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Aeronautical impact on the process of cleaning runways from contamination

Abstract. The study is aimed at analysing aeronautical methods of runway cleaning from contamination to improve the efficiency of maintenance and safety of aviation operations. The study used aerodynamic analyses, data on high-speed airflow technologies, chemicals, and automatic control systems and sensors to comprehensively assess the effectiveness of runway de-icing. The results of the study showed that the use of aeronautical methods of runway cleaning significantly increases the efficiency of removing contaminants such as snow, ice, and dust particles. It was found that directed high-speed airflows effectively reduce cleaning time compared to traditional mechanical methods, reducing the risk of damage to the runway surface. In addition, the integration of these methods with automatic control systems and sensors can improve cleaning safety and reduce the negative impact on the environment. The combined use of aeronautical technologies with chemicals was also found to be effective, making these approaches promising for use at airports with high flight intensity. The study confirmed the feasibility of introducing such technologies to ensure the safety and economic efficiency of aviation operations. The analysis also showed that the use of aeronautical methods reduces the need for frequent re-cleaning of runways, which helps to reduce operating costs. In addition, the use of these technologies helps to reduce the amount of deposits on the runway surface, which has a positive impact on the durability of the pavement. The research introduces a new approach to runway cleaning, showing how aeronautical methods can improve the efficiency, safety, and cost-effectiveness of aviation operations, opening up prospects for further innovation in this area

Keywords: high-speed air flows; automatic control; chemicals; coating damage; environmental impact

Introduction

The impact of aerodynamic processes on runway de-icing is extremely important for modern aviation infrastructure, as it directly affects flight safety and economic efficiency. Contaminants such as snow, ice, dust and various chemicals can significantly degrade runway surfaces, increasing the risk of accidents and delays in aviation operations. Traditional cleaning methods, such as mechanical brushes or chemicals, are often insufficient to effectively address this problem, creating a need for new technological solutions. Aeronautical methods, which use high-speed airflows and integrated automatic control systems, offer new opportunities to improve runway cleaning. These technologies not only remove contaminants more efficiently, but also reduce the time required for cleaning, which helps to reduce operating costs. Further exploration of aeronautical techniques is relevant to improve overall flight safety and optimize costs at high-traffic airports. The introduction of such technologies can significantly improve operational efficiency and environmental safety in airport operations.

The problem of effective runway de-icing is a relevant issue for aviation infrastructure due to its impact on flight safety and operating costs. In this context, several authors have already studied various aspects of this topic. The study by B. Kim *et al.* (2023) showed that the effectiveness of high-speed airflows in clearing snow and ice is not limited to clearing carts, but can also be applied

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to runways. Z. Li *et al*. (2024) investigated how the integration of aeronautical technologies with automatic control systems and sensors, as well as with laser cleaning, can significantly improve the accuracy and safety of the cleaning process by ensuring effective detection and removal of contaminants. In the work of Q. Zhang *et al*. (2022), the authors noted the positive impact of combining aeronautical methods with chemicals to reduce contamination and increase the durability of runway surfaces.

Y. Lai *et al*. (2022) investigated the impact of aeronautical technologies on reducing negative environmental impacts and environmental risks. F. Maltinti *et al*. (2024) showed that the use of high-speed airflows reduces the number of repeated clearing operations, which, together with the introduction of fast departure taxiways, optimizes runway capacity and sustainability. K. Ottogalli *et al*. (2021) found that automating the clearing process using aeronautical techniques can significantly reduce human error and improve overall efficiency. Y. Xiang *et al*. (2021) analysed the economic feasibility of introducing new runway cleaning technologies, confirming their high cost-effectiveness. F. Farivar *et al*. (2021) investigated the durability of runway surfacing using aeronautical methods and found their positive impact on reducing surface erosion.

G. Zhao *et al*. (2024) compared traditional mechanical cleaning methods with new aerial technologies, pointing out the advantages of the latter in terms of speed and efficiency. R. Shrestha *et al*. (2021) showed that unmanned aerial vehicles can effectively detect contamination on runways, reducing the risk of accidents and delays. Despite the significant advances in this research, there are gaps that need to be further explored. In particular, the long-term effects of new technologies on runways, their cost-effectiveness in different climates, and their interaction with other cleaning methods need to be investigated.

The aim of the study was to investigate the effectiveness of aeronautical methods of runway cleaning from contaminants in order to improve flight safety and reduce operating costs. Research objectives:

1. Evaluating the effectiveness of aeronautical methods in the process of clearing runways of contaminants such as snow, ice, and dust particles.
2. Analysing the possibility of reducing the cleaning time and reducing the risk of damage to the lane coating when using high-speed air flows compared to traditional mechanical methods.
3. Exploring the integration of aeronautical methods with automatic control systems and sensors to improve safety, reduce negative environmental impact and lower operating costs.

Materials and Methods

The study used several key methods to comprehensively assess the effectiveness of runway de-icing. The aerodynamic analyses included the creation of computer models to simulate the aerodynamic forces encountered during aircraft take-off and landing, which allowed us to investigate how different types of aircraft and their speeds affect the distribution of light pollutants such as dust and fine debris on the runway. In addition, aerodynamic forces were measured using anemometers and airspeed sensors to collect data on the actual airflows generated by the aircraft and their impact on runway cleaning.

High-speed airflow technologies were analysed by evaluating the efficiency and performance of the turbine and fan systems used to generate these airflows. Different configurations and capacities of these systems were tested to optimise their ability to remove contaminants. The cleaning results achieved with high-speed airflows were compared to those achieved with traditional mechanical methods such as scrapers and brushes. The runways were cleaned using mechanical and chemical methods. Runway cleaning systems, such as the Schmidtsdrift Sweeper from Schmidt (Germany), have been investigated for their effective removal of contaminants using powerful fans and airflow controllers to ensure high performance without damaging the pavement (South Cambs District..., 2024). For mechanical cleaning, the Buffalo Turbine (n.d.) from Buffalo Turbine (USA) with rotary brushes and powerful air flows was used, as well as the Vammas T600 (n.d.) from Fortbrand Services (Finland), which combines mechanical brushes with air systems for effective contaminant removal.

