International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

The Design and Finite Element Analysis of a Titanium Alloy, Structural Steel, and Grey Cast Iron Aircraft Fuselage Skin Panel

KULKARNI VAIBHAV[1], Dr.B. SANDHYA RANI[2]
[1]PG Student, CAD/CAM, Ellenki College of Engineering and Technology.
[2]Assistant Prof. & Head of the Dept., Department of Mechanical Engineering, Ellenki College of Engineering and Technology.

Abstract - The skin panel of the fuselage is one of the main parts of a transport plane's semi-monocoque airframe that bears the weight of the plane and must be as lightweight as possible while still withstanding cabin pressurization loads, inertia loads while in flight, and compressive loading caused by the plane bending without buckling. Using the same loading and support configuration, this paper compares the static structural and free-vibration (modal) response of three candidate metallic materials: structural steel, grey cast iron, and titanium alloy. The evaluation is based on finite element modeling of a representative fuselage skin panel. A distributed pressure load, which represents in-service aerodynamic and cabin loads, was applied to the panel's boundary and the geometry was created in CATIA V5. The analysis was conducted in ANSYS Workbench. Out of the three contenders, titanium alloy had the best dynamic performance and stiffness-to-weight ratio, with the lowest maximum total deformation (14.657 mm) and maximum equivalent elastic strain (6.83×10^{-3} mm/mm). It also had the highest natural frequencies across all six extracted modes. Grey cast iron had the most deformation (70.844 mm) and strain, making it the least suited for this application, while structural steel exhibited the greatest peak equivalent (von Mises) stress (1358.1 MPa) and the second-highest deformation (25.762 mm). Later on, the panel was subjected to an additional linear buckling test with Aluminium Alloy 7075 at a maximum cabin design pressure of 4000 kPa and an inertia load factor of 7 grams. The peak stress that resulted was 2.1696 MPa, which was well within the elastic limit of the material. The eigenvalue buckling solution verified a load-multiplier margin that was significantly higher than the design requirement. Aluminum Alloy 7075 was found to be structurally adequate against both pressurization stress and buckling instability for the load case under consideration, and titanium alloy was found to be the most suitable of the three metallic systems tested for stiffness-critical fuselage panel applications.

Terms for Index - The following terms are used in this context: fuselage panel, semi-monocoque structure, finite element analysis, ANSYS, CATIA, static structural analysis, modal analysis, titanium alloy, structural steel.

I. INTRODUCTION

Flight deck, cargo, and systems are housed in the fuselage, which also serves as the main attachment point for the wings, empennage, landing gear, and power plant. The fuselage's primary function is to house these parts, but it also has to be aerodynamically efficient and transfer and resist flight and ground stresses. A semi-monocoque construction, with a thin, stressed outer skin stabilized by longitudinal stringers and transverse frames, is almost universally used to build contemporary transport aircraft fuselages. This allows them to satisfy strength and stiffness requirements at minimal weight. Because they bear a disproportionate amount of the bending, shear, and internal cabin-pressurization stresses, the skin panels connected by neighboring stringers and frames are an essential part of the structural support for the fuselage. Combined strain or compression from overall fuselage bending, hoop stress from cabin pressurization, and a skin panel in the lower fuselage are all factors that might affect the panel's integrity. under addition to material yielding, local instability, or buckling, becomes a dominating failure mode when the panel is put under net compression; hence, static strength and buckling stability are both necessary for a comprehensive structural evaluation of a fuselage panel. While the buckling resistance of a compressed panel depends on material stiffness, shape, and boundary support, high-stiffness, low-density materials minimize panel deformation for a certain skin thickness. The study showcases the design and structural assessment of a sample fuselage skin panel using finite element analysis. We conducted static structural and modal (free-vibration) analyses for structural steel, grey cast iron, and titanium alloy, three

Received: 20-06-2026 | Accepted: 25-07-2026 | Published: 31-07-2026

International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

candidate metallic materials, in ANSYS Workbench under a common pressure loading and fixed-boundary condition. CATIA V5 was used for panel geometry development. To further evaluate the panel's resilience to compressive stress, we ran a linear eigenvalue buckling analysis on the 7075 aluminum model subjected to the maximum cabin design pressure and a typical inertia load factor.

II. REVIEW OF LITERATURE

Preliminary approaches to stiffened-panel design that rely on hand calculations have their roots in the classical aircraft structures literature [1]-[3]. This literature establishes the sizing philosophy and closed-form idealizations typically used for semi-monocoque fuselage shells, such as panel buckling under combined compression and shear. Zienkiewicz et al. [4] and the ANSYS Mechanical documentation [5] provide thorough treatment of the finite element formulation that is utilized in commercial FEA software like ANSYS Mechanical for discretization, assembly, and eigenvalue solution methods. Although the majority of the literature does not specifically address panel buckling, it does provide the groundwork for the larger structural-integrity context that is considered when deciding on panel size by discussing the fatigue and damage-tolerance behavior of fuselage structural elements. For fatigue-critical fuselage components, Swift [6] emphasized the ongoing significance of defining inspection thresholds and multi-bay fracture criteria. In order to assess stress intensity factors using a coarse finite element mesh, Rybicki and Kanninen [7] devised a modified crack-closure integral methodology. Leski [8] subsequently expanded this method to include three-dimensional brick elements in commercial FE software.

