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The Effect of Material Selection of Honeycomb Structures on Noise Reduction of Airplane Engines

By Tsz Ho Lee

AUTHOR BIOGRAPHY

Tsz Ho (Ben) Lee is a junior at The Hill School in Pennsylvania. Passionate about aviation, he founded his school's aviation club and enjoys STEM courses, particularly engineering and physics. Outside the classroom, Ben is a competitive swimmer and water polo player and is also an avid photographer and videographer.

ABSTRACT

Honeycomb structures are widely used in modern aircraft engines due to their exceptional strength-to-weight ratio, durability, and acoustic performance. This paper examines how material selection: specifically, aluminum, Nomex, and carbon fiber reinforced polymer (CFRP), drives differences in noise attenuation across three dimensions: acoustic absorption coefficients, effective frequency ranges, and integration with major engine families. By synthesizing quantitative data from the existing literature and organizing it around a cross-material comparative framework, this review provides a structured basis for understanding why manufacturers select specific materials in response to International Civil Aviation Organization (ICAO) Chapter 14 noise certification requirements. The analysis shows that while aluminum offers structural efficiency at low cost, Nomex dominates acoustic liner applications due to its superior sound absorption coefficient (up to 0.99 at resonance) and fire resistance, and CFRP is increasingly adopted where structural and acoustic demands converge. This synthesized comparison reveals clear trade-offs that are not visible when materials are analyzed in isolation and demonstrates that informed material selection is a direct lever for achieving regulatory compliance.

Keywords: honeycomb structures, aircraft engines, aerospace materials, Nomex, CFRP, aluminum core, acoustic panels, noise attenuation, ICAO standards, aviation engineering

INTRODUCTION

Noise pollution from aircraft engines is one of the most persistent environmental challenges in modern aviation. Communities near major airports continue to experience health and quality-of-life impacts from engine noise, and the International Civil Aviation Organization (ICAO) has responded with progressively stricter certification standards. The progression from Chapter 3 through Chapter 4 to the current Chapter 14 standard now demands a cumulative noise reduction of approximately 17 EPNdB (Effective Perceived noise level) relative to the original Chapter 3 baseline (ICAO, n.d.). Meeting these requirements has elevated material selection in engine components from an engineering detail to a strategic design priority.

Honeycomb structures appear throughout modern turbofan engines in fan cases, nacelles, and acoustic liners, and are a primary technological lever for noise attenuation. Three materials dominate: aluminum, Nomex aramid paper, and carbon fiber reinforced polymer (CFRP). Each offers a different combination of structural, thermal, and acoustic properties, and each is applied in different engine zones for different reasons. Despite this, the existing literature tends to describe these materials in isolation, making it difficult to understand the trade-offs that govern actual design choices or to predict how future regulatory tightening will shift material strategies (Indy Honeycomb, 2023; Belan et al., 2017).

This paper addresses that gap. Its central contribution is a cross-material comparative framework grounded in quantitative acoustic performance data drawn from the literature that makes explicit the trade-offs across aluminum, Nomex, and CFRP in a single analytical structure. By connecting this framework to observed material configurations in current engine families and to ICAO noise standards, the review demonstrates that material selection is not arbitrary but responds systematically to the acoustic, structural, and regulatory demands of each engine zone.

