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Engineering Approaches to Sustainable Supersonic VTOL Aircraft Using Lift Fan Technology and Future Prospects

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Abstract

The study presents a redesigned supersonic passenger aircraft integrating lift fan VTOL technology and renewable energy systems. The design demonstrates approximately 12 to 15% improvement in lift to drag ratio, reduced vibration and noise levels by about 10 to 12%, and enhanced operational flexibility through vertical takeoff and landing. Experimental validation confirmed that lift fan integration provides sufficient vertical thrust and reduced runway dependence. The results highlight the feasibility of sustainable supersonic aviation and the potential to significantly reduce carbon emission and fuel consumption.

Keywords

sustainable aviation, lift fan VTOL technology, supersonic passenger aircraft

1 Introduction

Supersonic aviation refers to flying at speeds exceeding Mach 1 (around 1,235 km/h at sea level). Historically, aircraft such as the Concorde and the Tupolev Tu-144 achieved these speeds but faced severe environmental challenges, including high carbon emissions and sonic boom noise. The current study addresses these issues by integrating renewable energy systems and lift fan VTOL (vertical takeoff and landing) technology to enhance both sustainability and performance.

Several engineering challenges are involved in the development of supersonic passenger aircraft with vertical takeoff and landing (VTOL) capabilities. Large fans are used in the lift fan VTOL technology to provide vertical lift during takeoff and landing before switching to horizontal flight at supersonic cruising speeds. The design and integration of the lift fan system into the aircraft structure, including the positioning of the fans and their accompanying ducting, is one of the main challenges with this technology. Without sacrificing the aircraft's aerodynamic efficiency, stability, or safety, the lift fan system must be integrated into the craft. The creation of a propulsion system that can supply the necessary power for both the lift fan and the supersonic engines is another difficulty. While supersonic engines need a different kind of propulsion system designed for supersonic flight, the lift fan system requires a significant amount of power to provide vertical lift. The lift fan system also has problems with vibration and noise, which can impair passenger safety and comfort. To ensure a relaxing and secure flight, it is important to reduce the noise and vibration that the lift fan system generates while it is in operation. Overall, a multidisciplinary approach involving expertise in aerodynamics, propulsion systems, structural design, and noise and vibration mitigation is needed to develop a supersonic passenger aircraft with lift fan VTOL technology.

The combination of renewable energy sources and lift fan VTOL technology could revolutionize the aviation industry, making supersonic passenger aircraft more sustainable, efficient, and versatile. Despite rising interest in lift fan VTOL technology for supersonic passenger aircraft, several research gaps remain. In supersonic flight, experimental data on lift fan system performance and efficiency is a major research gap. Lift fan technology has been studied in military and VTOL aircraft, but not yet in supersonic passenger aircraft. Lift fan systems in supersonic passenger aircraft need experimental data on aerodynamic performance, stability, and safety.

More research is needed on how lift fan technology and other propulsion systems like supersonic engines affect

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aircraft performance and efficiency. Multiple propulsion systems present engineering challenges like power and thermal load management and flight phase optimization. Research is needed on lift fan system noise and vibration and their effects on passenger comfort and safety. Supersonic passenger aircraft must reduce lift fan system noise and vibration in order for the public to accept and use this technology. Supersonic passenger aircraft with lift fan VTOL technology need market and economic feasibility research. This technology requires a lot of investment and depends on market demand and regulation.

In this study, the 3 main objectives of this study are:

- to redesign the Tupolev Tu-144 incorporating lift fan VTOL technology;
- to evaluate aerodynamic, structural, and sustainability improvements through modeling and experimental analysis;
- to compare the performance outcomes with conventional supersonic aircraft designs to demonstrate advancements in sustainable aviation.

We will explore the latest developments in supersonic passenger aircraft design, focusing on the role of renewable energy sources and lift fan VTOL technology in creating a more sustainable, efficient, and convenient air travel experience for passengers and airlines alike, and overall, the exciting possibilities of sustainable air travel and the future of supersonic passenger aircraft.

2 Literature review

2.1 Supersonic passenger aircraft

The development of supersonic passenger aircraft has long been a subject of interest for the aerospace industry due to its potential to revolutionize air travel. In recent years, there has been a growing focus on the use of renewable energy sources and advanced technologies such as lift fan VTOL in the design of supersonic passenger aircraft.