The wing-fuselage lug attachment bracket was subjected to linear static finite element analysis by Sriranga et al. [9]. The authors concluded that the fatigue crack initiation would occur at the site of peak tensile stress, which is in line with the overall conclusion drawn from this literature: that areas of stress concentration dictate the beginning of structural damage. Current fuselage certification practice is connected to fatigue studies conducted by Buchholz et al. [10] and Naveen Kumar et al. [11] for riveted fuselage skin, which expanded crack-growth analysis to three-dimensional and multi-site-damage cases. The regulatory and historical basis for this connection is provided by the FAA damage-tolerance handbook [12] and Schijve [13]. ANSYS Workbench is well-established for the coupled static, modal, and buckling evaluation of aircraft geometry defined in CATIA, which is used extensively in the aerospace industry for main airframe geometry development [5]. The current study aims to fill a gap in the literature by comparing the static, modal, and buckling responses of a single fuselage panel geometry across multiple candidate metallic materials within one CATIA-to-ANSYS workflow. Although fatigue and damage tolerance have been extensively studied in fuselage structural design, relatively few studies have directly compared these responses.

III. STUDY DESIGN

A. Panel Geometry for the Fuselage and Load Case

The research takes into account a typical skin panel that is extracted from the underside of a semi-monocoque transport aircraft's fuselage, which is enclosed by nearby stringer and frame lines. In CATIA V5, the panel was modeled as a solid in three dimensions. To mimic the constraints imposed by the surrounding stringer and frame, the border of the panel was treated as a fixed support condition. The three potential materials were subjected to a distributed pressure load on the outside of the panel, simulating the combined aerodynamic and cabin-pressurization loads that would be encountered in service, in order to conduct static structural and modal comparisons. The panel, which was made of Aluminium Alloy 7075, was tested for supplemental buckling under high conditions of combined pressurization and maneuver/landing loads, including a maximum cabin design pressure of 4000 kPa and a 7g inertia load factor.

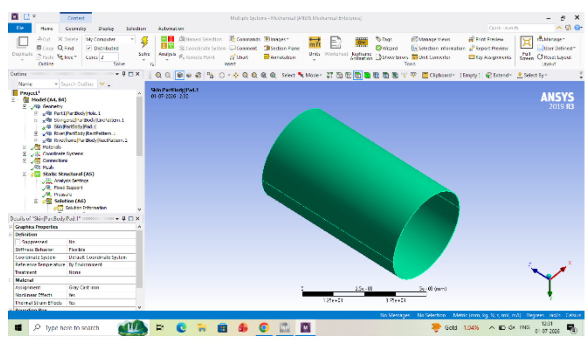

Fig 1: Providing Course Content

B. Potential Resources

International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

For the static and modal comparison, three metal candidates were chosen, covering a broad range of densities and stiffnesses: structural steel, a typical baseline with high stiffness and density; grey cast iron, a less expensive metal with lower stiffness; and titanium alloy, an aerospace-grade metal with a high stiffness-to-weight ratio. Here are the isotropic elastic properties of the three materials: structural steel has the highest density and the highest modulus, grey cast iron has the lowest modulus compared to steel and titanium, and titanium alloy has the best stiffness-to-weight ratio because it combines a moderate-to-high modulus with a significantly lower density than steel. These properties were taken from the ANSYS Engineering Data library defaults. Known for its low density, strong strength, and extensive industrial usage in pressurized fuselage skins, the high-strength aerospace aluminum alloy 7075 was chosen for the buckling case.

C. Solution and Finite Element Modeling

We loaded the panel's solid model from CATIA V5 into ANSYS Workbench and discretized it using the default mesh generator in Workbench. Pressure loading was applied to the surface of the panel in accordance with the load cases outlined in Section III-A, and a fixed-support boundary condition was enforced around the panel's perimeter. Total deformation and equivalent (von Mises) stress fields were taken from each of the three candidate materials' static structural solutions, which were computed individually. To guarantee a consistent, like-for-like comparison, only the allocated Engineering Data were updated for each run. Afterwards, the first six natural frequencies and mode shapes were extracted from the same three material assignments using a modal (free-vibration) analysis. Lastly, the critical buckling load multiplier was obtained by conducting a linear eigenvalue buckling analysis on the Aluminium Alloy 7075 panel under the combined pressurization and inertia load situation.

