

A Comparative Analysis of Different Placements of Engines in Aircraft

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ABSTRACT

The renewed interest in commercial supersonic transport has increased the need for aircraft designs that are aerodynamically and economically efficient. That being said, engine placement influences key aerodynamic aspects that determine an aircraft's efficiency. The review compares four engine placements: Underwing-mounted, Fuselage-mounted, Fuselage-embedded, and Blended Wing Body (BWB) embedded propulsion. The engine-placement configurations selected for study represent distinct strategies for integrating air-breathing engines into an aircraft and are commonly discussed in conceptual aircraft design. Additionally, engines embedded in a BWB aircraft were selected as a distinct configuration from standard embedded engines because they offer different aerodynamics due to the aircraft's airframe. A comparative literature review methodology was followed to evaluate and compare the configuration. In this paper, fuselage-mounted engines are hypothesized to be a promising strategy for deploying engines in commercial supersonic travel. The objective of the paper is not to determine a universally optimal configuration, but rather to identify trade-offs associated with each placement strategy and their suitability for supersonic travel.

INTRODUCTION

Commercial supersonic transport has regained considerable interest in recent years. To make commercial supersonic transport feasible, there has been a surge in research into developing aircraft that are both aerodynamically efficient and economically sustainable. One of the primary priorities for supersonic aircraft is to address challenges such as wave drag, shock waves, and pressure gradients. Engine placement plays a fundamental role in influencing aerodynamic performance and addressing these challenges. Although individual engine placements have been investigated extensively, comparative discussions evaluating the aerodynamic trade-offs among major engine placement strategies remain relatively limited. This study evaluates the engineering trade-offs of each configuration by comparing the published literature to assess their suitability for future supersonic transport (SST) aircraft.

1. METHODOLOGY

1.1 Literature Selection and Screening

A comparative review methodology was used to evaluate different engine placement configurations in supersonic aircraft. Literature was identified through keyword searches using Google Scholar, NASA Technical Reports Server (NTRS), AIAA Aerospace Research Central, ScienceDirect, SpringerLink, and other academic repositories. Search terms included combinations of “supersonic aircraft engine placement,” “propulsion-airframe integration,” “Underwing mounted engines,” “fuselage mounted engines,” “embedded propulsion,” “blended wing body propulsion,” “pressure recovery,” “boundary layer ingestion,” “wave drag reduction,” “area rule,” “sonic boom mitigation,” and “thermal management.” Boolean operators were used where appropriate to refine searches and identify studies directly relevant to propulsion integration and engine-placement strategies for future supersonic aircraft.

Information extracted from the sources was used to evaluate the performance of configurations in terms of pressure recovery and fuel-burn reduction, structural and thermal integration complexity (added weight due to thermal management), ease of maintenance, shockwave formation and interaction, and the ability to prevent shockwaves from propagating towards the ground. The abstracts of the sources were initially assessed for relevance to the paper’s question. Studies lacking relevance were excluded. Sources were considered relevant if they satisfied all of the following:

1. It evaluated an air-breathing engine-integration strategy in a generic or represented airframe of one of the four configurations;
2. It reported at least one of: pressure recovery, wave drag, sonic-boom signature, L/D ratio, fuel burn, or thermal management
3. Provided sufficient technical detail to enable evaluation of the performance characteristics of each engine-placement configuration.

Approximately 40 publications were initially identified through a literature search. Of these, 26 were tested for relevance, and 16 were retained after screening for relevance and publication quality, as well as direct discussion of the aerodynamic characteristics of engine placement.

1.2 Evidence Extraction and Interpretation

After selecting the sources, the full texts of the relevant studies were analyzed to identify findings on engine placement performance. Further synthesis of the layout's performance was then conducted, drawing information from the sources relied upon. The findings for each configuration were first analyzed independently to understand their individual performance characteristics. Once the advantages and limitations of each configuration had been identified, a comparative assessment was conducted to evaluate the trade-offs among them using a common set of performance criteria:

1. Aerodynamic efficiency
2. Sonic Boom Reduction
3. Pressure recovery
4. Fuel-burn reduction
5. Structural mass penalty due to thermal management

Subsonic and transonic sources were considered only in the study of fundamental engine installation mechanisms. The assessment of the configurations' supersonic performance was derived from studies of engine placement conducted under supersonic conditions.

