-condition methodology rather than serving as a certification-representative strength check.

Second, rather of having the piston slide within the cylinder bore and the pivot and clevis-pin joints rotate as they would in the real assembly, all forty-eight part-to-part interactions were shown utilizing bonded contact. For a first, fixed-configuration static-strength check, this bonded idealization is a common and defendable option [12], but the actual degrees of freedom for sliding and rotating would redistribute the load through the linkage differently, and the peak stress at the pivot-joint and clevis-fillet sites mentioned in Section IV-C could be locally increased or decreased. Future work will primarily focus on improving structural modeling by incorporating frictional or frictionless contact at the actual sliding and rotating interfaces,

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comparing the resulting load path to the present bonded baseline, conducting a formal mesh-convergence study (using the present 14,793-node mesh, which represents the node-count ceiling of the academic-license solver), and simulating a transient drop-test with the oleo strut's gas-spring and hydraulic-damping properties, as shown for related landing gear structures by Lin et al. [16] and Skorupka [17].

Titanium alloy is used for the strut and linkage bodies, while structural steel and aluminum alloy are assigned to the secondary bodies. This follows the established practice for landing gear materials [1], [6]. Despite not being assigned to the most stressed pivot-joint region, structural steel governs the assembly-wide factor of safety due to its lowest yield strength. This highlights the importance of assessing factor of safety on a per-material, per-body basis (Table IV), instead of relying solely on the single assembly-wide peak stress.

VI. CONCLUSION

The following components were added to the nine-body CATIA V5 model of the twin-wheel main landing gear leg: cylinder, piston, upper and lower stay arms, central pivot joint, axle, twin tyres, and wheel-retention bolts. The model was then imported into ANSYS Workbench and given the properties of Titanium Alloy, Structural Steel, and Aluminium Alloy. It was linked through 48 bonded contact regions and meshes with 14,793 nodes and 11,140 elements. The static structural solution, when subjected to a reference ground-reaction force of approximately 1000 N at the axle and a fixed support at the top trunnion, produced total deformations of up to 0.0277 mm, equivalent elastic strains of up to 3.13×10^{-5} mm/mm, and equivalent (von Mises) stresses of up to 2.10 MPa at the pivot-joint and clevis-fillet regions. This corresponds to a static factor of safety of around 119 against the lowest material yield strength. Rather of leaving them unanswered, two particular problems were brought to light and addressed as concrete recommendations: the simplified reference load, which replaced certificated FAR/CS load factors, and the completely bonded representation of moving and sliding joints. Providing a verified baseline digital model and a repeatable technique for subsequent, certification-oriented structural analysis, the article illustrates a comprehensive and transparently documented CATIA-to-ANSYS static-structural process for a multi-body landing gear leg.

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