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Noise Reduction in Commercial Aircrafts by Modelling and Analysis of Fuselage Structure

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***Abstract*— Noise levels inside aircraft cabins are primarily influenced by external sources like engines and aerodynamic flow, which propagate through the fuselage into the cabin. Optimized rib and frame configurations, panel modifications, wave reflection and transmission control. Boeing-737 Fuselage Modal Testing and Frequency Response Analysis tests identify the natural frequencies and response characteristics of the fuselage to excitation. Computational Fluid Dynamics (CFD) simulations can model airflow and turbulence around the fuselage, which generates noise. Coupling CFD with acoustic simulations helps in predicting and minimizing aerodynamic noise contributions. The results show promising pathways for reducing cabin noise by enhancing fuselage design, improving passenger comfort, and complying with increasingly strict noise regulations in the aviation industry.**

***Keywords*— Geometric Modeling and Grid Generation, Semi- monocoque, Boeing 737-circular section, ideal fuselage, CATIA model, ANSYS simulation.**

I. INTRODUCTION

1.1 Background

Noise within the cabins of commercial aircraft presents a significant challenge, impacting passenger comfort, health, and overall flight experience. This issue is exacerbated by external sources, such as engine noise, aerodynamic flow, and structural vibrations that penetrate the fuselage. Current noise reduction methods have limitations in addressing the complex interaction between the fuselage structure and acoustic fields. Therefore, there is a critical need to develop and analyze fuselage structures that can effectively minimize cabin noise through advanced materials, structural optimization, enhancing passenger comfort while complying with regulatory standards.

All these are happening due to lack of data of the components. Which is causing huge damage to airlines. The discovery has prompted airlines to change parts on a handful of planes and so far, only a fraction of the 23,000 existing CFM56 engines has been affected. Several false documents were identified. Some planes went through some emergency landings due to the improper function of the component or part and some planes have crashed also by killing several people.

1.2 Aeroacoustics

Aeroacoustics is a specialized field that examines how noise is generated and propagated when air flows over and around solid objects, especially those in motion. This field focuses on noise generated by turbulent airflow, which is common in applications such as aircraft wings, rotors, jet engines, high-speed trains, and wind turbines. Noise sources in aeroacoustics arise primarily from interactions between airflow and structural surfaces, leading to phenomena such as vortex shedding, shock waves, flow separations, and pressure fluctuations. The primary goal of aeroacoustics is to understand the complex mechanisms of sound generation in these flows and to develop methods to predict and control noise. For instance, in aviation, minimizing noise levels is critical to improving passenger comfort, reducing environmental noise pollution, and complying with increasingly stringent noise regulations. By combining principles from fluid mechanics and acoustics, aeroacoustics seeks to create quieter designs in both natural and engineered systems. Computational fluid dynamics (CFD) models and experimental techniques, such as wind tunnel testing and particle image velocimetry (PIV), are commonly employed to simulate and study noise sources. In doing so, aeroacoustics plays a crucial role in the design of quieter aircraft, vehicles, machinery, and urban environments, ultimately benefiting both industry and communities through reduced noise pollution and enhanced living standards.

1.3 Vibro-acoustic

Aircraft experience various sources of vibration and noise, including engine operation, aerodynamic forces, and structural responses to external conditions. Managing these effects is essential for safety, comfort, and performance. One key area of vibracoustic in aeronautics is cabin noise reduction. Passengers and crew are exposed to engine noise, airflow turbulence, and structural vibrations. Engineers use advanced materials, active noise control systems, and optimized structural designs to minimize these disturbances, enhancing comfort and communication inside the aircraft.

Another critical application is structural integrity and fatigue analysis. Continuous vibrations can lead to material fatigue and eventual structural failure. Vibracoustic analysis helps engineers predict how different components will respond to vibrational stress, ensuring the longevity and reliability of aircraft parts, including wings, fuselage, and engine mounts. In modern aeronautics, lightweight composite materials are increasingly used to reduce weight and improve fuel efficiency. However, these materials behave differently under vibracoustic stress, requiring specialized analysis to maintain performance and durability. By applying vibracoustic principles, aerospace engineers enhance aircraft safety, optimize noise control, and improve overall aerodynamics, leading to quieter, more efficient, and safer air travel.

