# Research progress on the effect of aircraft heating systems on wing anti-icing and dicing

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**Abstract.** As human technology developed, the aircraft flew much higher. But wings may experience varying degrees of icing due to the use of different materials and structures in different parts. The research topic of this article is the importance of aeroplane dicing systems and anti-icing systems. The research methodology of this text is as follows. We enumerate four mainstream aircraft wing dicing systems in the world today. Then we do further research on the structure of dicing systems and analyse the merits and demerits. The research finds that these four methods will also lead to some structure injuries. It will lead to the loss of power when the aircraft accelerates, these four systems all have good and effective effects on dicing. However, the advantages and disadvantages of these methods are prominent. Some systems will affect flights, and some systems are only installed on a few models. There is no doubt that humans have to solve these critical problems, but these dicing systems provide a lot of help for the development of aeroplanes. Humans will invent dicing systems of wings with lower energy consumption, higher efficiency and safety.

**Keywords:** dicing systematizing system, structures, aircraft, wing.

## 1. Introduction

The anti-icing system is an integral part of the plane used to remove or prevent the buildup of hazardous aircraft icing conditions through various active and passive means. At one time, the conditions under which an aircraft could fly were extremely harsh, if the wings of the aircraft iced up the aircraft had to face the end of a forced landing, but since the introduction of the world's first dicing design, mechanical dicing, in 1923, there are now about 40 different dicing and anti-systems. Including, but not limited to the systems that will be highlighted below, electrothermal anti-icing system, hot air anti-icing system, electrical pulse anti-icing system and ultrasonic anti-icing system. Icing system. It is these different systems that allow different aircraft to operate stably in different environments. Electrothermal anti-icing systems are widely used for their ability to precisely control the amount of heat needed at any given time, as well as for their environmentally friendly emissions. Although the Anti-icing Bleed Air System can't control the amount of heat added as precisely as its predecessor, its simple system makes it adaptable to many different models. The electrical pulse anti-icing system is a state-of-the-art technology with ultra-fast response enabling it to be used in fighter jets. Ultrasonic anti-icing system removes ice by penetrating the ice layer, not only reducing service life but also quickly removing large areas of ice. In aviation, ice formation on aircraft wings, engine inlets, and other parts during high-altitude flights can increase weight and negatively impact aerodynamic performance, potentially leading to accidents. Anti-icing technology is crucial for ensuring flight safety. As aviation technology advances, anti-icing systems are also evolving to improve efficiency, reduce energy consumption, and enhance reliability. Commonly used systems include electrothermal, hot air, electromagnetic pulse, and ultrasonic anti-icing systems. Electrothermal systems melt ice using electrical heat, but future improvements should focus on better materials and smart controls to reduce energy use. Hot air systems use heated air to remove ice and will benefit from advancements in heating technology.

And airflow optimization to improve effectiveness. Electromagnetic pulse systems break the bond between ice and surface with high-frequency pulses; future development will focus on increasing efficiency while minimizing interference with electronics. Ultrasonic systems use vibrations to dislodge ice without damaging surfaces, with future efforts aimed at enhancing precision and power for broader applications. These systems will continue to develop towards greater efficiency, intelligence, and environmental sustainability.

This paper will focus on introducing four types of wing heating and dicing systems, including their working principles, structures, frameworks, advantages and disadvantages, and the impact of wing anti-icing. It will also compare their pros and cons and summarize their suitable applications.

## 2. Comprehensive Analysis of four Aircraft Wing Deicing Systems

As aviation technology advances, the need for effective de-icing and anti-icing systems for aircraft wings has become increasingly critical to address the challenges posed by extreme climatic conditions. This part of the paper delves into four prominent technologies currently in use: Electrothermal, Anti-icing Bleed Air, Electronic Pulse, and Ultrasonic anti-icing systems. Each system is examined in terms of its design, operating principles, benefits, application scenarios, and potential future advancements.

### 2.1. Electrothermal anti-icing and dicing system

#### 2.1.1. Design and Principle of Operation

Electrothermal dicing and anti-icing systems are systems that remove or prevent ice build-up by converting electrical energy into heat through an electric heater and then transferring it to the surface through a solid shell [1]. The heat melts the broken ice or water droplets and removes them through the high-velocity airflow.

