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INVESTIGATING TYRE SURFACE TEMPERATURE AT TOUCHDOWN WITH PRE-ROTATION

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Abstract: This project investigates the changes in tyre surface temperature during aircraft touchdown when pre-rotation is applied to the landing gear. During the landing phase, tyres undergo rapid temperature fluctuations due to the sudden interaction with the runway, which can affect tyre performance, longevity, and safety. Pre-rotation involves rotating the tyres before touchdown to reduce the relative speed between the tyre and the runway, potentially minimizing the thermal shock upon initial contact. The project aims to analyse how pre-rotation influences the temperature distribution across the tyre surface at touchdown, by using experimental method. The results will help to identify the potential benefits of incorporating pre-rotation into landing procedures, providing insights into improved tyre durability, enhanced safety, and more efficient landing dynamics.

Keywords: Pre-Rotation, Aircraft Touchdown, Friction, Heat Generation and Tyre Surface Temperature

1. INTRODUCTION

The interaction between aircraft tires and the runway is one of the most crucial elements of aircraft landing dynamics. When an aircraft approaches the runway for landing, it experiences a significant change in velocity and pressure as the tires make contact with the surface. This process leads to rapid deceleration, which generates a considerable amount of heat due to friction between the tire and the runway.

The resulting increase in tire surface temperature can have a substantial impact on both the tire's performance and its longevity. When the tires hit the runway, there is a sharp contrast in their rotational speed relative to the runway, which causes a sudden increase in friction and heat generation. This phenomenon, known as thermal shock, can create a temperature gradient across the tire surface, potentially affecting the tire's structural integrity and overall performance. Excessive heat buildup can also lead to increased wear and tear, reducing the tire's lifespan and potentially leading to costly repairs or replacements.

The primary goal of this project is to investigate how pre-rotation influences the temperature distribution on the tire surface during touchdown. The research will focus on how different pre-rotation speeds impact the temperature changes, frictional forces, and overall heat generation during the landing phase. By conducting both experimental tests and numerical simulations, this project aims to create a comprehensive understanding of the thermal effects of pre-rotation on aircraft tires. The insights gained from this investigation may lead to practical recommendations for optimizing landing procedures and improving tire design, with the potential to reduce maintenance costs, improve safety, and enhance the overall performance of aircraft.

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Figure 1: Generation of smoke at touchdown

Several studies have shown that the friction between the tires and the runway surface is a significant contributor to temperature rise. The magnitude of this effect depends on several factors, including the landing speed, the tire pressure, the runway conditions, and the nature of the tire material. When the tires are rotating at a significantly slower speed than the aircraft's landing speed, the friction between the tire and the runway is high, leading to a sharp increase in temperature upon touchdown. This abrupt increase in temperature can cause uneven wear and potentially lead to dangerous tire blowouts if not properly managed.

Figure 2: Worn out tyres

Pre-rotation has been suggested as a potential solution to mitigate these thermal effects. The concept behind pre-rotation is simple: if the tires are rotated before touchdown to match the aircraft's speed the relative velocity between the tire and the runway will be minimized. This, in turn, reduces the frictional forces during touchdown, limiting the heat generated and the associated temperature rise. While this concept appears promising, there is limited research on its specific impact on tire surface temperature, friction, and heat generation during landing. The current study seeks to fill this gap by investigating the temperature changes that occur during touchdown with pre-rotation and exploring the potential benefits of this technique for improving tire performance and safety.

2. LITERATURE SURVEY

1) Without pre-rotation, tire temperatures can exceed critical thresholds (329°C observed in simulations), which jeopardizes structural integrity and safety. High-speed pre-rotation (75% of landing speed) significantly reduces maximum temperature to around 104°C. Frictional force peaks shortly after touchdown, influenced by the relative speeds of the tire and runway. Pre-rotation drastically reduces the duration and magnitude of peak frictional forces and associated heat generation. While reducing overall friction energy, it can lead to localized temperature spikes in certain

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tire areas due to delayed friction engagement. High-speed pre-rotation is proven to mitigate heat and wear effectively, making it a viable strategy for improving aircraft tire lifespan and safety. The MATLAB algorithm offers a faster and scalable alternative to traditional finite element analysis tools for operational predictions.