Noise Propagation Analysis

Noise is transmitted via vibro-acoustic and aero-acoustic pathways from jet engines and aerodynamic interactions.

The study assumes that vibrations in the fuselage skin propagate sound into the cabin.

A mathematical model based on Helmholtz's integral equation is used to estimate the **s**ound pressure level (SPL) inside the cabin.

Noise Reduction in the Fuselage:

• *Acoustic Insulation* - Soundproofing layers inside the fuselage reduce engine and aerodynamic noise.

• *Vibration Damping* - Using composite structures and active damping techniques.

• *Optimized Panel Stiffness* - Reduces structural-borne noise transmission.

Helmholtz's integral equation

This research used the Helmholtz's integral equation to build a mathematical model for the airplane body and enhanced it with finite element analysis. The sound pressure level reduction can be calculated using the formula

$$L_p = L_N + 10\log_{10}\left(\frac{|D}{4\pi r^2} + \frac{4(1-\alpha_m)}{S_a}\right)$$

where:

L_p Sound pressure level received by the passenger in dB.

L_N Sound pressure level produced from the jet engine in dB.

α_m The average absorption coefficient.

D The directivity coefficient.

r The distance between passenger and jet engine on the wing.

$$S_a = \sum_{i=1}^{n} A_i \alpha_i$$

where:

S_a The total cabin sound absorption.

A_i The surface area of each sheet in the external airplane body.

n The number of sheets.

α_i The absorption coefficient of each sheet (depends on material and frequency).

II. Literature Survey

2.1 Motivation and Objective

The aim of this study is to develop and validate effective methods for reducing cabin noise in commercial aircraft through advanced modelling.

1. To evaluate structural modifications, including optimized rib and frame configurations, panel modifications.
2. To validate the proposed noise reduction methods through experimental and numerical testing, ensuring compliance with noise regulations and improved passenger comfort.

III. Methodology

For this project two different software are used and the project is divided into major phase, first phase discusses about the design in the Catia software which is a 3d interactive software, and next the crucial phase is of analysis of the model which is carried out in ANSYS where the results are extracted with definite boundary conditions.

***3**.1 Catia V5 Software*

A comprehensive software suite called Computer-Aided Three-Dimensional Interactive Application (CATIA) was created by Dassault Systems, a French business. Computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), 3D modelling, and product lifecycle management (PLM) are just a few of the design and engineering tasks for which it functions as a multiplatform solution. Widely known as CAX software, CATIA offers a variety of features to assist with many phases of product development. It provides tools for engineering, design, manufacturing, and conceptualization processes.

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CATIA's 3D Product Lifecycle Management methodology makes it easier for teams to work together and offers an integrated cloud solution for effective data sharing. The software suite encompasses a wide range of fields, including mechanical engineering, systems engineering, electrical systems design, fluid and electronic systems design, and surfacing and shape design. It gives users the ability to work on intricate projects and complete modelling, simulation, analysis, and documentation activities on a single platform. Because of its adaptability, collaboration capabilities, and connection with other technical areas, CATIA is a strong instrument for businesses engaged in design engineering and product development.

3.1.1 Design Approach

The study focuses on reducing noise in aircraft cabins and fuselage. The fuselage structure is modeled using finite element analysis (FEA), and different noise control strategies are analyzed.

Fuselage Structural Model

The aircraft body skin is simulated with ANSYS software.

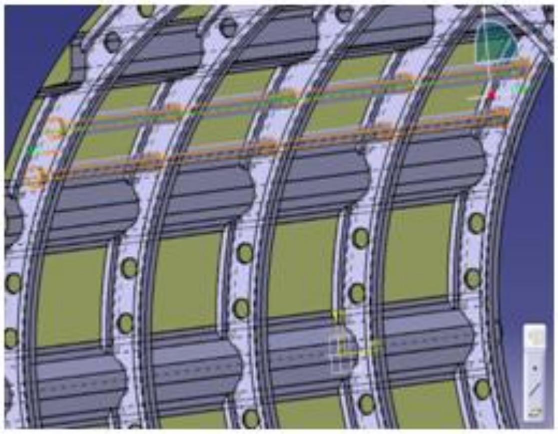
The skin consists of 2mm thick aluminum sheets(2024-T3) curved with a 3760mm radius.