The system consists of many thermometers and sensors, as well as heaters, which are mounted on the inside of the wing, separated from the outside world by a solid shell. Fig.1 is a two-position plan view of a typical electrically heated dicing system mounted on the inside of a wing with seven electric heaters. The power of each heater is adjustable. Normally, for example, heater 3 will generally have a higher power than the other heaters because icing is generally most severe at that location [2].

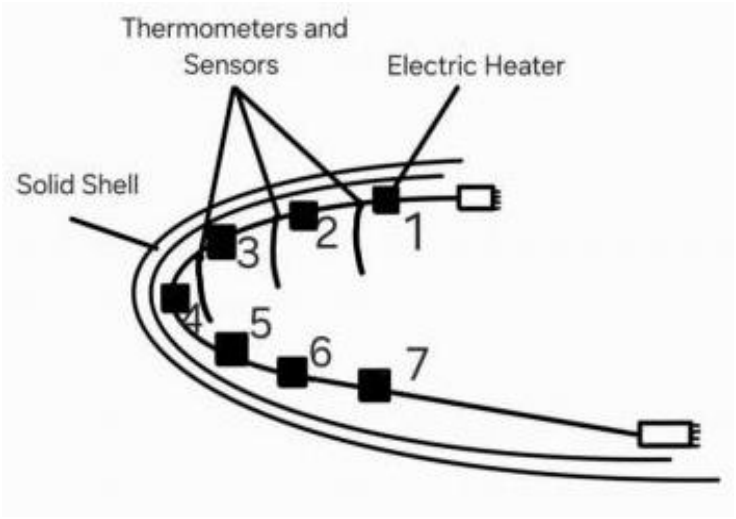



**Fig. 1** Two-dimensional view of the wing cross-section

#### 2.1.2. Application Scenarios and Advantages

The popularity of electric heating systems is also inseparable from the trend of gradual electrification of aircraft. Initially, this technology was used to protect helicopter blades, propellers and pitot tubes. However, with the development of more advanced electric wing IPS, this technology has been gradually promoted, with the Boeing 787 on the installation of an electric heating anti-icing

system, electric heating system anti-icing has gradually become the mainstream dicing solution for aircraft [3].

The promotion of a system is often due to the presence of some compelling flashpoints on that system, and electric heating systems are no exception. Two of its main advantages are the flexibility of performance adjustment and energy savings [4]. Thanks to the high degree of customisation that is common in electrical and electronic appliances, electric heating systems have the flexibility to manually adjust, or automatically adjust according to an algorithm, the power input during heating to achieve energy savings. As an example, the IPS, the electric heating system fitted on the Boeing 787, uses individual heating pads mounted at key points on the wing of the aircraft, with automatic and adjustable power inputs that allow the pads to be activated and deactivated sequentially, which facilitates customised heat distribution on the surface of the aircraft to achieve energy savings in the light of the environment, and power reductions in certain areas where high power dicing is not required [5].

On the other hand, electric heating technology has an extremely important advantage in that it is environmentally friendly. The use of electricity as an energy source does not produce harmful exhaust emissions, which means that they do not directly emit carbon dioxide (CO2), nitrogen oxides (NOx), sulphur oxides (SOx) or other harmful particles into the atmosphere, minimising air pollution and improving urban air quality [6].

#### 2.1.3. Discussion of Limitations and Future Development

Although the electric anti-icing and dicing system has been designed to minimize energy consumption, and in fact, it does not consume much, the energy it uses, electrical energy, is the same energy on which other systems on the aircraft operate. So, it can put a burden on the airplane's energy system. The aircraft must provide external energy for this anti-icing method. Especially on long flight routes, the crew must carefully manage electrical power to ensure that the aircraft is fully powered throughout.

To correct this shortcoming, the author believes that special devices can be installed in aeroplanes to replenish electrical energy. For example, solar power systems or wind power systems to increase the range of aeroplanes. In addition, for short-haul aeroplanes, a device that generates electricity from internal fuel can be installed to use the excess fuel to generate electricity to cope with certain special conditions.