1.3 Comparative Engineering Assessment

While the studies did not provide directly comparable quantitative data, rankings were assigned based on reported performance trends and qualitative findings. These rankings do not represent numerical measurements. The final comparative assessment was developed through qualitative synthesis of the sources' findings, and the ranking convention (Highest, Optimal, High, Moderate, Low, Lowest) was used to rank the configurations for evaluation of each criterion. The conclusion was derived by considering the overall trade-offs of the engine placements and identifying which placement offers the best compromise.

1.4 Limitations

The rankings presented in this review represent a qualitative synthesis of the available literature and should be interpreted as evidence-based judgments rather than definitive performance. Different weighting of the evaluation criteria could reasonably produce different rankings. Actual engine placement performance may vary in practice, as the lack of original CFD simulations and flight-test validation limits the paper, which is why it relies entirely on a qualitative literature review. Actual performance may vary depending on aircraft geometry, propulsion-airframe structure, and future technological developments. In addition, differences in aircraft size, wing geometry, and overall airframe structure among the review studies may influence the performance of each configuration. Although the hypothesis presented in the abstract was proposed only as a starting point for the investigation, defining it before the literature review may have influenced the emphasis placed on certain engineering trade-offs during the analysis.

2. EVALUATION OF INDIVIDUAL CONFIGURATIONS

2.1 Underwing Mounts

Underwing-mounted engines are the most widely used placement, especially in commercial aircraft, as shown in Figure 1. The underwing-mounted engines offer several aerodynamic and maintenance benefits. Underwing-mounted engines achieve efficient inlet pressure recovery as they predominantly ingest freestream air. Additionally, the engines ingest minimal low-momentum boundary-layer air, which may help maintain pressure recovery, since the ingestion of boundary-layer air can degrade it (Wang et al., 2025).

Moreover, underwing-mounted engines provide relatively direct access to the ground for inspection and maintenance. Unlike embedded engines, these engines and their major components remain externally accessible, simplifying inspection, removal, and replacement.

Mounting engines under the wings requires external pylons and structural reinforcements that disrupt the smooth, gradual distribution of area prescribed by Whitcomb's area rule (Blaesser et al., 2019), thereby increasing transonic and supersonic wave drag. Underwing-mounted engines offer no structural advantage in preventing shockwaves from propagating to the ground, unlike fuselage-mounted engines (Ueno et al., 2016). As a result, a very loud sonic boom follows.



Figure 1 shows A standard underwing setup.

Source: *The Boeing Company (n.d.)*

2.2 Fuselage-embedded engines

A fuselage-embedded engine is positioned within or partially buried inside the fuselage, usually towards the rear. It varies from exposed podded engines in that it is streamlined into the body, whereas mid-fuselage hidden engines are located towards the rear. These placements have been known to reduce drag and support low-boom shaping and fuel efficiency. In addition, embedding engines avoids uneven geometrical changes, which helps maintain a smooth cross-sectional area distribution along the aircraft, in accordance with the area rule. Hence, the airframe has a reduced N-wave shock signature, as sudden changes in aircraft geometry can intensify shockwave formation and increase wave drag.

Wings can now be thinner because they no longer have to bear engine weight. Wings specialized for performance thereby improve the aircraft's aerodynamic efficiency, as the wings' sole purpose is now to support the aircraft's aerodynamics, enabling them to be optimized primarily for lift generation and maneuverability, as shown in Figure 2. The streamlined container for the engines (engine nacelles) can be a component of gradual, smooth changes, thereby meeting the area rule, if the aft-mounted engines are smoothly blended into the fuselage.

However, one major challenge of embedding engines is inlet flow distortion, in which the air entering the engine's intake varies in speed, direction, or pressure (Nichols, 1966). Additionally, the fuselage's thermal stress increases when the engine is embedded. Thermal management becomes more complicated as the embedded engines are confined within a tight cavity, which makes ambient cooling less effective and maintenance more difficult and less cost-effective than with the underwing setup (Heerden et al., 2022). Figure 2 illustrates a fuselage-embedded engine configuration in which the engines are integrated into the fuselage.



As shown in Figure 2, the wings of the fuselage-integrated engine configuration are optimized for aerodynamic efficiency and maneuverability.