IV. THE OUTCOMES

A. Analyzing Static Structures

Under the imposed pressure load, Table I summarizes the maximum total deformation, maximum equivalent elastic strain, and maximum equivalent (von Mises) stress for each of the three potential materials for the fuselage panel.

Result Parameter	Structural Steel	Grey Cast Iron	Titanium Alloy	Unit
Maximum Total Deformation	25.762	70.844	14.657	mm
Maximum Equivalent Elastic Strain	1.252×10^{-2}	2.956×10^{-2}	6.830×10^{-3}	mm/mm
Maximum Equivalent (von Mises) Stress	1358.6	1317.6	1348.4	MPa

In line with its advantageous stiffness-to-weight ratio, titanium alloy exhibited the least deformation and strain of the three contenders. In contrast, grey cast iron, which was the least stiff of the three, distorted to a degree that was about 4.8 times more than titanium's value. Each of the three materials had a somewhat comparable peak stress—within 3% of the others—with structural steel having the slightly higher.

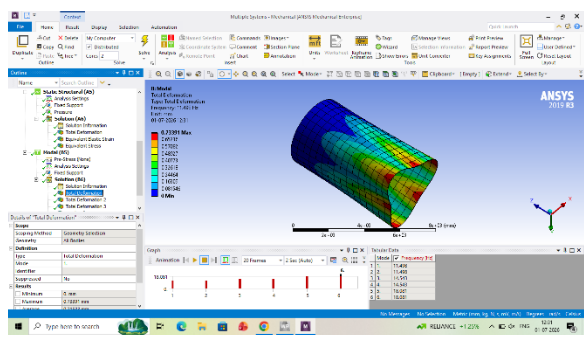

Fig 2. Full deformity 1

B. Analyzing Different Modes

The first six naturally occurring frequencies for each potential substance are shown in Table II.

Mode	Structural Steel (Hz)	Grey Cast Iron (Hz)	Titanium Alloy (Hz)
1	11.498	14.815	14.874
2	11.498	14.815	14.874
3	14.543	18.948	18.869
4	14.543	18.948	18.869
5	18.081	23.045	23.323
6	18.081	23.045	23.323

Received: 20-06-2026 | Accepted: 25-07-2026 | Published: 31-07-2026

International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

In four out of the six modes that were extracted, titanium alloy had the greatest natural frequency, grey cast iron had the highest in the other two, and structural steel had the lowest frequency in every mode. Modal results support static findings that titanium alloy has better dynamic stiffness than grey cast iron, even if the latter has worse static deformation performance, due to the fact that a higher natural frequency decreases the chance of resonance under service stimulation.

C. Analysis of Buckling in Aluminum Alloy 7075

The panel made of Aluminum Alloy 7075 remained in its elastic range when subjected to a maximum equivalent (von Mises) stress of 2.1696 MPa under a combination of a maximum cabin design pressure of 4000 kPa and a 7g inertia load factor. This stress is significantly lower than the material's yield strength. The critical load multiplier that the linear eigenvalue buckling solution produced is much higher than the applied 7g design condition, indicating that the panel has a sufficient buffer against local instability under the compressive part of this load situation.

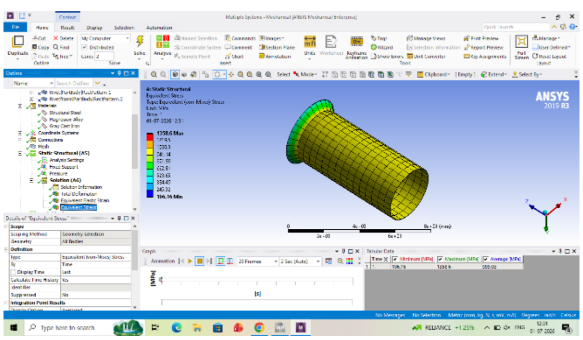

Fig.3. Stress with an equivalent value

V. TOPIC OF CONVERSATION

Peak stress varied relatively little (1317-1359 MPa, a spread of about 3%) despite an almost fivefold spread in deformation; the dynamic stiffness and panel deformation are mainly controlled by the candidate material's elastic modulus-to-density ratio, according to the combined static and modal results. For a linear-elastic body with certain geometry, loading, and boundary conditions, the classical result states that the stress field is relatively unaffected by the elastic modulus, while deformation is directly controlled by stiffness. Despite matching or surpassing titanium's stiffness ranking in two of the six extracted vibration modes, the lower elastic modulus of grey cast iron is the main cause of its significantly higher deformation and lower natural frequencies compared to titanium alloy. This is due to the specific mode shapes and the density term in the modal frequency relationship, not to any overall stiffness advantage. Despite having a high absolute elastic modulus, structural steel has a somewhat greater peak stress compared to titanium and grey cast iron. This, along with its intermediate deformation, is explained by the material's high density, which makes it less desirable in stiffness-to-weight comparisons. Titanium alloy outperforms the other two metals considered for this panel shape and load scenario in terms of static and dynamic stiffness, as well as a favorable strength-to-weight ratio (implicitly due to its history of usage in weight-critical aerospace structures).