### 2.2. Anti-icing Bleed Air System

#### 2.2.1. Design and Principle of Operation

Anti-icing Bleed Air System (AI-BAS) is a crucial part of modern aircraft. It prevents ice formation on critical surfaces such as wings, engine inlets, and control surfaces that may potentially lower the lift force act on the aircraft which may result in insufficient lift force. Fig.2 This system, AI-BAS, as shown in the picture, operates by extracting high-temperature air, known as bleed air, from the engine’s compressor section——typically from the intermediate or high-pressure compressor stages. The hot air is then directed through dedicated ducting to areas prone to icing such as Wing leading edge, Engine inlet, and horizontal stabilizer. In the wing anti-icing process, hot bleed is routed through piccolo tubes which contain small, strategically placed holes that distribute the air along the leading edge of the wing [7-8]. The heat transferred from the inner surface of the wing prevents ice accumulation on the outer surface, preventing potential disruption to the aircraft’s aerodynamics.

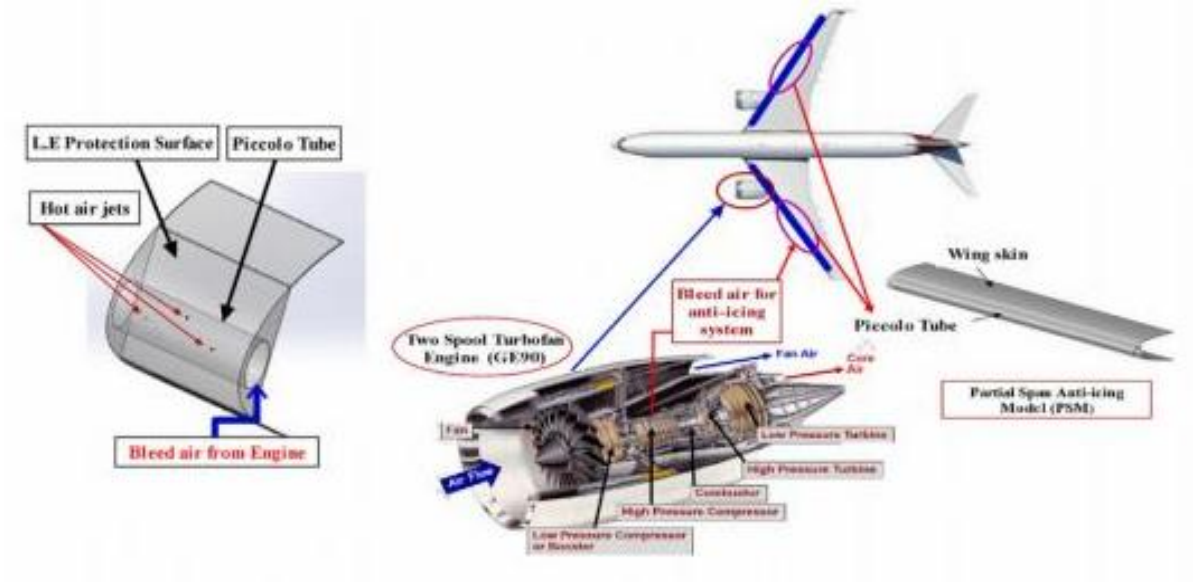



**Fig. 2** Anti-icing Bleed Air System [8]

Temperature and pressure regulation are essential to ensure the effectiveness of the system. Initially, the air extracted from the engine is too hot to use for the Anti-icing system directly, so it is passed through a cooler system before being delivered to the piccolo tubes. The cooler system uses ambient fan air to cool the bleed air to a usable temperature [7]. Additional sensors and valves ensure the temperature and pressure to meet the requirement, which is crucial to avoid overheating the aircraft's structure or losing engine power.

### 2.2.2. Application Scenarios and Advantages

AI-BAS is commonly used in high-altitude, sub-zero temperature environments where aircraft are susceptible to icing including long-haul commercial jets cruising at altitudes where icing conditions are prevalent. The system is particularly advantageous for its reliability and continuous operation, offering ice protection without the need for external heating elements or anti-icing chemicals [9]. Moreover, the integration of AI-BAS into the engine is also a great advantage, leveraging the already available high-temperature air with minimal additional complexity. Thus, it provides an effective solution compared to electric or chemical anti-icing systems, which would require additional infrastructure and materials. Additionally, the system can be adapted to protect various surfaces, from wings to engine nacelles, ensuring wider usage across different aircraft types [1].