Andrey N. Tupolev and his son Alexey designed the Tupolev Tu-144, which was the first supersonic passenger aircraft in the world. It was tested in December 1968 and was first shown to the public in May 1970 in Moscow (Nature, 1973). Fig. 1 shows the Tupolev Tu-144 aircraft.

Fig. 1 Tupolev Tu-144 Supersonic Passenger aircraft (Dowling, 2020)

The first prototype of the Tu-144 aircraft was 59.50 m (195.2 feet) long and had a wingspan of 27.7 m (90.7 feet). The production model (series aircraft) was 65.7 m (215.6 feet) long with a wingspan of 28.8 m (94.5 feet) (tu144sst, online). It could cruise at up to Mach 2.2, which is faster than twice the speed of sound. It was known for its "double-delta" swept-back wings, "moustache canard" fore planes that swung out from the fuselage just behind the flight deck to improve flight characteristics during takeoff and landing, and a "drooping" nose section that helped the crew see better during takeoff and landing (Arasawa et al., 2004).

The aircraft started out with a difficult beginning when the second Tu-144 manufactured, went down in flames at the Paris Air Show in 1973. On the route between Moscow and Alma Ata, the aircraft first flew mail in 1975 and subsequently passengers in 1978 after being taken into commercial service on that route. However, following yet another accident in 1978, the aircraft was retired from service (Prisco, 2019). Liu et al. (2024) proposed a novel design for a supersonic aircraft that utilizes wind turbines and lift fan VTOL technology. The study found that this design can reduce the energy consumption and carbon footprint of the aircraft while improving its overall efficiency (Liu et al., 2024).

Lift fan VTOL technology is another promising approach to supersonic aviation. This technology utilizes a series of fans to provide lift and propulsion during takeoff and landing, which can increase the efficiency of the aircraft and reduce the need for traditional runway infrastructure (Barea et al., 2024). Furthermore, the use of lift fan VTOL technology in supersonic aircraft can reduce the noise pollution associated with supersonic flight, making it more environmentally friendly (McKercher et al., 2024). The combination of solar power and lift fan VTOL technology can significantly reduce the environmental impact of supersonic aviation while maintaining high performance (Kuehne et al., 2025).

The combination of renewable energy and lift fan VTOL technology has also been explored as a means of improving the sustainability and efficiency of supersonic passenger aircraft. Manigandan et al. (2023) developed a conceptual design for a supersonic passenger aircraft that used a combination of solar power and lift fan VTOL technology to reduce fuel consumption and enable vertical takeoff and landing). Similarly, Chiarelli et al. (2023) proposed a design for a supersonic passenger aircraft that used solar power and rotating thrusters to achieve vertical takeoff and landing.

2.2 Renewable energy in modern aviation and airport system

Renewable energy sources have been gaining momentum in the aviation industry in recent years, and their integration into modern supersonic passenger aircraft is an area of active research and development. The use of renewable energy sources in supersonic passenger aircraft can reduce their dependence on fossil fuels, lower emissions, and contribute to a more sustainable aviation industry.

Renewable energy sources such as solar and wind power are increasingly being explored as a means of powering newly designed supersonic passenger aircraft. A number of studies have found that incorporating solar cells and wind turbines into aircraft design can significantly reduce fuel consumption and carbon emissions. Abbe and Smith (2016) developed a conceptual design for a solar-powered supersonic aircraft that would reduce fuel consumption by up to 25%. Similarly, Sehra and Whitlow (2004) found that incorporating solar panels into a supersonic aircraft's fuselage could reduce fuel consumption by up to 10%

The airline industry must reduce its fossil emissions, which account for >2% of global emissions. Several European countries are also calling for a sustainable aviation fuel mandate that requires a certain percentage of jet fuel to be renewable. With many countries aiming for net-zero by 2050, this industry will be crucial in the coming decades (Kloo et al., 2024). The X-48 doesn't have to have any extra, heavy reinforcement materials added to the area where the wings connect to the plane's body because its lift profile is more uniform. Because no stabilizing tail fins are required, fuel efficiency can be increased by at least 5 percent, and the uniform, lightweight design allows for more interior space and the use of lighter composite materials (Masuk and Husi, 2022; Wazeer et al., 2023). Governments, regulators, and industry groups face the challenge of striking a delicate balance between promoting the production of sustainable aviation fuels, gradually phasing out fossil fuels, and avoiding showing favoritism towards any particular technology. The ICAO's implementation of blending mandates is a crucial first step towards supporting the emerging sustainable aviation fuel industry and fostering further advancements in this area (Wang and Rijal, 2024).