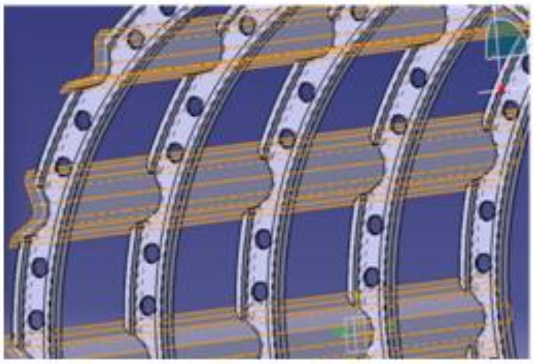
Bulk head thickness 6mm, bulk head spacing 5000mm provide structural support.

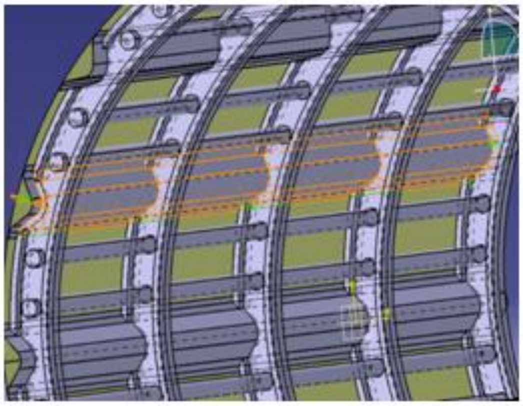
Stringers: Stringer length of 20000mm, Diameter 10mm

Longerons: Length of 20000mm, Thickness 5mm

Damping layer: Thickness 10mm.







3.2 ANSYS Software

ANSYS is a leading engineering simulation software that enables designers and engineers to analyse and optimize complex product designs across a range of industries, including aerospace, automotive, electronics, energy, and biomedical. Founded in 1970, ANSYS provides a comprehensive suite of tools for various physics simulations, such as structural mechanics, fluid dynamics (CFD), electromagnetics, heat transfer, and even Multiphysics simulations, where several types of physical phenomena interact.

One of the key features of ANSYS software is its ability to handle complex geometries and large-scale simulations with high accuracy. The software's advanced meshing tools create high-quality computational grids, essential for precise simulations. ANSYS also integrates powerful post-processing capabilities to visualize and interpret results, making it easier to understand and improve designs. Through these advanced features, ANSYS helps companies reduce the need for costly physical prototypes, shorten development cycles, and enhance product performance and reliability

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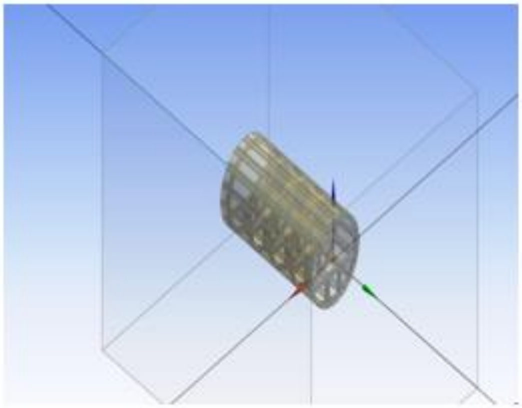
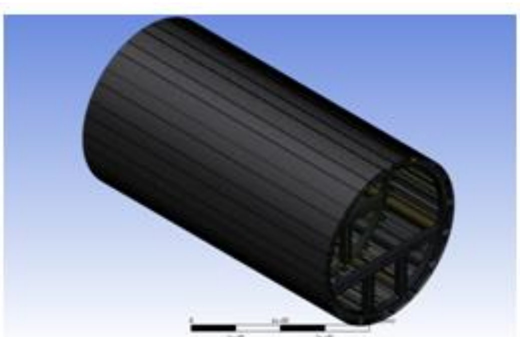


Figure 3.2.1 Domain in Front View

3.2.2 MESHING

Our next step involves creating a computational mesh in ANSYS Fluent which is essential for performing high-quality simulations in aeroacoustics analysis. This involves the discretization of the geometry into small cells that can represent complex fluid dynamics, enabling the calculation of vortex structures and their frequencies key elements in aeroacoustics.