### 2.2.3. Discussion of Limitations and Future Development

Despite AI-BAS's wide usage and effectiveness, the system is not perfect. One of the primary drawbacks is the impact on engine performance. Extracting bleed air from the engine reduces the air available for combustion, leading to an overall decrease in engine performance and efficiency, increased fuel consumption, and lower thrust output. Increasing the bleed air ratio can decrease engine efficiency by up to 4% for higher bleed air flow rates and at bleed air flow ratios of 2%, 4%, and 6%, the thermal efficiency decreased by 1.27%, 2.58%, and 3.94%, respectively [8]. This efficiency loss is problematic for long-haul flights, where fuel management is critical.

Furthermore, the temperature control in AI-BAS is another potential limitation. If the air temperature is not adequately regulated, there is a high risk of overheating key aircraft structures, especially during high engine power settings, such as during take-off or climb.[7]

In the aspect of future development, several steps can be made such as optimizing bleed air extraction and enhancing temperature control mechanisms. Cooperating with electrical heating systems as well as chemical anti-icing systems could also serve as supplementary methods, allowing for reduced reliance on bleed air and minimizing its impact on engine performance. Also, cutting-edged materials such as High-temperature resistant material can be used to further prevent the harmful impact caused by overheated air.

### 2.3. Electronic pulse anti-icing and dicing system

#### 2.3.1. Design and Principle of Operation

The Electric pulse dicing (EIDI) is composed of three parts, figure 3 illustrates the composition of the EIDI system. They are eddy current coils, capacitors and excitation devices inside the wing [10]. Figure 1 is a schematic diagram showing the working principle of the EIDI system as follows. The electromagnetic pulse coil is placed on the upper and lower inner surfaces of the wing [10]. So, the system in the wing will produce the magnetic field near the wing to induce a large eddy current instant to produce a strong electromagnetic force [10]. Then the force will produce an invisible slight vibration in the wing. So, the force can be icing.

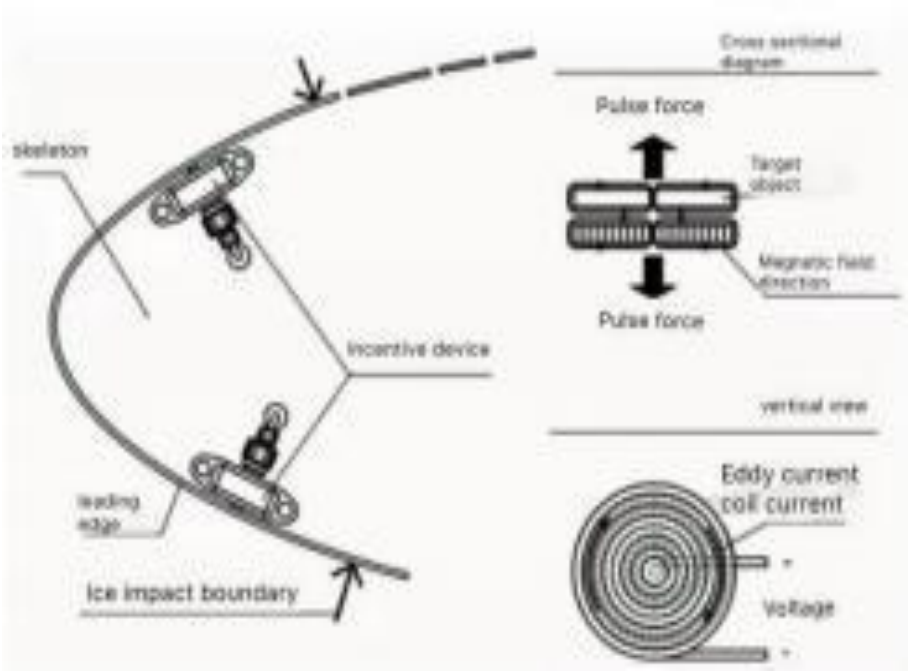



**Fig. 3** Sketch of EIDI system installed in wingspan [10]

In the research of the EIDI structure, there are two different aspects. One is Electric Power Mechanics, and another is Structural Mechanics [11]. The factors that affect the impulse of EIDI are two main research directions, including the acceleration, response characteristic and straining [11]. These factors assist people to do further research on the EIDI, which also brings some methods to do further study. Bernhart and Gien establish the closed statement equation to discover the relationship between the true reaction of skin and distribution in three-dimensional space, this discovery illustrates that the skin varies as time changes, the process of changes distributed along three-dimensional space [11-12].