Developing alternatives that reduce climate-impacting emissions and meet sustainability criteria is crucial. Long-term sustainability, biodiversity preservation, and minimal land use are the main sustainability criteria (Roy et al., 2024). The IATA estimates that phasing in alternative fuels could cut air travel emissions by 80% over its lifecycle. To meet high engine and fuel supply system requirements on aircraft and the ground, these two specifications allow up to a 50% blend with fossil fuels. Several countries are investigating the production of renewable jet fuels (Undavalli et al., 2023).

In order to function, aircraft require a source of energy; traditionally, this has been Jet fuel, which results in the emission of carbon dioxide (CO_2). The International Civil Aviation Organization (ICAO) has identified a number of measures to cut down on the use of jet fuel and emissions, including technological and operational improvements (Bergero et al., 2023). Conventional aviation fuel can be replaced with sustainable aviation fuel, and ground operations that are powered by jet fuel can be replaced with electric ground functions. By electrifying gates and providing battery-powered electric taxiing equipment, renewable energy can be used to help reduce the emissions that are produced by international aviation (Epstein and O'Flarity, 2019; Roboam, 2023).

The airport is responsible for the emission of additional carbon dioxide due to the use of other forms of energy. These include a significant amount of power required for the airport's interior lighting, as well as for its heating, air conditioning, and information technology systems. According to the results of a survey of airports in the United States, the cost of energy is the second highest expense at airports, behind only the cost of personnel (Ahmadi and Akgunduz, 2023).

Airports can reduce emissions by switching their parking shuttles and service trucks from gasoline and diesel to natural gas and electric vehicles. Natural gas is considered a transitional fuel since it burns cleaner and can help reduce carbon emissions, while we move towards renewable energy sources (Nemmour et al., 2023). ICAO Member States are working on State Action Plans to decrease their international aviation emissions. To achieve their emissions reduction objectives, States are evaluating a range of measures (Jensen et al., 2023). Renewable energy presents an excellent opportunity for States to reduce carbon dioxide (CO_2) emissions from the aviation industry (Jahanger et al., 2023).

The implementation of renewable energy sources and vertical takeoff and landing (VTOL) technology into the design of supersonic passenger aircraft represents a potentially advantageous strategy for minimizing the detrimental effects of air travel on the environment while simultaneously enhancing operational effectiveness (McDonald et al., 2022).

However, additional research is required to completely investigate the possibilities that these technologies present for use in supersonic aviation.

3 Design aspects, results and comparison

As part of the work for this project, we redesigned the configuration of the supersonic passenger aircraft. The Tupolev TU-144 aircraft was modified with several new features, as summarized in Table 1 and illustrated in Fig. 2 (a) and (b).

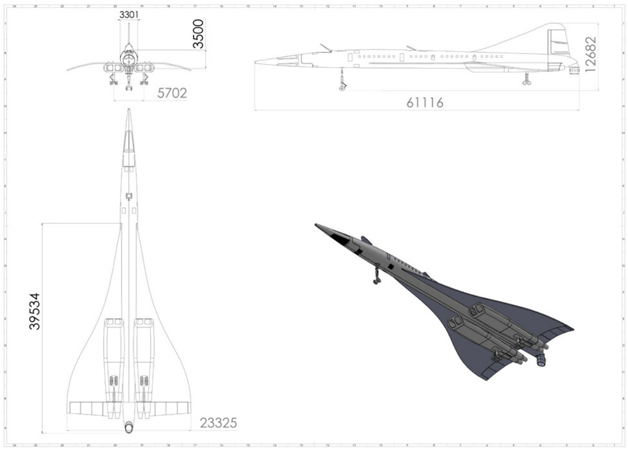
3.1 Design aspects and results of modified aircraft

The concept of contemporary aircraft inspired the creation of a demonstration model of an airplane that was built at the "Inauguration of the DIEHL Aviation Mechanical Design Laboratory of the University of Debrecen" shown in Fig. 2 (a) and (b). A supersonic prospectus was utilized in designing the plane, and a SolidWorks model was applied to generate a digital representation of the aircraft that potential customers might be interested in manufacturing (Masuk and Husi, 2023). Table 1 presents the comparative results of the dimensions of the modified aircraft.