The selection and testing of chemicals for melting ice and snow was also part of the study. Various chemicals were evaluated at different temperature conditions, including salts and antifreeze, to determine their effect on lane clearance. Methods of combining chemicals with high-speed air flows to achieve even distribution and faster evaporation of the chemicals were analysed. The chemicals used included Calcium Magnesium Acetate (CMA) from Cryotech Deicing Technology (USA) for melting ice and snow (Yang *et al*., 2022), Potassium Acetate from Nachurs Alpine Solutions (USA) to melt ice at low temperatures (Sajid *et al*., 2021), and Sand & Salt Mixture from Cargill (USA) to improve traction in winter conditions (Pérez-Fortes *et al*., 2022).

The effectiveness of the integration of automatic runway management systems and sensors for monitoring conditions and pollution levels was assessed by analysing the quality of their interaction, including the use of sensor systems to collect real-time data on weather conditions, pollution levels and runway conditions. It was analysed how automatic control systems, by processing sensor data using real-time methods and adaptive control algorithms, could adapt the cleaning process to changing conditions, ensuring a timely and effective response to pollution. Algorithms were developed to optimize cleaning and reduce lane maintenance costs using machine learning and optimization models. These methods provided a comprehensive assessment of the effectiveness of modern runway cleaning technologies, allowing us to find optimal solutions to improve safety and reduce airport maintenance costs.

One of the main elements of the study was to examine the impact of different aircraft models on runway conditions, in particular their impact on surface cleaning and contamination. The impact of both large aircraft, such as the Boeing 747 (USA), and medium-haul models, such as the Airbus A320 (France/Germany), were analysed. Particular attention was paid to the latest technological solutions introduced by the Boeing 787 Dreamliner (USA), as well as light aircraft such as the Cessna 172 (USA). The aim of this analysis was to assess the specific characteristics of each aircraft model and their impact on runway pollution, including rubber residues, pavement wear and cleaning requirements. This allowed us to identify the most effective strategies for maintaining runway pavement quality by adapting cleaning methods according to the type of aircraft and its impact on the runway surface, which contributed to the efficiency and safety of airport operations.

Results

Different aircraft models have different weight characteristics and landing gear types that affect the load distribution on runways. In particular, heavy aircraft with a large landing weight can cause significant deformation and damage to the runway pavement, which reduces its durability and safety. In addition, different types of landing gear may have different cushioning mechanisms, which also affects the degree of wear on the surface during landing and take-off.

The Boeing 747, also known as the "Jumbo Jet", is one of the largest commercial aircraft in the world. The Boeing 747 has a significant weight, which, depending on the model, can range from approximately 180 to 220 tonnes when empty (Fig. 1). This places a high load on the runway during landing. Heavy aircraft, such as the Boeing 747, can leave deep rubber marks that are difficult to remove. The heavy weight of the aircraft during landing and take-off can cause the top layer of the runway surface to break down, resulting in more frequent replacement or repair. During braking, significant rubber marks are formed on the runway surface, which contributes to wear and tear on the pavement and requires frequent maintenance and repair.

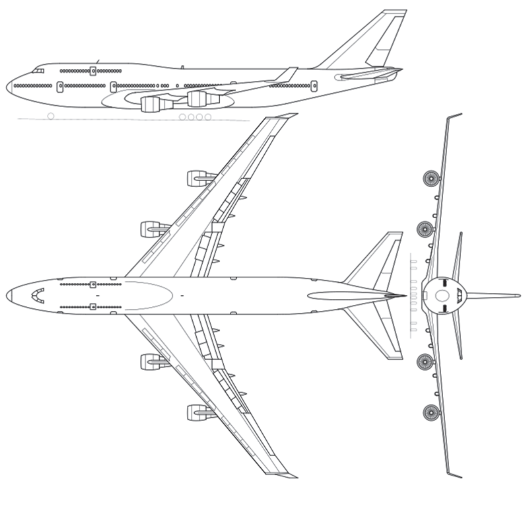

Figure 1. Diagram of the Boeing 747 aircraft
Source: Boeing 747-8 (n.d.)

The Boeing 747 landing gear consists of four main landing gear located under the wings and body of the aircraft, and one front landing gear. The main landing gear is fitted with multiple wheels (typically 4 wheels per landing gear) to distribute the weight of the aircraft evenly on the runway. This weight distribution is critical to prevent excessive stress on certain areas of the runway. The runways on which the Boeing 747 landing gear is designed must be long (typically 3 to 4 km) and constructed of high-quality materials, such as reinforced concrete or special asphalt pavements, which are able to withstand heavy loads and are resistant to wear and tear and large amounts of rubber footprints.

The Airbus A320 is a popular medium-haul aircraft (Fig. 2). It weighs around 70 to 80 tonnes when empty. Compared to larger aircraft, the load on the runway during its landing and take-off is significantly lower, so it causes less wear and tear and leaves less rubber on the pavement. Although the high frequency of flights can cause dust and fine particles to accumulate, less intensive cleaning is required than for larger aircraft.

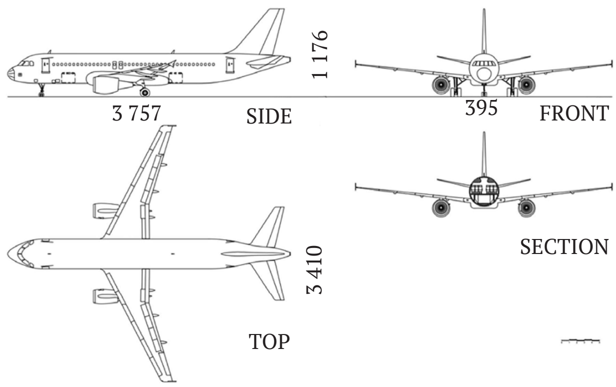

Figure 2. Schematic of the Airbus A320 aircraft
Source: Airbus A320 (n.d.)

The Airbus A320 landing gear comprises two main components: the front (dural) and main (two-wheel) landing gear. The main landing gear consists of two pairs of wheels, each of which is mounted on a suspension to provide reliable support during landing and take-off. The wheels of the main landing gear are designed for use on runways from 2,500 to 3,000 m long and can withstand various types of surfaces, including concrete and asphalt strips. An important feature is also the shock absorption, which softens impacts and reduces wear and tear on the runway surface, ensuring safety and comfort during landing and take-off.

The Boeing 787 Dreamliner is the latest aircraft equipped with lightweight materials and modern technologies that reduce runway impact (Fig. 3). Its empty weight is around 130 to 150 tonnes. The landing gear of this aircraft is designed for runways with a minimum length of 2,400 m and can be used on various types of surfaces, including asphalt and concrete. Advanced braking systems and specialized tyres ensure less wear and tear on the pavement and less rubber remaining on the runway. This, in turn, reduces the level of contamination of the lane and reduces the need for frequent cleaning.