#### 2.3.2. Application Scenarios and Advantages

The EIDI framework is only composed of four main parts. They are the pulse coil, control system, energy supply capacitor and skin of the aeroplane. These four parts are very significant for the aeroplane when flying at extremely high altitudes, especially the pulse coil. The pulse coil is the core of the EIDI system which installs under the upper wing skin of the airplane. In the first place, the energy supply capacitor will discharge. When the current flows through the pulse coil, a strong electromagnetic field will be produced [13]. Due to this behaviour, the eddy current will be formed on the wing skin by the electromagnetic induction. After that, the electromagnetic force produced by the coil will break the ice layer on the wing. To provide proper pulse force. The control system has to allocate the rational energy, adjust the timing and control the current in the coil. The energy supply capacitor provides the pulse by the order from the control system and stores the electric energy. The final part is airplane skin which is produced by special materials. These special materials will affect the distribution and generation of the electromagnetic force.

### 2.3.3. Discussion of Limitations and Future Development

The calculation of electromagnetic pulse excitation is the most difficult problem that people have to face [10]. But this kind of top-level dicing system also has some merits and demerits. As a kind of pure electric drive system, the EIDI owns the advantages of high reliability, lightweight and so on [14]. However, the drawbacks are also obvious, the structure could cause metal fatigue. In conclusion, although there are some drawbacks to EIDI, it can't prevent strong positive effects on aeroplanes. In future, the EIDI still have large progress in human technology.

## 2.4. Ultrasonic anti-icing system

### 2.4.1. Design and Principle of Operation

Just like Figure 4, the ultrasonic anti-icing system works by using ultrasonic vibrations to prevent ice formation. The system is designed with ultrasonic transducers that are placed on the surface of planes or other structures. When powered, these transducers generate high-frequency vibrations, which can either prevent ice from forming or break it apart before it fully develops. Instead of relying on traditional methods like heating or chemicals, this approach uses physical energy to directly shake water droplets off the surface or break the ice [14].

### 2.4.2. Application Scenarios and Advantages

Ultrasonic anti-icing systems have a wide range of applications, especially in the aviation industry, where ice buildup is a serious issue during flights at high altitudes [15]. The system can also be used in wind turbines, power lines, and offshore oil platforms—basically anywhere that operates in cold environments. Compared to traditional heating-based dicing methods, the ultrasonic system uses less energy and doesn't require as much power to keep surfaces ice-free. Plus, it is lightweight, which is a big advantage over chemical or mechanical systems that can add significant weight to equipment.