HONEYCOMB STRUCTURE: DESIGN AND ACOUSTIC FUNCTION

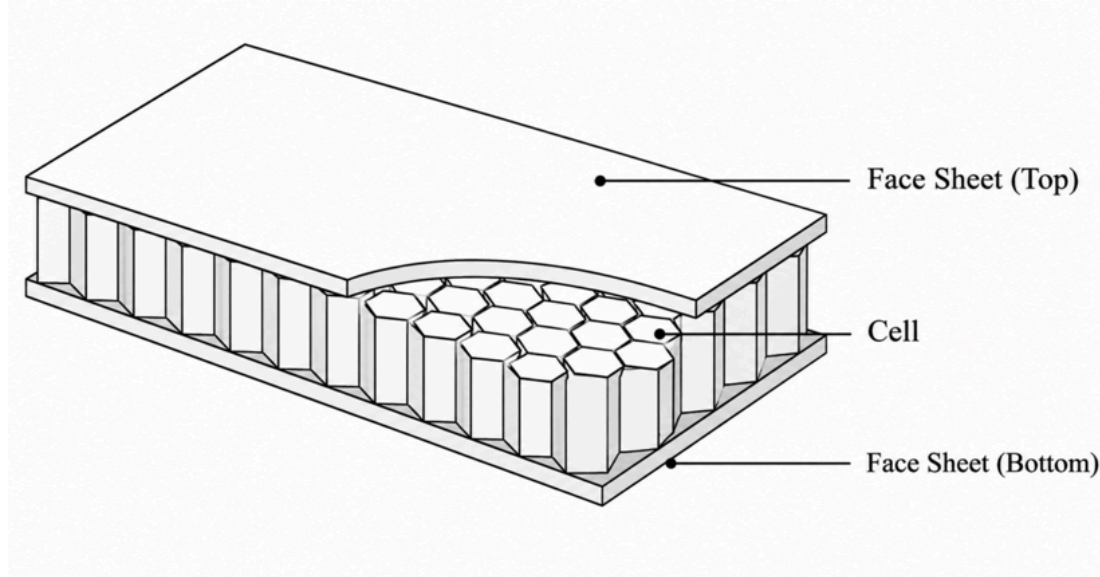
Honeycomb materials consist of a hexagonal cellular core bonded between two face sheets (as shown in Figure 1). This architecture distributes mechanical loads efficiently across a minimal mass, yielding a high strength-to-weight ratio (Mohammadi et al., 2023). In acoustic applications, each hexagonal cell also functions as a resonant cavity whose geometry determines the frequencies at which sound energy is absorbed (Nugroho et al., 2023).

In aircraft engines, noise attenuation occurs through two complementary mechanisms. The first is Helmholtz resonance: in the standard perforate-over-honeycomb-core (POHC) liner configuration—a

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perforated face sheet bonded atop the honeycomb core with a solid back plate—each cell acts as a quarter-wave resonator. The peak absorption frequency is governed by cell depth; greater depth shifts peak absorption toward lower frequencies. The perforated face sheet adds inertial loading that broadens the absorption peak across a wider frequency band (Xie et al., 2021). The second mechanism is structural vibration damping: stiff, lightweight panels shift the natural frequencies of engine components away from the dominant noise-generating frequencies produced by the rotating fan, reducing structure-borne sound emission.

Both mechanisms are material-dependent. The acoustic absorption coefficient (SAC) and effective frequency range of a honeycomb panel are shaped not only by cell geometry but by the wall material, core density, and surface treatment of the honeycomb. This material dependence is the foundation of the comparative analysis below (Mohammadi et al., 2023; Xie et al., 2021).

Figure 1*Honeycomb structure graphic*

Note. Adapted from “An Insight from Nature: Honeycomb Pattern in Advanced Structural Design for Impact Energy Absorption” (Mohammadi et al., 2023), *Journal of Materials Research and Technology*, 22, 2862–2887. <https://doi.org/10.1016/j.jmrt.2022.12.063>

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The following subsections examine how each of the three principal materials achieves noise attenuation, with reference to measured acoustic performance data.

Aluminum

Aluminum honeycomb is the most structurally robust option, with typical aerospace core densities of 50 to 77 kg/m³ (Corex Honeycomb, n.d.). Its noise reduction function is primarily structural: aluminum's rigid metallic cell walls provide a stable platform for perforated face sheets, enabling the formation of tuned resonator cavities without adding excessive weight. However, the metallic walls offer limited intrinsic acoustic damping. Studies report SACs of 0.15 to 0.40 for unfilled aluminum honeycomb panels across typical engine noise frequencies of 500 to 2,000 Hz, a modest performance compared to non-metallic alternatives (Viva ACP, 2024). Its principal acoustic contribution is therefore indirect: aluminum provides the structural substrate onto which acoustically active Nomex liners are bonded. Its thermal conductivity is a secondary benefit in high-temperature engine zones, though susceptibility to corrosion requires protective coatings that can affect long-term acoustic performance (Indy Honeycomb, 2023).