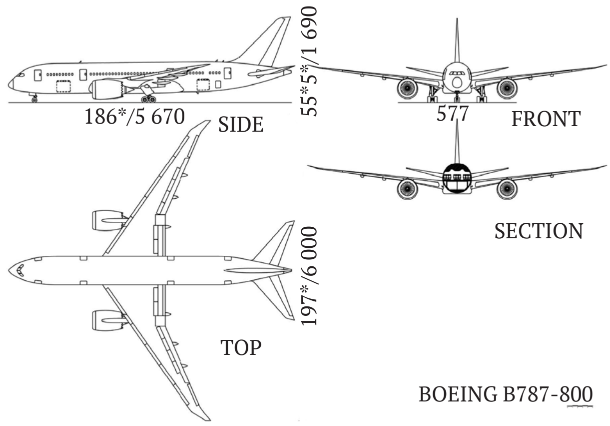

Figure 3. Schematic of the Boeing 787 Dreamliner aircraft
Source: Boeing 787 Dreamliner (n.d.)

The Cessna 172 is a lightweight aircraft often used for training and private flights. Its empty weight is around 1,200 to 1,300 kg (Fig. 4). This aircraft has a lower impact on runways due to its lightness and lower load, which does not cause significant wear and tear or runway contamination, but frequent use can contribute to the accumulation of light contaminants (dust).

The Cessna 172 landing gear is equipped with standard pneumatic wheels with shock absorption systems designed for medium runways (approximately 800 to 1,500 m). It is suitable for various types of surfaces, including asphalt and concrete runways, as well as non-asphalt surfaces such as dirt or grass runways. The pneumatic wheels provide good cushioning and reduce surface impact, but regular use on unpaved or uneven surfaces can lead to dust and fine particles accumulating, requiring periodic runway cleaning.

Different aircraft models have a significant impact on runway conditions, ranging from heavy wear and tear from heavy aircraft to less pollution from light aircraft. This study shows that each aircraft type requires a different approach to runway cleaning and maintenance management. Knowing these impacts allows for the development of effective strategies to keep runways in excellent condition and ensure flight safety. Table 1 shows the impact of different aircraft on runways depending on their weight and landing gear type.

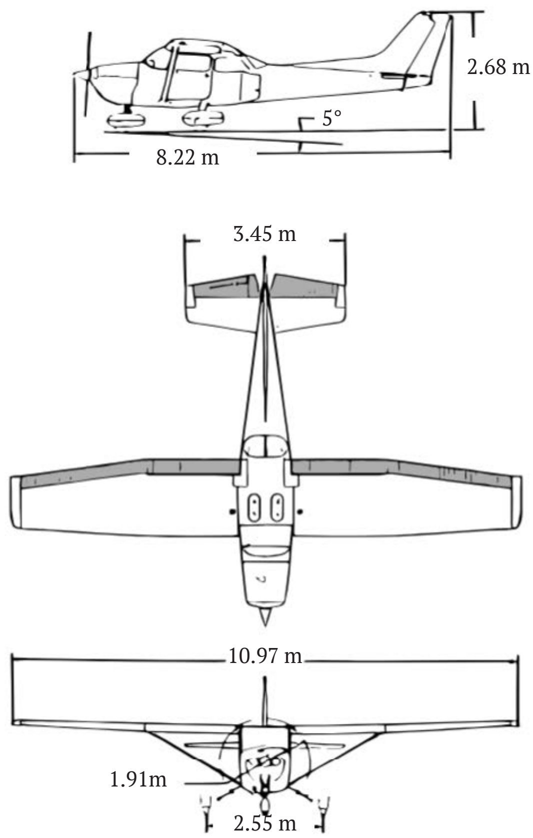

Figure 4. Schematic of the Cessna 172 aircraft
Source: Cessna 172 (n.d.)

Table 1. Impact of different aircraft on runways

Aircraft	Maximum take-off weight (kg)	Chassis type	Strip length (min.)	Type of coating	Impact on the coating
Boeing 747	400,000	Pneumatic wheels	3,000	Asphalt, concrete	High pressure, significant coating wear
Airbus A320	77,000	Pneumatic wheels	2,500	Asphalt, concrete	Medium pressure, moderate coating wear
Boeing 787 Dreamliner	250,000	Pneumatic wheels	2,500	Asphalt, concrete	Moderate pressure, medium coating wear
Cessna 172	1,100	Pneumatic wheels	800	Asphalt, concrete, soil	Low pressure, low coating wear

Source: compiled by the author based on data from E. Toraldo *et al*. (2023)

The aerodynamic properties of the airflow generated by an aircraft during its movement have a significant impact on the condition of runways (Frant *et al.*, 2024). During acceleration and take-off, an aircraft creates a powerful air jet that can interact with the runway surface. This natural airflow can ultimately help remove light contaminants, such as dust or small particles of debris, that are present on the surface.

When an aircraft is travelling on the runway, the airflow generated by its speed is quite strong. This can lead to the separation and lifting of fine particles, which are then blown to the side or lifted into the air. In this way, light contaminants can be partially removed due to the natural aerodynamic effect.

However, this cleaning method has significant limitations. First and foremost, the impact of the airflow is not sufficient to remove more serious contaminants such as ice or snow. These types of contaminants, especially in large quantities, are heavy and cannot be effectively removed by the simple action of airflow. Ice, for example, has a high density and strength, which makes it resistant to wind effects. Snow, in turn, can stick to the surface of the runway and turn into a crust, making it even more difficult to remove.

Therefore, additional measures are required to ensure flight safety and maintain optimal runway conditions. Depending on the type and extent of contamination, different cleaning methods can be used, such as mechanical, chemical or combined approaches. For example, to remove ice and snow, specialized machines with heated or mechanical means are often used to effectively cope with such conditions. Two models are worth highlighting among these machines: Buffalo Turbine and Vammas T600.

The Buffalo Turbine, developed in the USA, is one of the most effective snow and ice removal machines thanks to its innovative approach (Fig. 5). The main advantage of this machine is the use of powerful rotating brushes, which, together with powerful airflows, allow for fast and efficient removal of fine particles and dirt from runways. The brushes rotate at high speeds, which helps to distribute the airflow in such a way as to blow snow and ice off the runway surface, reducing the need for subsequent mechanical treatment. This is particularly important in high snowfall conditions, where traditional cleaning methods may be less effective.