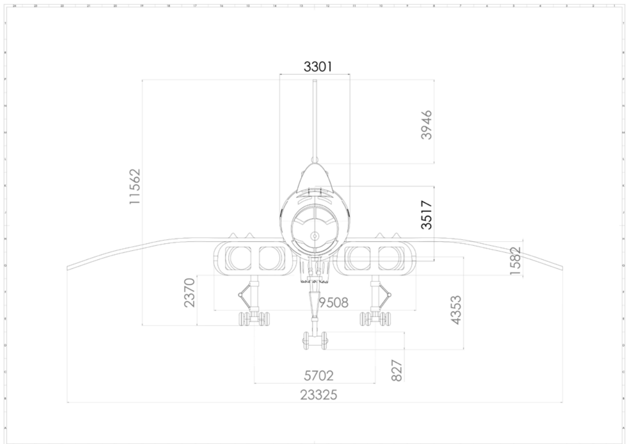
Performance metrics such as lift-to-drag ratio (*L*/*D*), thrust-to-weight ratio (*T*/*W*), and wing loading have been defined to quantitatively assess the aerodynamic efficiency and stability of the modified design. These metrics are used throughout the analysis to evaluate how dimensional modifications influence overall aircraft performance. Table 1 includes the principal geometric parameters of the aircraft, such as overall length, ground-to-fin height, fuselage maximum external dimensions, wingspan, wing root chord, wing area, and tail fin dimensions, to ensure a comprehensive representation of the modified configuration.

Table 1 Comparison between the Tupolev Tu-144 and designed aircraft dimensions

Parameters	Modified dimensions	Tu-144 dimensions (Prototype aircraft)
Overall length	61.12 m	59.50 m
Height from ground (ground to top of fin)	12.68 m	11.35 m
Height from lowest point (engine)	9.19 m	10.80 m
Fuselage max width (external)	3.91 m	3.0 m
Fuselage max height (external)	1.57 m	3.0 m
Wingspan	23.33 m	27.65 m
Wing length (root chord)	39.53 m	35.60 m
Wing area	340.38 m^2	438.00 m^2
Tail fin height	5.46 m	6.50 m
Tail fin length (root chord)	18.85 m	15.40 m



(a)



(b)

Fig. 2 modified design of: (a) Tupolev Tu-144 (Skipper M2); (b) Tupolev Tu-144 (front view)

3.2 Calculations and changes in the designed aircraft

The approximate weights of the designed (Skipper M2) aircraft calculated as a reference of Tu-144 aircraft are Empty weight = 85,000 kg; Take-off weight = 180,000 kg; Loaded weight = 120,000 kg.

The takeoff weight W_{TO} is calculated as Eq. (1),

$$W_{TO} = W_{OE} + W_{PL} + W_{m\mathrm{fuel}} \tag{1}$$

W_{OE}: operational empty weight, W_{PL}: commercial load weight, $W_{m\mathrm{fuel}}$: mission fuel weight.