Nomex

Nomex aramid paper honeycomb, available in densities from 29 to 144 kg/m³ (Nugroho et al., 2023), is the dominant material for acoustic liner applications in commercial turbofan engines. Its acoustic superiority over aluminum arises from two properties: the aramid paper walls are inherently compliant and partially absorbent, dissipating vibrational energy as heat rather than reflecting it, and Nomex cells can be manufactured to precise depth and geometry, allowing engineers to tune the Helmholtz resonance frequency to the dominant tonal noise of a given engine.

Measured SACs for Nomex acoustic panels range from 0.60 to 0.99, depending on cell geometry and face sheet perforation ratio (Wang et al., 2020). At a thickness of 25.4 mm (one inch), Nomex panels have been experimentally demonstrated to achieve 99.3% sound absorption at 624 Hz—a critical frequency in turbofan fan noise—by enabling multiple cells to act as a single resonator cavity (Wang et al., 2020). In engine liner applications, Nomex-based panels deliver 6 to 11 dB of fan noise attenuation, sufficient to contribute materially to Chapter 4 and Chapter 14 compliance (Belan et al., 2017; ICAO, n.d.). Nomex's inherent fire resistance further supports its use in the engine environment. Its main limitation is moisture absorption: prolonged humidity exposure causes aramid paper to swell and lose stiffness, degrading acoustic tuning and prompting the use of phenolic resin coatings or moisture-resistant face sheets (Wang et al., 2020).

CFRP

CFRP honeycomb achieves densities as low as 15 to 48 kg/m³ while providing specific compressive and shear strengths superior to both aluminum and Nomex (Sun et al., 2018). Its acoustic contribution operates through vibration damping rather than Helmholtz absorption: the high stiffness of carbon fiber shifts the natural frequencies of structural engine panels away from dominant noise-producing frequencies, reducing structure-borne sound emission. Transmission loss measurements for CFRP-integrated panels in noise-critical applications have reached up to 25 dB at targeted frequencies (Gong et al., 2022). CFRP also enables thinner, lighter structural components that reduce the mass available to couple with and amplify engine vibrations (Sun et al., 2018).

However, CFRP's brittleness makes it vulnerable to impact damage, and its high manufacturing cost and specialist repair requirements limit its application to structural components and face sheets rather than bulk liner cores. In practice, CFRP is typically paired with Nomex, as in the Rolls-Royce Trent 1000 acoustic liner, which uses a Nomex core with CFRP face sheets to combine Nomex's absorptive performance with CFRP's structural stiffness and reduced mass (Okura, 2015).

Cross-Material Comparative Analysis

Table 1 consolidates the quantitative acoustic and material characteristics discussed above into a single comparative framework. This synthesis is the primary analytical contribution of this review, making explicit the trade-offs that govern manufacturer material choices

Table 1

Comparative Material Properties and Acoustic Performance in Aircraft Engine Honeycomb Applications

Property	Aluminum	Nomex	CFRP
Core density (kg/m ³)	50–77	29–144	15–48
Typical SAC range	0.15–0.40	0.60–0.99	0.40–0.75
Peak absorption frequency (Hz)	500–2,000	400–5,000	500–4,000
Noise attenuation in nacelle liner (dB)	3–6	6–11+	Up to 25*
Thermal resistance	Moderate (degrades >150°C)	Excellent (fire-resistant)	Good (epoxy-dependent)

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Moisture / corrosion resistance	Poor; requires coating	Moisture absorption; degrades	Excellent; chemically inert
Relative cost	Low	Moderate	High
Repairability	Moderate	Moderate	Difficult
Primary engine application	Fan case structure	Acoustic liners / panels	Fan case + structural panels