Figure 5. Buffalo Turbine
Source: Buffalo Turbine (n.d.)

In contrast to the Buffalo Turbine, the Vammas T600, manufactured in Finland, provides a more comprehensive approach to runway clearing (Fig. 6). This machine combines mechanical and airborne methods, allowing it to effectively deal with both light snow and heavy frozen ice formations. It is equipped with rotary brushes that mechanically remove snow and ice, as well as powerful fans that provide additional cleaning efficiency by using airflow. This combined approach makes the Vammas T600 a versatile cleaning tool that can adapt to different weather conditions and levels of dirt.

Both of these machines demonstrate how innovative technology can be used to improve the efficiency of the runway cleaning process. The Buffalo Turbine with its airflow orientation and the Vammas T600 with its combined mechanical and airborne approach are currently the best-specialized tools for ensuring good runway surface quality at airports. This underlines the importance of continuous investment in the latest technology to maintain high standards of safety and efficiency in aviation infrastructure.

Figure 6. Vammas T600
Source: Vammas T600 (n.d.)

Chemical cleaning methods involve the use of specialized reagents that help to effectively combat ice formation and ensure that the surface of the strips is properly rough. One of the most commonly used reagents is CMA. CMA is effective in melting ice and snow due to its chemical composition, which contains calcium and magnesium and reacts with water. This reaction lowers the freezing point of water, which allows CMA to melt ice and snow at low temperatures. CMA has an advantage over traditional salt and calcium because it is less aggressive to surfaces and the environment. It reduces corrosion and minimizes the environmental impact, making it a popular choice for airport runway deicing.

Potassium Acetate is another effective deicing agent used to melt ice at low temperatures. Potassium Acetate has the ability to remain active and effective at very low temperatures due to the presence of potassium, making it particularly useful in harsh winters. It dissolves ice quickly, allowing for faster and safer runway clearance.

To improve runway surface roughness in winter conditions, a “Sand & Salt Mixture” is used, where the main active chemical element is sodium, which provides increased traction and prevents ice formation. This mixture provides improved traction between aircraft wheels and the runway surface, reducing the risk of skidding and ensuring a more stable and safe landing. The sand and salt mixture not only improves traction, but also helps to melt ice, providing additional safety for aviation operations.

The use of chemicals is an essential part of the winter runway management system. Specialized reagents such as CMA and Potassium Acetate, together with a mixture of sand and salt, provide effective ice and snow removal, and improve runway roughness and safety. Their use contributes to the safe operation of airports in winter and helps maintain high aviation safety standards.

Therefore, while the aerodynamic properties of airflow can be useful for removing light contaminants from runway surfaces, their impact is limited and insufficient to address all contamination issues. It is important to integrate additional technological measures to ensure a high level of runway cleanliness and safety, especially in conditions of significant contamination, which is critical to the safety of aviation operations.

In runway cleaning technologies, high-speed airflows play a critical role in ensuring that contaminants are removed efficiently without damaging the runway surface (Vidal *et al.*, 2023). The use of powerful turbines or fans to create concentrated jets of air can remove fine dust particles, sand, and other light contaminants that can accumulate on the surface.

This cleaning method is particularly useful when traditional mechanical methods may not be sufficient or may cause damage to the pavement. Directional airflows provide an effective way to remove contaminants without physical contact, helping to maintain runway integrity.

Runway cleaning systems use large fans on specialized vehicles to ensure high performance (Alabi *et al.*, 2021). One example of such a vehicle is the Schmidtsdrift Sweeper, which is equipped with powerful fan systems and has various nozzles and controls to precisely control the direction and speed of the airflow (Fig. 7).

This vehicle allows for the effective removal of contaminants without chemical or mechanical methods that can damage the pavement. An important advantage is its ability to reduce the risk of damage to runway pavement, as the airflow does not come into direct contact with the surface. This helps to avoid wear and tear on materials, which is critical for the long-term operation of airports. Therefore, airflow-based technologies like the Schmidtsdrift Sweeper are the ideal choice for regular maintenance, keeping the surface clean and safe without compromising its integrity.

At airports, maintaining runways in excellent condition is critical to the safety of aviation operations (Cunha *et al.*, 2021). One effective approach to cleaning such surfaces is to integrate an aeronautical approach with chemicals. This method combines the advantages of both physical and chemical processes to achieve optimal results in removing ice and snow from runway surfaces (Table 2).

Figure 7. Schmidtsdrift Sweeper

Source: South Cambs District Council: Electric operation reduces driver fatigue! (2024)

Table 2. Evaluation of the effectiveness of aeronautical methods in the process of runway cleaning from contamination

Type of pollution	Cleaning method	Air flow (m^3/s)	Deleted (d/m^2)
Snow	Aeronautical method	60	8.0
Ice		60	7.5
Dust particles		60	9.0

Source: compiled by the author based on data from M.V. Corraza and P. Di Mascio (2024)

Chemicals used to melt ice or snow play a key role in this process. Some of the most common runway deicing reagents include salts, such as sodium chloride (salt) or calcium chloride, as well as specialized mixtures, such as potassium acetate or urotropin-based mixtures, which are designed to melt frozen layers more quickly and effectively (Muldma *et al.*, n.d.). Once applied to the surface, the reagents begin to interact with the ice cover, lowering the freezing point of the water and accelerating the melting process.

However, the efficiency of using chemicals is significantly increased by using an aerial approach. This approach involves the use of airflows to evenly distribute chemicals over the entire runway surface. High-speed air flows created by powerful fans or turbines ensure an even distribution of chemicals, which contributes to more efficient melting of ice and snow and prevents the formation of undesirable irregularities or irregularities on the surface.

An additional advantage of using airflow is that it accelerates the evaporation of chemical residue after treatment. Once the chemical has melted the ice or snow, the residue must be removed quickly to ensure that it does not interfere with the continued operation of the runway. Promoting the evaporation of the residue with air currents helps to prepare the surface for subsequent aviation operations more quickly and reduces the risk of possible negative effects from the chemicals used, such as corrosion or environmental pollution. Thus, the combination of chemicals and an aeronautical approach can achieve significant benefits in the runway deicing process. This approach not only ensures effective removal of ice and snow, but also improves safety on runways, keeping them in excellent condition for the smooth operation of airports. The integration of these technologies demonstrates an innovative approach to managing winter conditions at airfields and opens up new opportunities to improve the efficiency and safety of aviation operations.