Source: U.S. Department of Defense (2016)

2.3 Fuselage-mounted engines

For this review, fuselage-mounted engines are discussed as two distinct configurations: high-position fuselage-mounted engines and side-body-mounted engines, as these configurations exhibit different pressure-recovery characteristics and aerodynamic behavior. Despite these differences, both configurations share several aerodynamic and structural advantages that make them attractive for future supersonic aircraft.

Fuselage mounting offers unique aerodynamic and structural advantages for aircraft during supersonic travel. One of the main advantages is reduced foreign object damage (FOD) because the engines are mounted high above the ground, as illustrated in Figure 3. Mounting engines above the wing can help reduce the boom carpet effect by minimizing the concentration of the shock wave. Fuselage-mounted engines can be quite beneficial for overland flight, as they can prevent the sound waves from propagating to the ground. Frequent adoption of mounting the engine on the fuselage in conceptual supersonic aircraft designs highlights the structural advantages of this approach.

The configuration has great potential for managing shock waves and engine plume interactions through

airframe design optimization, making it suitable for future low-boom supersonic transport aircraft. (Liebhardt et al., 2020)

High-position fuselage-mounted engines:

The engines placed in the elevated position of the fuselage may experience cross-flow over the wing, degrading pressure recovery, and, along with a reduced lift-to-drag ratio due to the negative lift caused by the nacelle shock wave, result in low range performance (Ueno et al., 2016).

Side-body-mounted engines:

Engines mounted on the fuselage side body overcome the problems mentioned above; however, they also suffer from inlet pressure-recovery penalties due to boundary-layer losses and flow distortions caused by the aircraft's wide airframe. Inlet pressure recovery losses and flow distortion may occur depending on the engine installation and the interaction between the inlet and the surrounding airframe (Ueno et al., 2016).

However, external structural reinforcements, such as pylons, are used to support engines mounted on the fuselage, just as is required for mounting the engine under the wing, which presents a general structural disadvantage as it can increase the aircraft's weight and require design optimization to mitigate drag (Wegener, 2021).

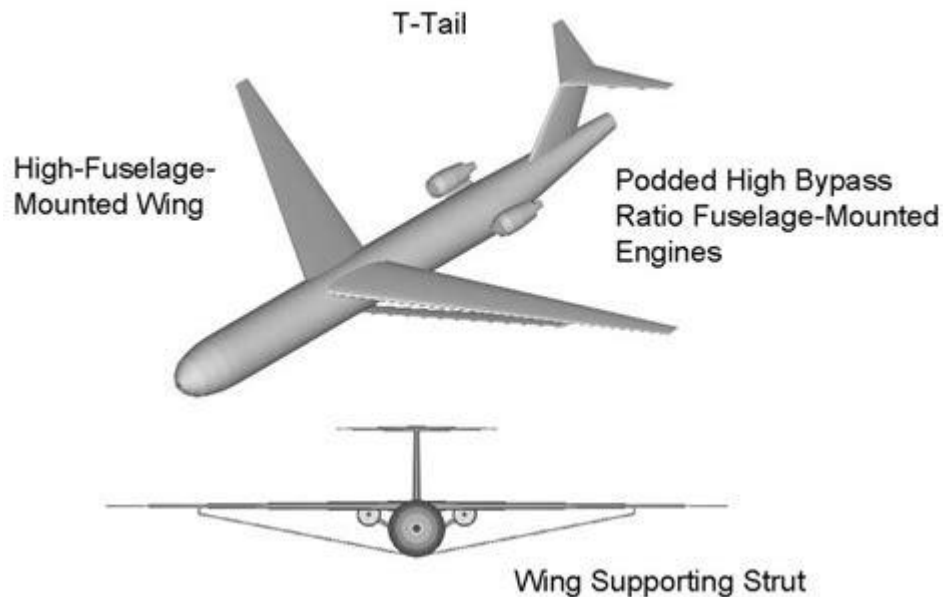


Figure 3 illustrates that aft-mounted engines enable good ground clearance.