2) Wheels skid abrasively during the initial moments, transitioning to rolling motion. Skidding generates heat, sometimes re-softening rubber and affecting braking and directional stability. Wet runways increase spin-up time and reduce horizontal forces. Drag forces and wear are influenced by friction coefficients, sink rates, and tire temperature. Reduces tire temperature spikes and prevents rubber burning during touchdown. Distributes wear more evenly around the tire, reducing concentrated damage. Enhances braking efficiency and minimizes environmental pollution from rubber deposits.

3) A consistent linear relationship exists between surface temperature and TDD, enabling the prediction of internal thermal penetration from surface measurements. Both friction speed and duration significantly affect surface temperature and thermal penetration, with higher values leading to greater heat penetration depths. The landing speed increases TDD due to higher friction energy, whereas vertical landing speed impacts the duration and consistency of the contact surface but has little effect on the Decomposition Depth to Surface Temperature Ratio (DTR). The MATLAB model effectively simplifies the calculation of heat distribution and TDD, offering a practical tool for real-time or predictive maintenance applications. The established linear relationship between surface temperature and TDD allows airlines to implement effective monitoring systems for aircraft tyre maintenance, enhancing operational safety and efficiency.

3. INFRARED THERMOGRAPHY

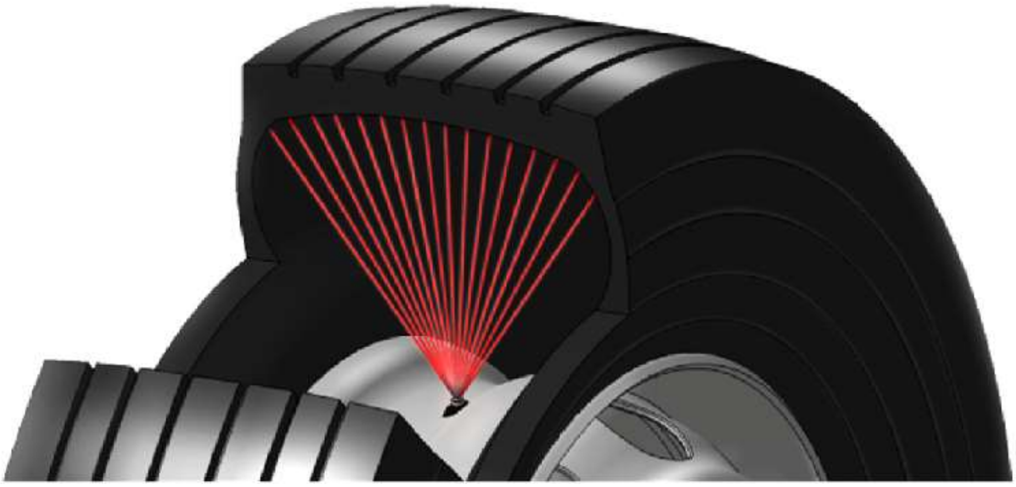

Figure 3: Infrared sensors on the inline

Infrared thermography (IR thermography) is a non-contact imaging technique used to measure and visualize the temperature distribution of an object or surface. It relies on the principle that all objects emit infrared radiation as a function of their temperature.

This method is widely applied in various fields, including industrial inspection, medical diagnostics, electrical maintenance, and, as previously mentioned, for monitoring tire surface temperatures during touchdown or pre-rotation in high-speed applications like aircraft landings.

All objects emit infrared radiation based on their temperature. The higher the temperature, the more infrared radiation they emit. This radiation is invisible to the human eye, but infrared cameras can detect it. An infrared camera (often referred to as a thermographic camera) detects the infrared radiation emitted by the object or surface and converts it into a thermal image or thermogram. These cameras are equipped with infrared sensors that capture the infrared energy and create a visual representation of the temperature distribution. The camera generates a thermogram, which is an image where colors or shades represent different temperatures. Typically, warmer areas are shown in brighter colors (e.g., red, white, yellow), while cooler areas are shown in darker colors (e.g., blue, purple, black). This allows easy identification of temperature variations on the surface. Thermograms are then analyzed to detect hot or cold spots, temperature gradients, and other temperature-related phenomena. The temperature of specific points can be measured using the software associated with the thermal camera, which often provides numeric values.