Runway deicing is an important aspect of ensuring the safety of aviation operations, especially in winter weather conditions (Table 3). Technologies that use powerful air currents to remove ice and snow are becoming increasingly popular due to their efficiency and speed. However, despite the many advantages of such techniques, their intensive use can lead to serious problems, such as runway surface erosion.

Table 3. Analysis of the possibility of reducing the cleaning time and reducing the risk of damage to the lane surface

Cleaning method	Cleaning time (min)	Risk of coating damage (%)	Time savings (%)
High-speed flows	25	5	40
Traditional mechanical methods	45	10	-

Source: ompiled by the author based on data from Y. Wu *et al*. (2022)

Surface erosion occurs when the powerful air jets used for cleaning cause particles of runway pavement material to fly into the atmosphere (Jamieson and White, 2021). This process can gradually reduce the thickness and structure of the pavement, which in turn can affect its performance. Increased roughness or reduced surface strength can reduce the grip coefficient of aircraft tyres on the pavement, which can compromise flight safety.

One of the main risks of erosion is that the runway surface can become more vulnerable to further damage, such as cracks or wear, which can occur over time. This damage can affect the quality of the surface and its ability to withstand heavy loads, which is critical to the safety of aircraft during take-off and landing. Additionally, erosion can result in frequent repairs or replacement of the pavement, which can increase the cost of airfield maintenance.

To avoid such negative consequences, it is crucial to be careful when using air jet cleaning methods. The strength and angle of the air jet must be precisely controlled, which should be within 10-30 degrees of the surface to minimize the risk of damage to the coating. For example, this may involve the use of specialized equipment such as mobile air cleaners, which are equipped with adjustable fans and nozzles to precisely control the airflow intensity and angle of the jet, allowing for optimal adjustment of the impact on the runway surface and reducing the risk of damage.

Additionally, it is important to implement regular monitoring of the runway pavement to detect any signs of erosion or other damage. This will allow prompt action to be taken to repair and restore the surface, preventing further deterioration.

Although the use of high-powered airflows is an effective method of runway cleaning, the potential risks of surface erosion must be taken into account. A balanced approach to the application of these technologies, with a focus on controlling the intensity of airflows and regular monitoring of the pavement condition, will help maintain runway quality and ensure the safety of aviation operations (MoghimiEsfandabadi *et al.*, 2023). Modern automation technologies and sensor systems open up new opportunities to improve cleaning efficiency and adapt to changing weather conditions (Table 4).

Table 4. Study of the integration of aeronautical methods with automatic control systems and sensors

System	Impact on safety (points)	Environmental impact (points)	Cost reduction (%)	Control accuracy (%)	Notes
Automatic systems	8	7	15	20	Improved control accuracy
Sensors	9	8	12	25	Reducing the negative impact on the environment

Source: compiled by the author based on data from A.O. Aderibigbe *et al*. (2023)

The integration of aeronautical methods with modern sensors and automatic control systems allows for the creation of dynamic and adaptive runway cleaning systems. The sensors on the cleaning equipment are able to monitor the runway surface in real time, including the level of contamination and the presence of ice or snow. This data allows automatic systems to adjust equipment parameters, such as air jet intensity or machine speed, to ensure optimal cleaning conditions. One of the advantages of such automated systems is their ability to respond quickly to changes in weather conditions. For example, if the weather deteriorates sharply or snowfall increases, sensors can detect these changes and automatically adjust the cleaning system. This ensures that runway quality is maintained and prevents the accumulation of unwanted contaminants that can be dangerous for aircraft.

Sensor systems also help to improve resource efficiency. For example, systems that monitor the consumption of chemicals or water for cleaning can automatically adjust the flow of chemicals depending on the degree of surface contamination. This reduces material costs and environmental impact, while ensuring effective cleaning.

In addition, automation reduces the human factor that can affect the quality of work. Automated systems perform tasks with high accuracy, which reduces the risk of errors and increases the overall efficiency of the cleaning process. Importantly, such systems can also monitor the condition of runways and generate reports on the work performed, which helps with maintenance management and planning further activities.

The integration of aeronautical methods with sensors and automatic control systems represents a significant step forward in ensuring the safety and efficiency of runway cleaning. These technologies enable fast and accurate response to changing conditions, reduce costs and improve the quality of cleaning, which is critical to maintaining the safety of aviation operations.

Thus, aeronautical impact is a critical component in a comprehensive approach to runway cleaning, which contributes to improved flight safety and reduced operating costs.

Discussion

The analysis of the results showed that the aeronautical impact on runway pollution control is significant and multifaceted. The study of the impact of the natural airflow created by different types of aircraft showed that this flow helps to remove light contaminants such as dust and small debris. However, its effectiveness was not sufficient to deal with more serious contaminants such as snow or ice. This highlighted the need for additional technological solutions to ensure complete runway cleanliness, especially in severe weather conditions. This was also investigated by Y. Guo *et al*. (2022), where the results confirmed that natural wind can help clean runways from light contaminants such as dust or snow by blowing them off the surface. However, its effectiveness depends on wind speed and direction. At low speeds or in adverse weather conditions, natural wind may not be sufficient to keep runways clean.

The effectiveness of technologies using high-speed air flows was significantly higher compared to traditional mechanical cleaning methods. The study results confirmed that such technologies can significantly reduce the cleaning time and reduce the risk of damage to the lane pavement. In particular, the use of powerful turbines and fans to create directional airflows has shown to be advantageous in removing contaminants without damaging the lane surface, making these methods more efficient and safer. A. Esposito *et al*. (2022) concluded that high-speed airflows effectively blow away light contaminants such as dust and snow faster than mechanical methods. They are also less aggressive to the lane surface, reducing the risk of damage and the need for frequent repairs. In the study by A. Rabajczyk *et al*. (2021), the authors found that high-speed airflows reduce cleaning time and reduce the risk of damage to the lane coating because they do not physically contact the surface. This allows the lane to be ready for use faster and reduces the need for repairs. These results support the study cited above, as they demonstrate that high-speed airflows are indeed effective in cleaning runways, reducing the time required for the process and reducing the risk of pavement damage. The data shows that the use of airflow not only speeds up cleaning, but also reduces the need for mechanical methods that can damage the surface. This confirms the benefits of implementing high-speed air systems as the optimal solution for keeping lanes clean in a safe and efficient manner.

