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Sustainable Aviation Engineering: Decarbonizing Air Transport Through Hydrogen Propulsion, Electrification, and Advanced Aerodynamic Design

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Abstract

The aviation industry is one of the fastest-growing contributors to greenhouse gas emissions, accounting for a significant share of global CO_2 output. With increasing demand for air travel, decarbonizing air transport has become a critical engineering challenge. Sustainable aviation engineering emphasizes the development of hydrogen propulsion, electrification, and advanced aerodynamic designs as pathways to achieve net-zero aviation. This paper explores the potential of hydrogen fuel cells and combustion systems, electric and hybrid-electric aircraft architectures, and novel aerodynamic configurations—including blended wing bodies and morphing structures—in reducing aviation's carbon footprint. Technical feasibility, infrastructure requirements, and environmental impacts are analyzed, alongside challenges such as fuel storage, energy density, certification, and scalability. The study concludes that while no single solution will achieve full decarbonization, the integration of these innovations, coupled with supportive policies and global collaboration, can transform aviation into a more sustainable sector.

Keywords

Sustainable Aviation, Hydrogen Propulsion, Electrification, Aerodynamic Design, Decarbonization

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Introduction

Aviation plays a vital role in global connectivity, commerce, and economic development. However, it is also responsible for approximately 2–3% of global carbon dioxide emissions and has a disproportionately high impact on climate change due to non-CO_2 effects such as contrail formation and nitrogen oxides. As international travel demand continues to rise, aviation emissions are projected to grow unless transformative engineering solutions are adopted.

Sustainable aviation engineering represents a multidisciplinary approach that combines propulsion innovation, advanced energy systems, and aerodynamic optimization to reduce carbon intensity. Emerging technologies in hydrogen propulsion, electrification, and advanced aerodynamic design are increasingly viewed as cornerstone solutions for achieving long-term climate goals.

This paper discusses how these three domains collectively support the transition to carbon-neutral aviation, analyzing their technical, environmental, and socio-economic implications.

Subheadings

1. The Case for Decarbonizing Aviation

Global aviation emissions are expected to triple by 2050 without intervention.
International bodies such as ICAO and IATA have set ambitious net-zero targets, making decarbonization a priority for research and development.

2. Hydrogen Propulsion: Promise and Challenges

Hydrogen offers nearly three times the energy density of conventional jet fuel by weight, making it an attractive alternative.
Hydrogen can be used in fuel cells for electric propulsion or combusted in modified gas turbines, producing only water vapor.
Challenges include cryogenic storage at −253°C, fuel infrastructure, and aircraft redesign to accommodate large tanks.

3. Electrification of Air Transport

Battery-electric and hybrid-electric aircraft are under active development, particularly for regional and short-haul flights.
Electrification improves efficiency, reduces noise, and eliminates direct emissions during operation.
Current limitations include low battery energy density, which restricts range and payload capacity for large commercial aircraft.

4. Advanced Aerodynamic Design for Efficiency

Aerodynamic optimization reduces drag, fuel consumption, and emissions regardless of propulsion system.
Designs such as blended wing bodies, laminar flow control, and morphing wing structures improve lift-to-drag ratios.
Lightweight materials and additive manufacturing also contribute to structural efficiency.

5. Integration of Technologies and Future Pathways

No single technology will decarbonize aviation; rather, integration of hydrogen propulsion, electrification, and aerodynamic innovation is necessary.
Regional air mobility may lead the adoption of electric aircraft, while long-haul flights may rely on hydrogen or hybrid systems.
Synergies with sustainable aviation fuels (SAFs) and carbon offset mechanisms may further accelerate decarbonization.

6. Barriers and Policy Enablers

High development costs, certification hurdles, and lack of global hydrogen infrastructure remain significant barriers.

Government incentives, international collaboration, and public-private partnerships are critical to advancing sustainable aviation engineering.

Conclusion

Decarbonizing aviation requires bold innovation in propulsion, electrification, and aerodynamic design. Hydrogen propulsion offers a scalable long-term solution, while electrification is poised to transform regional aviation in the near term. Advances in aerodynamic design further enhance efficiency, enabling all propulsion types to operate more sustainably. Although challenges such as fuel infrastructure, storage, and certification persist, the integration of these technologies, supported by strong policy frameworks and international cooperation, can place aviation on a sustainable trajectory. The next decades will be pivotal in shaping the future of air transport, making sustainable aviation engineering central to achieving global climate goals.

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