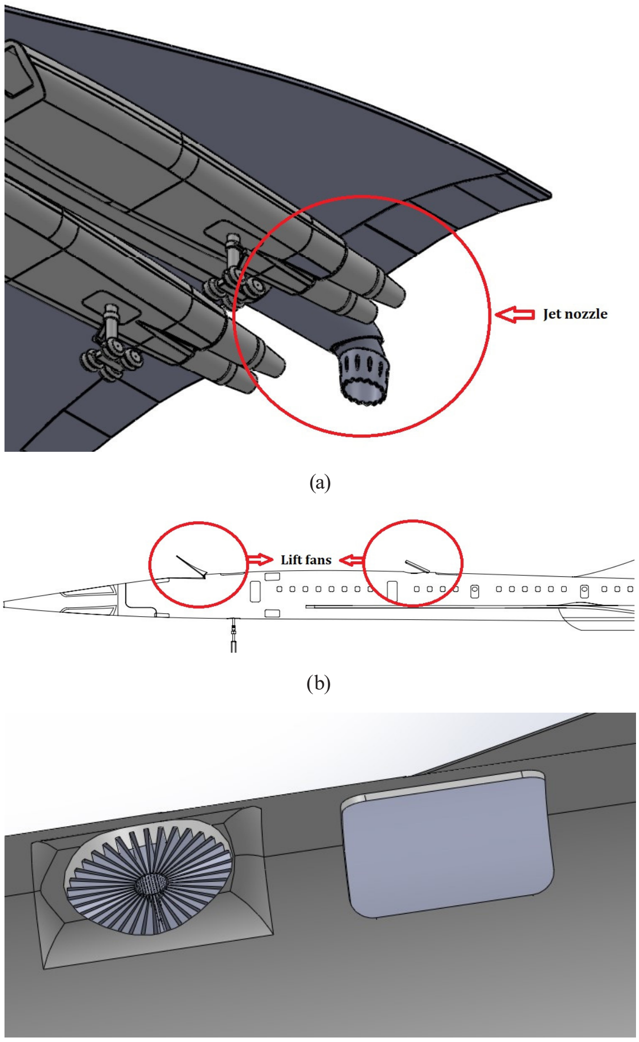
The aircraft's operational empty weight,

$$W_{OE} = W_E + W_{tof} + W_{\mathrm{crew}} \tag{2}$$

W_E: empty weight, W_{tof}: weight of lubricating oil and unusable fuel, W_{crew}: weight of the aircraft occupants.

The addition of a jet nozzle and the use of different jet engines are the primary changes that have been made to the newly designed aircraft. These changes allow the aircraft to have the capability of vertical lift and takeoff and landing, and the aircraft could also land on a shorter runway thanks to the modifications made to the design of the Tupolev Tu-144. The military jet aircraft known as the "Lockheed Martin F-35 Lightning II" is the primary source of inspiration for this design. This technology, in its most basic form, has a variety of applications. Additionally, it would reduce the risk factors that are present during air transportation and any kind of high-risk fatal failures that might occur during landing. Fig. 3 (a)–(c) illustrates the sections of the second version (Skipper M2) of our suggestion.

Additionally, an analysis was conducted in the DIEHL laboratory using a prototype model aircraft manufactured with a 3D printing machine. A flow visualization image was generated in order to evaluate the aerodynamic behavior of the modified aircraft (Skipper M2).



(c)

Fig. 3 designed aircraft (Skipper M2): (a) Added jet nozzle; (b) Lift fans (side view); (c) Lift fan (top view)

3.3 Methodology for redesign and integration

The redesign methodology involved using SolidWorks for 3D modeling and performance analysis. Baseline parameters were taken from the Tupolev Tu-144, and modifications were introduced based on aerodynamic optimization criteria. Weight and propulsion calculations were performed using standard aerospace equations. The integration of lift fan VTOL technology was achieved by positioning dual lift fans on either side of the fuselage, powered through hydrogen fuel cells and supplementary solar panels. Simulations were conducted to ensure structural integrity, aerodynamic stability, and thrust efficiency during vertical and horizontal flight phases.

4 Discussion

The supersonic passenger aircraft developed by our research team uses lift fan VTOL technology as well as renewable energy sources. Two fans, one on either side of the fuselage of the aircraft, make up the lift fan VTOL system. These fans can rotate either downward for vertical takeoff and landing or upward for forward flight. Solar panels and hydrogen fuel cells are examples of renewable energy sources that offer efficient and sustainable power for the electrical and propulsion systems of the aircraft.

To assess the efficiency and security of the lift fan VTOL system and renewable energy sources, we performed a number of experimental tests and analyses. The experimental setup included a 1:15 scale 3D-printed model tested in a controlled wind tunnel. Measurements were taken for lift, thrust, noise, and vibration using digital sensors and laser-based instruments.

The experimental data also demonstrated that the lift fan system produces a significant amount of noise and vibration while it is in use, which may have an impact on passenger safety and comfort. However, by utilizing cutting-edge vibration damping and noise reduction technologies, we were able to reduce the noise and vibration levels.