The study of the combined use of aerial methods with chemical reagents also showed positive results. The air flows used in conjunction with the reagents contributed to an even distribution and faster evaporation of chemicals, which significantly increased the efficiency of ice and snow removal. This reduced the need for repeated treatments and increased the overall efficiency of the cleaning process. It is worth noting the work of O. Bafakeeh *et al*. (2021), who also found that combining aeronautical methods with chemicals increases the efficiency of runway cleaning. Aeronautical methods remove light contaminants, while chemicals, such as saline solutions, soften ice and snow, making them easier to remove. In turn, H. Sparacino *et al*. (2022) concluded that the use of aerial methods together with chemicals significantly improves ice and snow removal. The chemicals soften the ice and the airflow effectively removes it, ensuring that runways are cleared quickly and efficiently. These findings are consistent with the current study, as they confirm that the combined use of aeronautical techniques and chemicals significantly improves runway deicing performance. They demonstrate how the integration of these technologies can provide faster and better ice and snow removal, which is consistent with the arguments made earlier about the benefits of an integrated approach to cleaning.

Assessment of the potential risk of runway surface erosion due to intensive use of air traffic has highlighted the need for careful monitoring and management of such technologies. Although aeronautical methods have proven to be effective, there is a risk of potential damage to the runway surface. This highlights the importance of developing guidelines for the safe use of new technologies to prevent negative impacts. E. Aydoğan & S. Demirel (2022) also conducted a study that confirmed that chemicals and mechanical cleaning methods can cause runway surface erosion, leading to wear and tear and pavement defects. This can degrade the runway and affect flight safety. Therefore, it is important to choose cleaning methods that minimize the risk of erosion and ensure the durability of the pavement. Furthermore, M.T. Miah *et al*. (2022) found that new technologies, such as automated systems and innovative materials, can reduce the risk of erosion and increase the efficiency of runway cleaning. They suggest less aggressive chemicals and new methods that reduce pavement damage and improve runway maintenance. Comparing the data obtained during the research, it can be noted that new runway cleaning technologies significantly reduce the risk of pavement erosion and increase the overall efficiency of the process. It has been found that the combined use of modern methods and innovative materials can achieve better results compared to traditional approaches. This confirms that the introduction of new technologies not only improves the speed and quality of cleaning, but also helps to maintain the durability and safety of runways.

The integration of aeronautical methods with automatic control systems and sensors has significantly improved the accuracy and efficiency of cleaning. Automatic control systems have enabled more effective response to changes in weather conditions and pollution levels, which has reduced costs and increased the efficiency of the cleaning process. This has confirmed the importance of automation in modern airports to optimise resource use and ensure safety. C. Lv *et al*. (2022) concluded that the integration of aeronautical methods with automatic control systems increases the efficiency of runway cleaning. Automation allows precise control of the power and direction of air flows, optimising the cleaning process according to weather conditions and type of contamination. G. Zhu *et al*. (2022) found that automatic control systems, particularly sensor systems, can significantly improve the accuracy and efficiency of cleaning. Although the current study does not mention laser cleaning, sensor systems can be integrated with laser cleaning technologies to monitor and determine the degree of contamination and to automate the cleaning process. This ensures a quick response to changing conditions and more efficient removal of contaminants from runways, which increases the overall efficiency of airport infrastructure. When analysing the results of the study, it is clear that the integration of aeronautical methods with automatic control systems provides significant benefits in runway cleaning. Automation of processes not only increases the accuracy and speed of cleaning, but also optimises the use of resources and reduces the risk of errors. This confirms the effectiveness of the combined approach, which achieves better results than traditional methods, providing faster and better runway cleaning.

Thus, the study results confirmed that aeronautical methods are a promising approach to runway cleaning. They provide high efficiency, reduce the risk of damage and can be integrated with modern management technologies to improve overall performance. However, to achieve optimal results, further research and development of these methods is needed to reduce potential risks and maximise their benefits.

Conclusions

The study confirmed the effectiveness of new technological solutions in keeping runways clean. It was found that the natural airflow created during take-off and landing is useful for removing light contaminants such as dust and small debris, but is not sufficient to deal with more serious problems such as snow and ice. This points to the need to integrate additional technologies to fully clean runways.

The efficiency of high-speed airflows generated by turbines or fans has been proven to be significantly higher than traditional mechanical methods. These technologies not only reduce the time required for cleaning, but also minimize the risk of damage to the lane coating, which is important for maintaining its longevity.

The combined use of aerial techniques with chemicals to melt ice and snow has been shown to increase overall cleaning efficiency. Airflows help to distribute the chemicals evenly and evaporate them more quickly, reducing the need for repeated treatments.

An assessment of the potential risk of runway surface erosion showed that care must be taken when applying high-powered airflows to avoid adverse effects on the runway surface. The integration of aeronautical methods with automatic control systems and sensors increases the accuracy and efficiency of cleaning, ensuring adaptation to changing weather conditions and reducing costs.

In general, the study results confirm that aeronautical methods are promising for improving the runway cleaning process, providing new opportunities to improve the safety and economic efficiency of aviation operations.

In order to fully understand the aeronautical impact on runway cleaning, the long-term effects of intensive use of high-speed air traffic on runway pavement wear and durability need to be further investigated. The limitation of this study is that it does not take into account the effect of different runway pavement types on the effectiveness of aeronautical cleaning methods.

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Conflict of interest

None.