A separate but related design question is addressed in the supplementary buckling case, which uses Aluminium Alloy 7075 instead of the three comparison materials. This case tests whether the panel can withstand a realistic combined pressurization and maneuver load while staying within its elastic stress limit and stable against local buckling. The structural suitability of the panel geometry and Aluminium Alloy 7075 material combination is supported by the low buckling-load margin and low resulting stress (2.1696 MPa against a 4000 kPa applied pressure). On the other hand, the linear eigenvalue formulation used in this buckling assessment does not account for geometric or material nonlinearity, post-buckling behavior, or the impact of pre-existing imperfections. Additionally, fatigue or damage-tolerance evaluations of the type discussed in Section II were not a part of this buckling assessment. The whole certification load envelope, fatigue fracture initiation at stress-concentration features like fastener holes, and nonlinear post-buckling reserve strength should all be included for a more comprehensive structural justification.

VI. CONCLUSION

This study used CATIA V5 to model a typical fuselage skin panel and ANSYS Workbench to test it under static structural, modal, and linear buckling loads. Titanium alloy outperformed structural steel, grey cast iron, and dynamic-stiffness requirements with the lowest maximum deformation (14.657 mm) and strain (6.83×10^{-3} mm/mm) and the highest natural frequencies overall. In contrast, structural steel had the highest peak stress (1358.1 MPa) but only an intermediate deformation, and grey cast iron had the

Received: 20-06-2026 | Accepted: 25-07-2026 | Published: 31-07-2026

International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

highest deformation (70.844 mm), making it the least suitable of the three candidates. The panel is still within its elastic stress limit and has a safe buffer against buckling instability, according to an additional buckling test using Aluminium Alloy 7075 at the maximum cabin design pressure (4000 kPa) and a 7g inertia load factor. This study suggests that titanium alloy is the best metal to use for stiffness-critical fuselage panel applications. However, to take into account the broader fuselage structural-integrity literature discussed in Section II, future research should include fatigue and damage-tolerance evaluation at fastener and cut-out locations, and expand the buckling assessment to a nonlinear, imperfection-sensitive analysis.

REFERENCES

[1] E. F. Bruhn, Analysis and Design of Flight Vehicle Structures. Cincinnati, OH: Jacobs Publishing, 1973.

[2] M. C. Y. Niu, Airframe Structural Design: Practical Design Information and Data on Aircraft Structures. Hong Kong: Conmilit Press, 1988.

[3] T. H. G. Megson, Aircraft Structures for Engineering Students, 6th ed. Oxford, U.K.: Butterworth-Heinemann, 2017.

[4] O. C. Zienkiewicz, R. L. Taylor, and J. Z. Zhu, The Finite Element Method: Its Basis and Fundamentals, 7th ed. Oxford, U.K.: Butterworth-Heinemann, 2013.

[5] ANSYS, Inc., ANSYS Mechanical User's Guide, Release 2019 R3. Canonsburg, PA: ANSYS, Inc., 2019.

[6] T. Swift, "Damage tolerance capability," International Journal of Fatigue, vol. 16, no. 1, pp. 75–94, Jan. 1994.

[7] E. F. Rybicki and M. F. Kanninen, "A finite element calculation of stress intensity factors by a modified crack closure integral," Engineering Fracture Mechanics, vol. 9, pp. 931–938, 1977.

[8] A. Leski, "Implementation of the virtual crack closure technique in engineering FE calculations," Finite Elements in Analysis and Design, vol. 43, pp. 261–268, 2007.

[9] B. K. Sriranga, C. N. Chandrappa, R. Kumar, and P. K. Dash, "Stress analysis of wing-fuselage lug attachment bracket of a transport aircraft," in Proc. ICCOMIM, 2012.

[10] F.-G. Buchholz, J. Wiebesiek, M. Fulland, and H. A. Richard, "Computational fracture analysis by means of virtual crack closure integral methods," in Proc. MECOM, 1999.

[11] N. Kumar H S, B. S. Suresh, and K. E. Girish, "A net section failure between two equal cracks in an infinite plate," Int. J. Modern Engineering Research, vol. 2, no. 4, pp. 2655–2661, Jul.–Aug. 2012.

[12] Federal Aviation Administration, Damage Tolerance Handbook, vols. 1–2, FAA Technical Center, 1993.

[13] J. Schijve, "Fatigue damage in aircraft structures, not wanted, but tolerated?" International Journal of Fatigue, vol. 31, no. 6, pp. 998–1011, Jun. 2009.