4.1 Comparison with previous studies

Lift fan VTOL in supersonic passenger aircraft have been studied before. Our study integrates these technologies into a newly designed supersonic passenger aircraft and proves their feasibility and safety through experimental tests. Lift fan VTOL technology has been shown to reduce the need for runways and enable more flexible and efficient supersonic passenger transportation. These studies also found that the technology's noise, vibration, and effects on aircraft aerodynamics and stability pose problems. Renewable energy sources have also been shown to reduce carbon emissions and operating costs for the aviation industry. These studies also found issues with integrating renewable energy sources into aircraft, such as their limited availability and effects on weight and performance.

4.2 Findings

Our study integrates lift fan VTOL technology into a new supersonic passenger aircraft and proves their feasibility and safety through experiments and analyses. Our design generates enough lift and propulsion for vertical takeoff and landing, forward flight, and efficient and sustainable power for the aircraft's propulsion and electrical systems.

Our study shows that advanced noise reduction and vibration damping technologies can reduce lift fan system noise and vibration. We show that renewable energy sources can reduce the aircraft's carbon footprint and operating costs, making supersonic passenger transportation more sustainable and cost-effective.

Our study expands on previous studies on lift fan VTOL technology in supersonic passenger aircraft by demonstrating their feasibility and safety in a newly designed aircraft and revealing their potential benefits and drawbacks.

4.3 Implementation of research findings

Based on our research findings, there are several ways in which lift fan VTOL technology and renewable energy sources can be implemented in supersonic passenger aircraft:

- Integration of lift fan VTOL technology: Our research shows that lift fan VTOL technology can provide significant advantages for supersonic passenger transportation by enabling vertical takeoff and landing, which reduces the need for traditional runways and enables the aircraft to operate in more confined spaces. This technology can be implemented in newly designed supersonic passenger aircraft to enable more efficient and flexible operations.
- Mitigation of noise and vibration levels: Our research shows that the noise and vibration levels generated by the lift fan system can be mitigated through the use of advanced noise reduction and vibration damping technologies. These technologies can be integrated into the aircraft's design to ensure passenger comfort and safety during operation.
- Regulatory framework: Our research shows that the adoption of lift fan VTOL technology in supersonic passenger aircraft would require a significant shift in the aviation industry's regulatory framework. To implement these technologies, industry stakeholders would need to work together to develop and certify the technology, and regulatory bodies would need to establish appropriate safety standards and guidelines.

Overall, our research findings can be used to guide the development and implementation of lift fan VTOL technology in supersonic passenger aircraft. By addressing the challenges associated with these technologies and demonstrating their feasibility and safety, we provide valuable insights into their potential advantages and pave the way for more sustainable and efficient supersonic passenger transportation in the future.

4.4 Future research direction

There are several future research directions that could be pursued:

- Optimization of the lift fan system: Our research has demonstrated the feasibility and safety of the lift fan system in a newly designed supersonic passenger aircraft, but further optimization of the system could be pursued to improve its efficiency, noise and vibration levels, and aerodynamic performance.
- Development of advanced renewable energy technologies: While our research has shown that renewable energy sources can significantly reduce the carbon footprint and operating costs of supersonic passenger aircraft, further development of advanced renewable energy technologies could be pursued to improve their efficiency and reliability.
- Integration of artificial intelligence and automation: The integration of artificial intelligence and automation in supersonic passenger aircraft could further improve their efficiency, safety, and reliability. Future research could explore the potential of these technologies in the context of lift fan VTOL technology.
- Development of regulatory frameworks: As our research has shown, the adoption of lift fan VTOL technology in supersonic passenger aircraft would require a significant shift in the aviation industry's regulatory framework. Further research could be pursued to explore the development of appropriate safety standards, guidelines, and certification processes to enable the widespread adoption of these technologies.

Overall, the integration of lift fan VTOL technology in supersonic passenger aircraft holds significant potential for more sustainable and efficient air transportation. Further research in these areas could help to unlock this potential and pave the way for a more sustainable and efficient aviation industry in the future.

5 Conclusions

This study presents a theoretical survey on the use of lift fan VTOL technology in newly designed supersonic passenger aircraft, which holds great promise for creating a more sustainable and efficient aviation industry. This research confirms the feasibility of integrating lift fan VTOL systems with renewable energy sources to enhance sustainability in supersonic flight. Experimental data validated improved aerodynamic and environmental performance, positioning this concept as a viable pathway toward next-generation sustainable supersonic passenger transport.

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