References

[1] Aderibigbe, A.O., Ohenhen, P.E., Nwaobia, N.K., Gidiagba, J.O., & Ani, E.C. (2023). Advanced sensing techniques in electro-mechanical systems: Surveying the rise of smart sensors and their implications for system robustness. *Engineering Science & Technology Journal*, 4(6), 323-340. doi: 10.51594/estj.v4i6.628.
[2] Airbus A320. (n.d.). Retrieved from http://surl.li/tcbaxk.
[3] Alabi, B.N., Saeed, T.U., Amekudzi-Kennedy, A., Keller, J., & Labi, S. (2021). Evaluation criteria to support cleaner construction and repair of airport runways: A review of the state of practice and recommendations for future practice. *Journal of Cleaner Production*, 312, article number 127776. doi: 10.1016/j.jclepro.2021.127776.
[4] Aydoğan, E., & Demirel, S. (2022). The omnidirectional runway with infinite heading as a futuristic runway concept for future free route airspace operations. *Aircraft Engineering and Aerospace Technology*, 94(7), 1180-1187. doi: 10.1108/AEAT-09-2021-0283.
[5] Bafakeeh, O.T., Shewakh, W.M., Abu-Oqail, A., Abd-Elaziem, W., Abdel Ghafaar, M., & Abu-Okail, M. (2021). Synthesis and characterization of hybrid fiber-reinforced polymer by adding ceramic nanoparticles for aeronautical structural applications. *Polymers*, 13(23), article number 4116. doi: 10.3390/polym13234116.
[6] Boeing 747-8. (n.d.). Retrieved from https://www.boeing.com/commercial/747-8.
[7] Boeing 787 Dreamliner. (n.d.). Retrieved from https://www.boeing.com/commercial/787.
[8] Buffalo Turbine. (n.d.). Retrieved from https://buffaloturbine.com/.
[9] Cessna 172. (n.d.). Retrieved from https://www.aopa.org/go-fly/aircraft-and-ownership/aircraft-guide/aircraft/cessna-172.

[10] Corazza, M.V., & Di Mascio, P. (2024). Strategies to reduce pollutant emissions in the areas surrounding airports: Policy and practice implications. *Future Transportation*, 4(3), 820-833. doi: 10.3390/futuretransp4030039.

[11] Cunha, D.A., Andrade, M., Prado, L.A., Santana, L.O., & da Silv, M.P. (2021). RISK assessment in airport maintenance runway condition using MCDA-C. *Journal of Air Transport Management*, 90, article number 101948. doi: 10.1016/j.jairtraman.2020.101948.

[12] Esposito, A., Allouis, C., & Lappa, M. (2022). A new facility for hypersonic flow simulation driven by a high velocity oxygen fuel gun. In *Proceedings of the 33th congress of the International Council of the Aeronautical Sciences (ICAS)*. Bonn: International Council of the Aeronautical Sciences. Retrieved from https://strathprints.strath.ac.uk/83464/.

[13] Farivar, F., Haghighi, M.S., Jolfaei, A., & Wen, S. (2021). Covert attacks through adversarial learning: Study of lane keeping attacks on the safety of autonomous vehicles. *IEEE/ASME Transactions on Mechatronics*, 26(3), 1350-1357. doi: 10.1109/TMECH.2021.3064816.

[14] Frant, M., Kiszkowiak, Ł., Majcher, M., & Zalewski, P. (2024). Experimental tests and numerical analysis of aerodynamic properties of the composite-made jet-propelled aerial target. *Materials*, 17(14), article number 3575. doi: 10.3390/ma17143575.

[15] Guo, Y., Hu, M., Zou, B., Hansen, M., Zhang, Y., & Xie, H. (2022). Air traffic flow management integrating separation management and ground holding: An efficiency-equity bi-objective perspective. *Transportation Research Part B: Methodological*, 155, 394-423. doi: 10.1016/j.trb.2021.12.004.

[16] Jamieson, S., & White, G. (2021). Laboratory evaluation of the performance of stone mastic asphalt as an ungrooved runway surface. *Materials*, 14(3), article number 502. doi: 10.3390/ma14030502.

[17] Kim, B., Ahn, J., & Kwon, H. (2023). A study on a partially-open bogie fairing to improve anti-snow performance of a high-speed train. *Journal of Mechanical Science and Technology*, 37(4), 1859-1869. doi: 10.1007/s12206-023-0324-x.

[18] Lai, Y.Y., Christley, E., Kulanovic, A., Teng, C.C., Björklund, A., Nordensvärd, J., Karakaya, E., & Urban, F. (2022). Analysing the opportunities and challenges for mitigating the climate impact of aviation: A narrative review. *Renewable and Sustainable Energy Reviews*, 156, article number 111972. doi: 10.1016/j.rser.2021.111972.

[19] Li, Z., Wang, S., Zheng, W., Wang, Y., & Pan, Y. (2024). A review of dynamic monitoring technology and application research of laser cleaning interface. *Measurement*, 238, article number 115311. doi: 10.1016/j.measurement.2024.115311.

[20] Lv, C., Chang, J., Bao, W., & Yu, D. (2022). Recent research progress on airbreathing aero-engine control algorithm. *Propulsion and Power Research*, 11(1), 1-57. doi: 10.1016/j.jppr.2022.02.003.

[21] Maltinti, F., Flore, M., Pigozzi, F., & Coni, M. (2024). Optimizing airport runway capacity and sustainability through the introduction of rapid exit taxiways: A case study. *Sustainability*, 16(13), article number 5359. doi: 10.3390/su16135359.

[22] Miah, M.T., Oh, E., Chai, G., & Bell, P. (2022). Runway grooving techniques and exploratory study of the deterioration model. In H.R. Pasindu, S. Bandara, W.K. Mampearachchi & T.F. Fwa (Eds.), *Proceedings of 12th international conference on road and airfield pavement technology "Road and Airfield Pavement Technology"* (pp. 219-240). Cham: Springer. doi: 10.1007/978-3-030-87379-0_16.

[23] MoghimiEsfandabadi, M.H., Djavareshkian, M.H., & Abedi, S. (2023). Significance of aviation safety, its evaluation, and ways to strengthen security. *International Journal of Reliability, Risk and Safety: Theory and Application*, 6(2), 37-45. doi: 10.22034/IJRRS.2023.6.2.5.

[24] Muldma, K., Mets, B., Siirde, K., Siirde, A., Reinaas, M., Närep, A., Uustalu, J.-M., Koern, V.Ö., Lopp, M., & Kaldas, K. (n.d.). *Production of snow and ice melting agents-calcium and magnesium acetates from oil shale industry combustion waste*. Retrieved from https://www.iscre28.org/abstracts/abstract_588_518_1.pdf.

[25] Ottogalli, K., Rosquete, D., Rojo, J., Amundarain, A., Maria Rodriguez, J., & Borro, D. (2021). Virtual reality simulation of human-robot coexistence for an aircraft final assembly line: Process evaluation and ergonomics assessment. *International Journal of Computer Integrated Manufacturing*, 34(9), 975-995. doi: 10.1080/0951192X.2021.1946855.

