

Abstract

Bridging the Icing Challenge in Innovative Air Mobility: Current Technologies, Limitations, and Future Directions

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The rapid evolution of Innovative Air Mobility (IAM) is transforming the future of aviation by introducing new classes of aircraft, novel operational concepts, and highly automated flight systems designed to support sustainable, efficient, and accessible air transportation. Electric vertical take-off and landing (eVTOL) aircraft, unmanned aerial vehicles (UAVs), and other advanced aerial platforms are expected to operate in complex environments, including urban and suburban airspace, while performing a wide range of passenger, cargo, and emergency service missions. As these aircraft increasingly operate beyond traditional aviation environments and in all-weather conditions, ensuring their safety, reliability, and operational resilience becomes a critical challenge. Among the various environmental hazards affecting flight operations, atmospheric icing remains one of the most significant threats due to its adverse impact on aerodynamic performance, propulsion efficiency, flight stability, and overall flight safety.

This presentation provides a comprehensive overview of aircraft icing within the context of Innovative Air Mobility. It begins by introducing the fundamental physical mechanisms responsible for ice formation on aircraft surfaces, including the role of supercooled liquid water droplets, ambient temperature, liquid water content, droplet size distribution, and atmospheric conditions that promote ice accretion. The presentation discusses the formation and characteristics of the primary icing types, including rime ice, glaze ice, and mixed ice, and explains how it affects aircraft aerodynamics, increases drag, reduces lift, alters stall characteristics, and may impair flight control systems, propulsion components, and onboard sensors.

The presentation subsequently reviews the current state of aircraft ice protection technologies, distinguishing between anti-icing systems, which prevent ice formation, and de-icing systems, which remove accumulated ice during flight. Existing technologies—including pneumatic boots, thermal bleed-air systems, electro-thermal heaters, electro-mechanical actuators, and emerging hybrid solutions—are presented together with their operating principles, advantages, and limitations. Particular emphasis

is placed on the suitability of these systems for modern electrically powered aircraft, where conventional solutions often become impractical due to limited electrical power availability, weight restrictions, and the absence of turbine bleed air.

Special attention is devoted to the unique engineering challenges associated with integrating ice protection systems into next-generation IAM vehicles. Electric propulsion architectures, distributed propulsion systems, lightweight composite structures, compact airframes, and stringent energy efficiency requirements significantly constrain the design of conventional icing mitigation solutions. The presentation discusses how these characteristics influence system architecture, certification requirements, operational limitations, and maintenance strategies. Furthermore, the increasing level of aircraft autonomy introduces additional challenges related to autonomous icing detection, decision-making, and adaptive control of ice protection systems during flight.

The presentation also identifies current research gaps and future development opportunities in aircraft icing science and technology. These include improvements in icing prediction models, numerical simulations, experimental validation methods, certification procedures for novel aircraft configurations, and the development of reliable ice detection technologies capable of real-time operation. Emerging research directions involving smart materials, multifunctional composite structures, advanced sensing technologies, digital twins, artificial intelligence, and intelligent control algorithms are discussed as promising approaches for creating energy-efficient, lightweight, and adaptive ice protection systems suitable for future IAM applications.

By combining current knowledge of icing physics with recent technological developments in aerospace engineering, this presentation aims to provide a comprehensive introduction to aircraft icing challenges in Innovative Air Mobility. It highlights the necessity of interdisciplinary research integrating aerodynamics, materials science, propulsion, sensing technologies, and systems engineering to develop effective icing mitigation strategies. Ultimately, the presentation outlines future research priorities that will support the certification, safety, sustainability, and operational reliability of next-generation air transportation systems operating in increasingly demanding atmospheric environments.

Abstract should be between 500 to 1500 words.

Biography

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Maciej Osiewicz M.Sc. in Rzeszów University of Technology, Faculty of Mechanical Engineering, Mechanical Engineering and currently pursuing a Ph.D. in UAV icing at the Military University of Technology. R&D Advanced Lead Design Engineer and Project Leader at Łukasiewicz – Institute of Aviation.



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