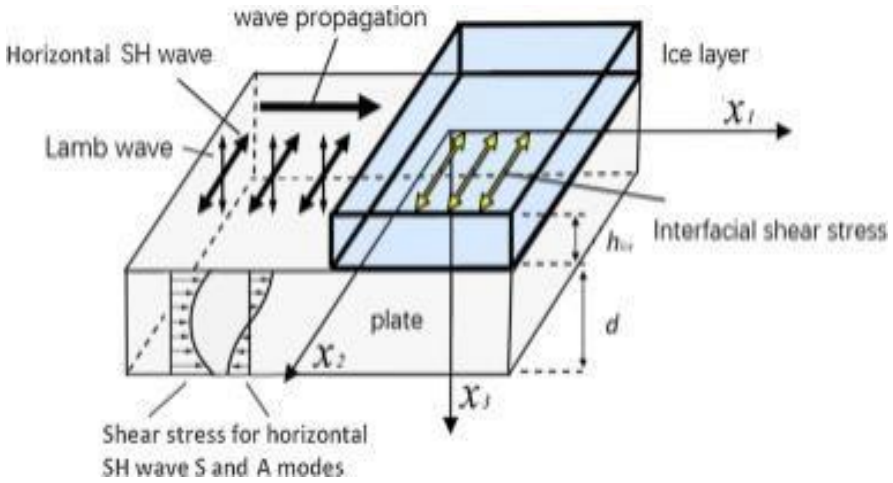



**Fig. 4** How Ultrasound de-icing works [20]

### 2.4.3. Discussion of Limitations and Future Development

While ultrasonic anti-icing systems have clear advantages, they also have some limitations. One challenge is their effectiveness in extreme conditions, where ice can form too quickly for the system to keep up [16]. Additionally, the placement and maintenance of the ultrasonic transducers are crucial; if not done properly, the system's performance can drop. The cost of installing and maintaining these systems, especially over large areas like aircraft wings or power lines, is another concern [17]. There are also questions about how well the system can last in tough weather conditions over time [18].

In the future, improvements could focus on making energy transfer more efficient, so that the system works better in different environments [19]. New materials or surface coatings that complement the ultrasonic vibrations could also improve ice removal. As technology advances, we might see this system used in more industries where ice buildup is a problem, making it a more practical and widely used solution.

## 3. Discussion

Various aircraft de-icing and anti-icing systems are compared, and the advantages, disadvantages and application scenarios of each system are analysed. The electrothermal de-icing system provides precise temperature control but requires a high electrical load, so it is suitable for electric aircraft. Meanwhile, the anti-icing bleed air system is environmentally friendly and reliable and can operate continuously without external heating elements or chemicals. However, it reduces engine performance and increases fuel consumption, so it is suitable for long-distance commercial flights. The electronic pulse anti-icing system is lightweight, fast-response, and highly reliable, but it may cause metal fatigue and requires complex calculations to accurately apply electromagnetic pulses, so it is well suited for fighters and other highly dynamic aircraft. Finally, the ultrasonic anti-icing system stands out for its fast response and suitability for high-performance aircraft, with energy-saving performance and environmentally friendly design. However, it is less effective in extreme temperatures or high humidity and faces challenges in evenly distributing energy over a large area, so it is mainly used in high-altitude flights. Through the comparison, the advantages, disadvantages and best applications of each de-icing system are highlighted, guiding technology selection based on aircraft type, operational needs and environmental factors.

## 4. Conclusion

This paper discusses the principles, benefits, and challenges of four types of aircraft dicing and anti-icing systems: electric heating, hot air, electromagnetic pulse (EMP), and ultrasonic dicing. It also explores how these systems can evolve in the future to meet the growing demands of flight safety.

The electric heating system uses electrical energy converted into heat to remove ice from the surface of the aircraft. One of its main advantages is that it provides precise temperature control and can use environmentally friendly energy. However, it can drain the aircraft's energy, especially during long flights, as it competes with other systems for power. In the future, this system could be improved by incorporating renewable energy sources like solar or wind power, or even by developing equipment that generates energy internally in emergencies.

The Anti-icing Bleed Air System works by using hot air from the engine to prevent ice formation. This method is highly reliable and operates continuously, but it can affect the engine's performance and increase fuel consumption. Future improvements may focus on optimizing the way hot air is extracted from the engine, better-controlling temperatures, or even combining it with other systems like electric or chemical dicing.

The EMP system uses electromagnetic pulses to create a strong force inside the wing, which removes the ice. It's reliable and lightweight, but the repeated stress could cause metal fatigue. Future advancements might focus on making the pulse more efficient and designing the structure in a way that minimizes wear and tear.

Ultrasonic dicing systems use high-frequency vibrations to stop ice from forming or break up ice that's already there. These systems are especially useful in high-altitude flights but can struggle in extreme cold or high humidity. In the future, scientists could explore new materials or surface coatings to improve how well ultrasonic dicing works under challenging conditions.

As aerospace technology moves forward, dicing and anti-icing systems will need to become more efficient, reliable, and environmentally friendly. Future research will likely focus on reducing energy use, enhancing durability, and incorporating smart technology like artificial intelligence to make real-time adjustments. These advancements will lead to safer and more sustainable dicing and anti-icing systems in the future.

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All the authors contributed equally, and their names were listed in alphabetical order.

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