*Note. SAC = sound absorption coefficient. *CFRP figure refers to transmission loss in CFRP-panel acoustic liner systems, not Helmholtz absorption. Core density ranges: aluminum from Corex Honeycomb (n.d.); Nomex from Nugroho et al. (2023); CFRP from Sun et al. (2018). SAC ranges: aluminum from Viva ACP (2024); Nomex from Wang et al. (2020); CFRP from Gong et al. (2022). Noise attenuation: aluminum and Nomex from Belan et al. (2017); CFRP from Gong et al. (2022). Thermal and moisture resistance: Indy Honeycomb (2023) and Okura (2015). Engine applications: Belan et al. (2017) and Okura (2015).*

Three findings emerge from this comparison. First, no single material optimizes all dimensions simultaneously. Aluminum excels in structural robustness and cost but provides the lowest acoustic absorption (SAC 0.15–0.40). Nomex provides superior noise attenuation across the widest frequency range (400–5,000 Hz) but is vulnerable to moisture degradation and cannot bear structural loads. CFRP offers the best structural performance at the lowest weight but at high cost and limited repairability, and achieves acoustic benefit through a different physical mechanism than Nomex.

Second, the materials are rarely used in isolation. Every major commercial turbofan engine analyzed below pairs Nomex acoustic liner cores with CFRP or fiberglass face sheets, and uses aluminum or CFRP composites for structural components. This reflects a design philosophy of functional differentiation: structural and acoustic requirements are addressed by different materials in different engine zones.

Third, the effective frequency ranges differ meaningfully. Aluminum-based liner configurations operate most effectively at 500–2,000 Hz; Nomex panels extend coverage up to 5,000 Hz and can be tuned down to 400 Hz; CFRP damping addresses 500–4,000 Hz but through structural vibration control rather than cavity absorption. Because broadband turbofan noise spans from below 100 Hz to above 10 kHz, no single material provides complete coverage, reinforcing the multi-material configurations observed in practice.

Engine Applications

Table 2 maps the material configurations across six major commercial turbofan engine families, illustrating how the trade-offs in Table 1 translate into engineering decisions. A diagram of the location of the fan case and acoustic liner are illustrated in Figure 2.



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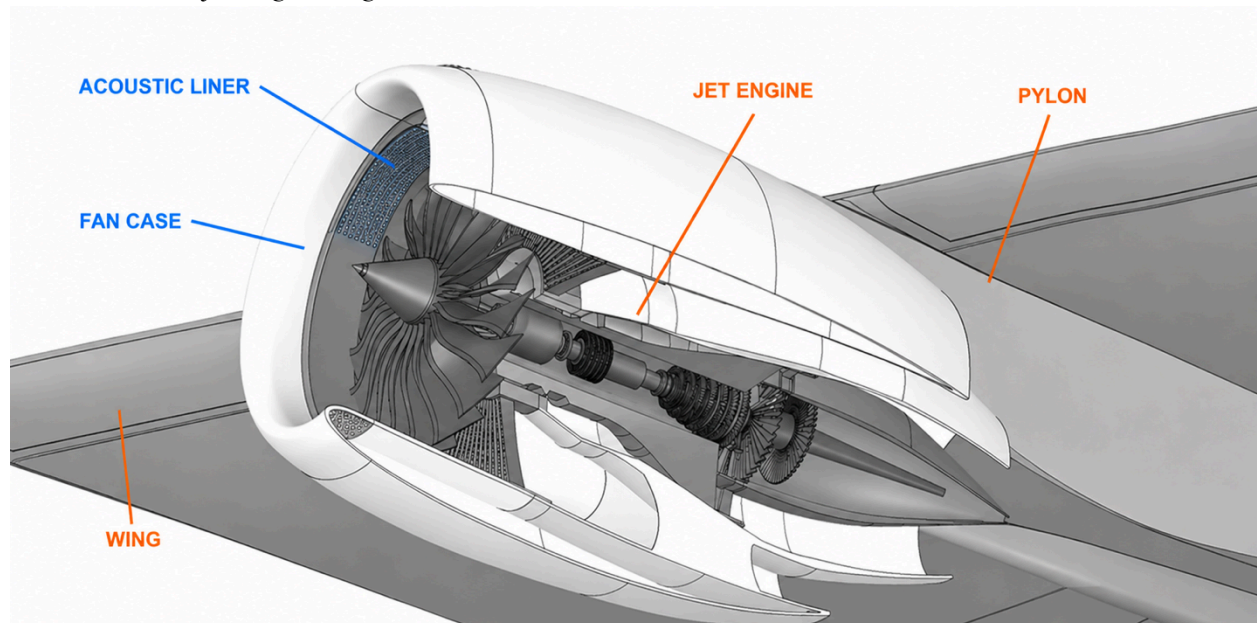
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Figure 2