To perform a detailed aeroacoustics analysis, this geometry serves as the foundation for studying flow-induced vortices and acoustic effects. Next, select a meshing strategy that meets both computational and accuracy requirements. For aero-acoustic applications, a Poly-Hexacore mesh is often preferred due to its efficiency in balancing detailed resolution with computational cost. This mesh structure uses polyhedral elements near walls to adapt to complex geometries and hexahedral cells in the main fluid domain for the benefits of a structured grid.



Specifications of Mesh

The mesh was generated using an element size of 10 mm. The model has a bounding box. k diagonal of 23,143 mm and an average surface area of approximately 5.8329 × 10^5 mm^2. The minimum edge length is set to 10 mm, with a transition ratio of 0.272 to ensure smooth element size variation. A maximum of five layers is used, and the element growth rate is maintained at 1.2. The resulting mesh consists of 5,50,50,310 nodes and 1,91,94,315 elements, indicating a highly detailed discretization suitable for accurate numerical analysis.

IV. RESULTS

4.1 Harmonic Response

The harmonic response analysis was performed over a frequency range of 0–2000 Hz using a 200 N sinusoidal excitation, with results stored at all frequency steps. The structure's behaviour was examined through directional velocity and acceleration outputs, with Bode plots provided for frequency response interpretation.

The maximum dynamic response occurred at the upper end of the excitation range, around 2000 Hz, where the structure displayed its peak vibration amplitude. At this frequency, the system exhibited:

- Maximum Velocity Amplitude: 1.8517 mm/s
- Maximum Acceleration Amplitude: 23,269 mm/s^2 (≈ 237 m/s^2)
- Phase Angle:
  - Velocity: –90°
  - Acceleration: 0°
- The velocity response was predominantly imaginary, indicating the structure is responding in a typical out-of-phase harmonic mode near resonance.

The modal analysis indicated a cluster of natural frequencies between 703–960 Hz, but additional higher modes up to ~2000 Hz can amplify responses further. Since the highest response appears at the maximum input frequency (2000 Hz), this suggests that the excitation frequency approaches another mode beyond the first 100 resolved modes.

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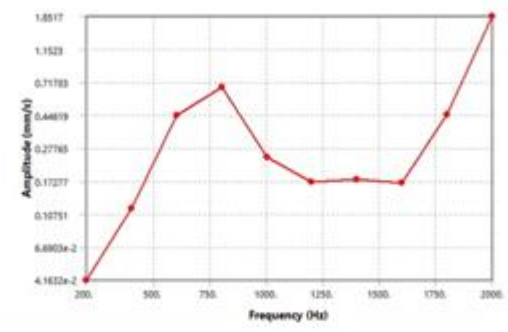

Frequency-response charts

- At low frequencies (0–500 Hz), the structure is stiff, exhibiting very small velocity and acceleration.
- Approaching 700–900 Hz, the response gradually increases, in alignment with the first modal cluster.
- Between 900–1500 Hz, the amplitude continues to rise, with multiple minor peaks due to closely spaced modes.
- Near 2000 Hz, the system reaches its global maximum amplitude, indicating the excitation frequency aligns closely with a higher natural mode.
- The –90° phase shift in velocity at resonance is characteristic of harmonic systems when passing through natural frequencies

The harmonic response analysis was performed for a 200 N sinusoidal load over 0–2000 Hz. The structure demonstrated increasing vibration amplitudes with rising frequency, with the highest response occurring at 2000 Hz. At this frequency, the system reached a maximum velocity amplitude of 1.8517 mm/s and an acceleration amplitude of 23,269 mm/s^2, with velocity lagging the excitation by –90°. The results indicate that the structure experiences its most significant dynamic amplification near the upper frequency limit, likely due to proximity to an unlisted higher natural mode beyond 1000 Hz. Overall, the structure remains moderately stable at lower frequencies but experiences amplified responses at frequencies approaching resonance.