Source: Leifsson (2006)

2.4 Integrated Propulsion within Blended Wing Body (BWB)

A Blended Wing Body (BWB) aircraft integrates the wing and fuselage into a single continuous lifting surface. Unlike conventional aircraft, in which lift is generated predominantly by the wings, the BWB configuration enables both the wings and the central body to contribute to lift, thereby improving aerodynamic efficiency (Liebeck, 2004; Ali et al., 2025). In BWB design, engines are typically mounted on or partially integrated into the upper rear fuselage, but this paper focuses only on integrated propulsion within BWB. The BWB configuration is highly compatible with the Boundary Layer Ingestion (BLI) concept, in which the engines ingest air influenced by the aircraft's fuselage, slowing it and reducing its total pressure. Figure 4 shows a BWB aircraft designed to maximize the ingestion of boundary-layer air. BLI reduces the aircraft's overall drag and can save up to 10-12% of fuel (Carrera et al., 2025; Gray et al., 2018). While the data have been projected under subsonic conditions, the actual percentage of fuel reduction might be much lower than this due to shock-boundary interaction, causing lower pressure recovery. However, if the design is optimized to control the shock-boundary-layer interaction, the inlet pressure recovery can be improved. (Wang et al., 2023)

Moreover, placing engines within the body reduces the aircraft's shock wave signature. The aircraft's broad upper surface also acts as an acoustic shield, reducing the propagation of engine noise toward the ground during overland supersonic flight. Furthermore, engines mounted on or partially integrated into the upper rear body reduce interference drag by eliminating external pylons. BWB can better manage the distribution of cross-sectional area. It makes the Blended Wing Body better suited for drag control and allows the shock waves to be shaped to reduce the intensity of the sonic boom.

The BWB-integrated propulsion complicates maintenance due to limited access for engineers to the engine's components. Engines are embedded or mounted at the top of the rear fuselage. Managing the engine's thermal energy becomes even more complicated when the configuration includes BLI, as BLI uses slower airflow, resulting in less effective heat dissipation. Reduced natural ventilation further complicates thermal management for engineers. (Heerden et al., 2022) Moreover, engine-failure scenarios must be considered to ensure airflow within the BWB body. The shock-induced flow separation creates severe total pressure distortion at the compressor face, reducing its pressure recovery.



Figure 4 shows an airframe designed to shield the ground from noise while optimizing fuel efficiency.

Source: [NASA \(n.d.\)](#)

3. COMPARATIVE ANALYSIS OF THE EVALUATED CONFIGURATIONS

3.1 Pressure Recovery

$$\frac{P_{t2}}{P_{t0}} = \eta_i \cdot (1 - 0.075 \cdot [M - 1]^{1.35})$$

The total pressure recovery is the ratio of the total pressure of the airflow at the engine face (P_{t2}) to that of the freestream (P_{t0}). (Ran & Mavris, 2005) Under supersonic conditions, boundary-layer ingestion increases pressure distortion and reduces total-pressure recovery. Under-wing engines achieve efficient pressure recovery because they sit out in the open, allowing clean, undisturbed freestream air to flow

through the inlet. The fuselage-mounted configuration incurs moderate penalties because it ingests only a limited mass flow from the boundary layer. In contrast, fuselage-embedded engines incur a significant penalty. BWB-integrated layouts achieve lower pressure recovery than fuselage-embedded engines (Geiselhart et al., 2003) because the BWB layout's large airframe increases the boundary-layer mass flow.

3.2 Sonic Boom Reduction

The high-speed exhaust exiting the engine contributes significantly to the sonic boom. That being said, traditional under-wing-mounted engines produce a pronounced sonic boom as the N-wave signature expands unhindered down to the ground (Han et al., 2024). Fuselage-embedded engines and BWB-integrated engines produce a moderate signature as the engine is contained within the fuselage. At the same time, fuselage-mounted engines produce a low boom because the fuselage acts as a physical shield for the engines. In contrast, side-body-mounted engines allow the nacelle shock wave to act around the trailing edge, deflecting the signature waves. (Ueno et al., 2016)

3.3 Wave drag and Aerodynamic efficiency

A geometric configuration of an aircraft with minimal abrupt changes in cross-sectional area, in accordance with the area rule, along with geometry with smoother pressure distribution, is an ideal configuration to reduce wave drag. This is why under-wing-mounted engines have a high interference drag, as they are mounted on pylons. Their placement disrupts the smooth cross-sectional area, resulting in an unfavorable pressure distribution. Similarly, engines are exposed in the fuselage-mounted configuration. However, fuselage-embedded and fuselage-mounted engines were classified as moderate in this section because they are placed at the rear of the aircraft (Ueno et al., 2016), where the body tapers, thereby allowing the aircraft's overall area rule to be managed more effectively. Meanwhile, the BWB configuration has the potential to achieve the lowest wave drag by integrating the engines into a continuous body, thereby producing a smoother cross-sectional area distribution and more favorable pressure distribution.