Commercial turbofan engine diagram



*Note. Adapted from “Vibration Analysis of a Jet Engine” by SimScale CAE Forum.
<https://indyhoneycomb.com/metallic-structural-honeycomb-uses-in-aviation-industry-indy-honeycomb/>*

Table 2

Honeycomb Material Configurations in Current Commercial Turbofan Engines

Engine	Aircraft	Fan Case Material	Acoustic Liner Material
GE GE90	Boeing 777	Al (aluminum) honeycomb + CFRP face sheets	Nomex honeycomb + fiberglass face sheets
RR Trent 1000	Boeing 787	Al honeycomb + CFRP face sheets	Nomex honeycomb + CFRP face sheets
P&W PW1000G	A320neo / A220	Al honeycomb + composite face sheets	Nomex honeycomb + fiberglass face sheets

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CFM LEAP	A320neo / 737 MAX	CFRP composite + Al honeycomb core	Nomex honeycomb + CFRP or fiberglass face sheets
GE GENx	Boeing 787 / 747-8	Al honeycomb + composite face sheets	Nomex honeycomb + fiberglass face sheets
GE GE9X	Boeing 777X	CFRP composite with honeycomb	Nomex honeycomb + CFRP / fiberglass face sheets

Note. Data from Belan et al. (2017) and Okura (2015).

A consistent pattern appears across all six engines: Nomex honeycomb is the universal choice for acoustic liners, paired with fiberglass or CFRP face sheets; fan cases use aluminum or CFRP-aluminum hybrid cores for structural requirements. This functional division directly reflects the trade-offs in Table 1. Nomex's SAC of 0.60–0.99 and broad frequency coverage make it the appropriate choice where acoustic performance is the priority; aluminum's and CFRP's structural advantages make them appropriate for load-bearing components (Belan et al., 2017; Okura, 2015).

The shift toward CFRP face sheets in newer engines—particularly the Rolls-Royce Trent 1000 and CFM LEAP—reflects a regulatory driver as well as a performance one. As ICAO Chapter 14 demands cumulative noise reductions of approximately 17 EPNdB relative to Chapter 3, manufacturers have sought every incremental gain available. Replacing heavier fiberglass face sheets with CFRP reduces total panel mass, enables higher bypass ratio engine architectures, and adds CFRP's vibration-damping contribution to the acoustic system (Belan et al., 2017; Okura, 2015).

ICAO Noise Certification Standards and Material Response

The ICAO certification framework provides the regulatory context in which material selection occurs. Chapter 3 set baseline thresholds of 89–106 EPNdB during takeoff, scaled by aircraft maximum takeoff weight (MTOW) (ICAO, n.d.). Chapter 4 required a cumulative 10 EPNdB reduction across takeoff, sideline, and approach measurements relative to Chapter 3 (ICAO, n.d.). Chapter 14, currently operative for new type certifications, requires a further reduction, reaching a total cumulative improvement of approximately 17 EPNdB relative to Chapter 3 (ICAO, n.d.).

Each tightening of standards has driven observable shifts in honeycomb material strategy. The transition to Chapter 4 compliance was achieved in large part through wider deployment of Nomex acoustic liners in nacelles and bypass ducts, providing the 6–11 dB of fan noise reduction achievable with tuned POHC configurations (Belan et al., 2017; Wang et al., 2020). The further reductions demanded by Chapter 14 required combining acoustic liner performance with structural weight reduction achieved through CFRP fan cases and

face sheets to enable the higher bypass ratios that reduce source noise. This sequence illustrates a direct, traceable connection between regulatory stringency and material adoption: each successive standard has pushed the industry toward materials with superior acoustic profiles and lower structural weight.