4.2 Harmonic Acoustic

The harmonic acoustics analysis evaluates how the acoustic domain responds to a range of excitation frequencies from 1 Hz to 2000 Hz.

The results mainly include Sound Pressure Level (SPL) and Far-field SPL at a microphone location placed at: (-500 mm, 0 mm, 0 mm)

1. Frequency Range and Setup

- Frequency Range: 1 Hz → 2000 Hz (logarithmic spacing).
- Analysis Type: Harmonic Response in acoustics domain.
- Acoustic Medium: Air (compressible).
- Loads: Imported structural velocity data mapped onto acoustic boundaries.
- Boundary: Radiation boundary applied

2. Sound Pressure Level (SPL) Results (In-Domain)

The SPL inside the acoustic enclosure shows:

- Maximum SPL: 120.37 dB
- Minimum SPL: 42.417 dB
- These occur on the structure's enclosure surfaces.

3. Far-Field SPL Microphone Results

Far-field SPL microphone values were computed at the last frequency (2000 Hz).

Peak Output at 2000 Hz:

- Far-field SPL: 75.467 dB (highest measured far-field value).

Low-Frequency Response (1–100 Hz):

- SPL values are very low or even negative (attenuation), e.g.
  - At 1 Hz: –29.031 dB
  - At 68.219 Hz: –24.451 dB

Intermediate Response (100–900 Hz):

- SPL gradually increases with frequency:
  - 158.74 Hz: 6.785 dB
  - 369.38 Hz: 9.38 dB
  - 859.51 Hz: 26.12 dB

High-Frequency Response (~2000 Hz):

- Very strong acoustic radiation due to resonance and high structural velocities.
- 75.467 dB at 2000 Hz (peak radiated noise).

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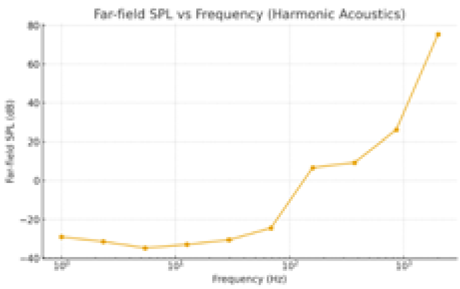

NOISE REDUCTION

FREQUENCY (Hz)	**BASELINE (dB)**	**MODIFIED (dB)**	**ΔSPL (dB)**
200	-5.1484	-29.031	23.88
400	6.896	-29.031	35.93
600	10.398	-29.031	39.43
800	12.942	-29.031	41.97
1000	22.024	-24.451	46.47
1200	25.541	6.785	18.75
1400	42.65	9.3799	33.27
1600	53.592	26.126	27.47

V. CONCLUSION

The harmonic structural response shows that the system remains stable at lower frequencies, but vibration levels increase significantly as the excitation approaches higher natural modes, with the maximum response occurring near 2000 Hz. This indicates a potential resonance zone where the structure may experience amplified deformation and stress.

The aero-acoustic evaluation identifies a dominant low-frequency noise component of about 19.54 Hz, caused by flow-induced oscillations such as vortex shedding. Meanwhile, the harmonic acoustic analysis reveals that the surrounding fluid domain also exhibits its highest acoustic pressure near 2000 Hz, aligning with the peak structural response.

This suggests possible structural–acoustic coupling at higher frequencies, where both vibration and acoustic pressures are simultaneously amplified. Overall, the results highlight that although the system generates low-frequency aerodynamic noise, its most critical behaviour occurs at high frequencies, where dynamic amplification and acoustic resonance are strongest. These findings emphasize the importance of avoiding high-frequency excitation near resonance and implementing measures to control vibration and noise for improved performance and reliability.

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