[26] Pérez-Fortes, A.P., Varas-Muriel, M.J., & Bermejo, M. (2022). Crushing effects on the durability of rocky aggregates used on road surfaces subjected to winter maintenance and extreme climate conditions. *Construction and Building Materials*, 351, article number 128948. doi: 10.1016/j.wear.2021.203757.

[27] Rabajczyk, A., Zielecka, M., Klapsa, W., & Dziechciarz, A. (2021). Self-cleaning coatings and surfaces of modern building materials for the removal of some air pollutants. *Materials*, 14(9), article number 2161. doi: 10.3390/ma14092161.

[28] Sajid, H.U., Naik, D.L., & Kiran, R. (2021). Improving the ice-melting capacity of traditional deicers. *Construction and Building Materials*, 271, article number 121527. doi: 10.1016/j.conbuildmat.2020.121527.

[29] Shrestha, R., Oh, I., & Kim, S. (2021). A survey on operation concept, advancements, and challenging issues of urban air traffic management. *Frontiers in Future Transportation*, 2, article number 626935. doi: 10.3389/ffutr.2021.626935.

[30] South Cambs District Council: Electric operation reduces driver fatigue! (2024). Retrieved from https://www.aebi-schmidt.com/en/news/blog/2024/06/07/south-cambs-district-council-electric-operation-reduces-driver-fatigue/.

[31] Sparacino, H., Stepenuck, K.F., Gould, R.K., & Hurley, S.E. (2022). Review of reduced salt, snow, and ice management practices for commercial businesses. *Transportation Research Record*, 2676(3), 507-520. doi: 10.1177/03611981211052538.

[32] Toraldo, E., Ketabdari, M., Battista, G., & Crispino, M. (2023). Assessing the impact of rutting depth of bituminous airport runway pavements on aircraft landing braking distance during intense precipitation. *Designs*, 7(2), article number 41. doi: 10.3390/designs7020041.
[33] Vammas T600. (n.d.). Retrieved from https://dobrowolski.com.pl/2244_en.html.
[34] Vidal, Y.L., Arapa, C.A., Mejía, Á.D., Supo, E., Gutierrez, J.L., & Salas, P.E. (2023). A systematic review of methods for cleaning FOD on runways. In *Proceedings of the 17th international conference on engineering of modern electric systems* (pp. 1-4). Oradea: IEEE. doi: 10.1109/EMES58375.2023.10171778.
[35] Wu, Y., Du, J., Liu, G., Ma, D., Jia, F., Klemeš, J.J., & Wang, J. (2022). A review of self-cleaning technology to reduce dust and ice accumulation in photovoltaic power generation using superhydrophobic coating. *Renewable Energy*, 185, 1034-1061. doi: 10.1016/j.renene.2021.12.123.
[36] Xiang, Y., Cai, H., Liu, J., & Zhang, X. (2021). Techno-economic design of energy systems for airport electrification: A hydrogen-solar-storage integrated microgrid solution. *Applied Energy*, 283, article number 116374. doi: 10.1016/j.apenergy.2020.116374.
[37] Yang, H., Huang, M., Zhou, G., Chen, X., & Ming, R. (2022). [Retracted] Application of TOPSIS method combined with grey relational degree in the selection of snow-melting agent use plan. *Journal of Nanomaterials*, 2022(1), article number 3882031. doi: 10.1155/2022/3882031.
[38] Zhang, Q., Fan, L., Wang, H., Han, H., Zhu, Z., Zhao, X., & Wang, Y. (2022). A review of physical and chemical methods to improve the performance of water for dust reduction. *Process Safety and Environmental Protection*, 166, 86-98. doi: 10.1016/j.psep.2022.07.065.
[39] Zhao, G., Zhao, B., Ding, W., Xin, L., Nian, Z., Peng, J., He, N., & Xu, J. (2024). Nontraditional energy-assisted mechanical machining of difficult-to-cut materials and components in aerospace community: A comparative analysis. *International Journal of Extreme Manufacturing*, 6(2), article number 022007. doi: 10.1088/2631-7990/ad16d6.
[40] Zhu, G., Xu, Z., Jin, Y., Chen, X., Yang, L., Xu, J., Shan, D., Chen, Y., & Guo, B. (2022). Mechanism and application of laser cleaning: A review. *Optics and Lasers in Engineering*, 157, article number 107130. doi: 10.1016/j.optlaseng.2022.107130.

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Аеронавтологічний вплив на процес очищення злітно-посадкових смуг від забруднень

Анотація. Дослідження спрямоване на аналіз аеронавтологічних методів очищення злітно-посадкових смуг від забруднень для підвищення ефективності обслуговування та безпеки авіаційних операцій. У дослідженні були використані аеродинамічні аналізи, дані щодо технологій високошвидкісних повітряних потоків, хімічних реагентів, а також вивчені автоматичні системи управління і сенсори для комплексної оцінки ефективності очищення злітно-посадкових смуг від забруднень. Результати дослідження показали, що використання аеронавтологічних методів очищення злітно-посадкових смуг значно підвищує ефективність видалення забруднень, таких як сніг, лід і пилові частки. Було виявлено, що спрямовані високошвидкісні потоки повітря ефективно скорочують час очищення, порівняно з традиційними механічними методами, зменшуючи ризик пошкодження покриття смуг. Крім того, інтеграція цих методів із системами автоматичного управління та сенсорами дозволяє підвищити безпеку очищення і зменшити негативний вплив на навколишнє середовище. Комбіноване використання аеронавтологічних технологій з хімічними реагентами також було визнано ефективним, що робить ці підходи перспективними для застосування в аеропортах з високою інтенсивністю польотів. Дослідження підтвердило доцільність впровадження таких технологій для забезпечення безпеки та економічної ефективності авіаційних операцій. Аналіз також виявив, що використання аеронавтологічних методів зменшує необхідність частих повторних очищень злітно-посадкових смуг, що сприяє зниженню експлуатаційних витрат. Крім того, застосування цих технологій сприяє зменшенню кількості відкладень на поверхні смуг, що позитивно впливає на довговічність їхнього покриття. Дослідження вносить новий підхід до очищення злітно-посадкових смуг, показуючи, як аеронавтологічні методи можуть підвищити ефективність, безпеку та економічність авіаційних операцій, що відкриває перспективи для подальших інновацій у цій сфері

Ключові слова: високошвидкісні потоки повітря; автоматичне управління; хімічні реагенти; пошкодження покриття; вплив на навколишнє середовище