Future standards tightening is likely to drive further innovation, particularly in broadband low-frequency attenuation below 500 Hz, a range where current POHC liner configurations perform poorly due to the cell depth required for quarter-wave resonance. Additive manufacturing of variable-geometry honeycomb panels, where cell depth varies continuously across the liner surface, represents a potential pathway to addressing this limitation without proportional increases in liner thickness or mass (Nugroho et al., 2023).

DISCUSSION

The cross-material comparison in Table 1 reveals a structural logic to current engine material configurations that is not visible when materials are described individually. Nomex's dominance in acoustic liner applications reflects its position at the intersection of several favorable properties: high SAC, broad frequency coverage, fire resistance, low density, and precision tunability. Aluminum's continued presence in fan cases reflects its cost and thermal management advantages, not its acoustic performance. CFRP's growing share reflects the convergence of structural and acoustic demands at the panel level, as lighter face sheets reduce both mass and vibration coupling.

Critically, acoustic performance alone does not determine material selection. Moisture resistance, repairability, cost, and thermal stability all constrain the design space. Nomex's moisture sensitivity, for instance, necessitates phenolic coatings or moisture-resistant face sheets that add complexity and cost. CFRP's brittleness limits its application to zones where impact risk is manageable. These multi-criteria constraints explain why no single material dominates all engine zones, and why the functional differentiation observed in Table 2 is likely to persist even as individual material performance improves.

A methodological limitation of this review is its reliance on published performance data from heterogeneous experimental conditions. SAC values are sensitive to test configuration, cell geometry, face sheet properties, and measurement frequency, meaning numerical comparisons across studies should be treated as indicative. Controlled experimental comparisons of the three materials under standardized engine-relevant conditions would substantially strengthen the evidence base for these trade-offs.

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FURTHER RESEARCH

Future research should prioritize controlled experimental comparisons of aluminum, Nomex, and CFRP honeycomb panels under standardized conditions of equivalent cell geometry, face sheet perforation ratio, and acoustic measurement protocol to enable rigorous cross-material SAC comparisons not currently possible from the heterogeneous literature. Engine test-bed and wind tunnel studies would also allow measurement of noise attenuation across a broader frequency range, including the sub-500 Hz region where current POHC liners underperform and where next-generation high-bypass turbofans are generating increasingly significant tonal noise.

Long-term durability studies tracking the effect of moisture cycling, thermal loading, and mechanical fatigue on acoustic performance would address a significant gap in the understanding of Nomex and aluminum behavior over operational lifetimes. Finally, investigation of additive-manufactured honeycomb geometries with continuously graded cell size and depth represents a promising avenue for achieving broadband attenuation profiles not achievable with conventional uniform-cell configurations, and could provide the low-frequency performance required under future ICAO standards.

CONCLUSION

This paper has presented a structured cross-material analysis of aluminum, Nomex, and CFRP honeycomb structures as noise reduction technologies in aircraft engines. The central contribution is a synthesized comparative framework that makes material trade-offs explicit in quantitative terms not available when materials are analyzed individually. Nomex emerges as the dominant acoustic liner material, achieving SACs of 0.60–0.99 and nacelle noise reductions of 6–11 dB across the 400–5,000 Hz range (Wang et al., 2020; Belan et al., 2017). Aluminum provides structural efficiency at lower cost but limited acoustic absorption (SAC 0.15–0.40; Viva ACP, 2024). CFRP contributes vibration damping and structural weight reduction that enables the high-bypass engine architectures inherently quieter at the source, with system-level transmission losses reaching 25 dB in targeted applications (Gong et al., 2022).

The cross-engine analysis confirms a consistent pattern of functional material differentiation: Nomex for acoustic liners, aluminum or CFRP for structural components. This pattern responds directly to the trade-offs in Table 1 and to the progressive tightening of ICAO noise standards from Chapter 3 through Chapter 14. Future regulatory requirements are likely to continue driving adoption of materials and geometries capable of broadband low-frequency attenuation beyond current POHC configurations. This review provides a comparative foundation to support those future design and research efforts.

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