3.4 Fuel Burn Variance

Ingesting boundary-layer air reduces an aircraft's fuel burn by reducing the energy required to fill the aircraft's wake and improving the overall propulsive efficiency of the system. These gains are heavily dependent on the management of shock-boundary-layer interaction; however, this management is out of scope for this paper. (Wang et al., 2023) While other configurations ingest boundary-layer air, underwing-mounted engines operate in clean freestream air, yielding the least fuel-burn reduction from BLI. Fuselage-embedded engines exhibit a moderate reduction in fuel burn because they ingest a limited volume of boundary layer. Fuselage-mounted engines may also ingest a very limited volume of boundary-layer air, which is why they achieve lower fuel-burn reductions than embedded engines. BWB achieves the most significant saving, due to its geometry, which ingests an expansive boundary layer of air. Although BWB integrated propulsion and fuselage-embedded engines suffer from flow distortion, this

problem could be mitigated by placing the inlet in a favorable location and aligning it with the flow (Nichols, 1966). Integrated propulsion also requires managing the shock-boundary-layer interactions. (Wang et al., 2023)

3.5 Thermal Integration structural mass penalty

As effective ambient air cooling is limited because the free-stream air temperature increases with increasing air pressure at higher Mach numbers, thermal management becomes more complicated. It requires increased focus on thermal management structures. These thermal management systems, while effective for cooling, inevitably add to the aircraft's overall weight. This section qualitatively assesses the extent to which thermal management of each engine placement might increase the aircraft's overall weight. Underwing-mounted engines incur a lower structural mass penalty due to thermal management, as they are exposed to free-stream air, which partially cools them. Similarly, fuselage-mounted engines are exposed to freestream air but may ingest a limited amount of air heated by friction against the aircraft's body. Fuselage-embedded engines restrict ambient air cooling because they are buried in a narrow, unventilated cavity and, along with the ingestion of hot boundary-layer air, incur a high structural mass penalty. Even though the large airframe of a BWB aircraft avoids the severe confinement as associated with fuselage-embedded engines, it ingests a large amount of hotter air, which is significantly affected by friction with the aircraft's body, resulting in a critical thermal integration burden. The thermal management requirements of the placements require the addition of thermal management structures, such as heat exchangers. Further studies are needed to balance structural mass penalties against specific aerodynamic and propulsive advantages. (Heerden et al., 2022)

Table 3.1 summarizes the comparative analysis.

Assessment Metric	Under-Wing Pod	Fuselage-mounted	BWB-Integrated engines	Fuselage-Embedded
Pressure Recovery	Optimal	Moderate	Lowest	Moderate
Wave Drag (area-rule adherence)	High	Moderate	Lowest	Moderate
Fuel Burn Reduction (BLI/ wake-filling benefit)	Lowest	Moderate	Optimal	Moderate
Sonic Boom Reduction	Lowest	High	Highest	Moderate

Thermal structural mass penalty	Lowest	Low	Highest	High
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4. CONCLUSION

Engine placement is one of the most important factors in an aircraft, which determines the aircraft's aerodynamic efficiency and sonic boom signature. Findings suggest that no single configuration is universally perfect; each offers distinct aerodynamic advantages, accessibility, and trade-offs, so each is best suited to a specific mission. While underwing-mounted engines are easier to maintain, they are not as aerodynamically efficient as the other selected engine placements. Fuselage-embedded engines and BWB-embedded engines offer better shockwave control as their major advantage; however, embedding the engines complicates pressure recovery and thermal management, making them economically challenging for a commercial aircraft. Fuselage-mounted engines offer a better balance between structural complexity, economic sustainability, and aerodynamic efficiency, suggesting they are a better fit for future commercial supersonic aircraft. Fuselage-mounted engines are considered in conceptual designs for supersonic travel (Kawanabe & Lei, 2025). An ideal engine placement must offer aerodynamic efficiency and accessibility, ensuring both efficient supersonic travel and maintainability. Further research is needed to assess the practical feasibility and determine the optimal engine placement for commercial supersonic travel.

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