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Infrared thermography is a powerful and versatile tool for monitoring tire surface temperatures during touchdown and pre-rotation, offering advantages in terms of non-contact measurement, real-time data acquisition, and the ability to assess large areas quickly. Its applications extend beyond tire temperature analysis to fields like electrical inspections, industrial maintenance, medical diagnostics, and building inspections. Despite its many advantages, it requires careful consideration of factors like surface emissivity and environmental conditions to ensure accurate and reliable results.

4. SOFTWARE IMPLEMENTATION

The Arduino IDE (Integrated Development Environment) is software used to write compile, and upload code to Arduino boards. It supports a variety of sensors including temperature sensors, through its simple programming interface an extensive library ecosystem. It is a versatile platform for programming and controlling Arduino boards to interface with various temperature sensors. Below is a comprehensive guide, covering everything from setup to advanced features.

5. HARDWARE IMPLEMENTATION

1) Arduino UNO:

Figure 4: Arduino UNO

Arduino Uno is a popular microcontroller board used for various such as temperature sensing etc. Here are some applications of Arduino Uno:

i) Monitor machinery and equipment for overheating.
ii) Sensor integration: Arduino Uno can read data from various sensors, such as ultrasonic, infrared, and temperature sensors, to navigate through obstacles and detect fires.
iii) Algorithm implementation: Arduino Uno can implement various algorithms, such as line following, obstacle avoidance, and mapping, to navigate through the environment.

2) Non-Contact Infrared Temperature Sensor:

Measures ambient and object temperatures without physical contact. Provides accurate readings based on infrared radiation emitted by objects. Monitor high-temperature machinery or detect fires.

Figure 5: IR Temperature Sensor

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3) OLED SH1106:

The SH1106 is a popular OLED display driver IC used in monochrome OLED displays. It supports I2C, SPI, and parallel interfaces, making it versatile for use in projects with microcontrollers like Arduino. Here is a detailed guide to working with the SH1106 OLED display.

Figure 6: OLED SH1106

4) 12v DC Motor:

DC Motor is an electrical machine which, when provided with direct current electrical energy, converts it into mechanical energy. It is based on electromagnetic induction, where a conductor carrying current (normally a coil of wire) placed in a magnetic field experiences force to rotate. This rotation is used to perform mechanical work.

Figure 7: DC Motor

5) 12v Battery:

Battery for rotation of wheels. The nine-volt battery, or 9-volt battery, is an electric battery that supplies a nominal voltage of 9 volts. Actual voltage measures 7.2 to 9.6 volts, depending on battery chemistry. This 9mv battery is connected in series to provide 12v.

Figure 8: 12 Volt Battery

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6) Rubber Wheels:

The wheels and tyres of an aircraft support it when on the ground and provide it with a means of mobility for take-off, landing and taxiing. The pneumatic tyres cushion the aircraft from shocks due to irregularities both in the ground surface and occasionally, lack of landing technique.

Figure 9: Rubber Wheel

7) Jumper Wires:

Jumper wires are used to make connections in a circuit.

8) Bread Board:

A breadboard (sometimes called a plug block) is used for building temporary circuits. It is useful to designers because it allows components to be removed and replaced easily.

6. TESTING

Friction and Heat Generation: The study highlights the significant friction and resulting heat generated at touchdown due to the speed difference between the runway and the landing gear. This heat can raise tire temperatures beyond critical thresholds, leading to material decomposition and safety concerns.

Pre-Rotation Strategy: Pre-rotation of the tires before touchdown is proposed to reduce the frictional heat. Various pre-rotation speeds were tested using a model developed. Results show that higher pre-rotation speeds significantly reduce friction and heat generation.

Impact of Pre-Rotation: While high pre-rotation speeds significantly decrease the peak tire temperature, low pre-rotation speeds may paradoxically increase the maximum temperature due to localized friction dynamics. The study concludes that pre-rotation is an effective method to address tire wear and thermal issues, recommending further optimization for real-world application in high-intensity operational environments.

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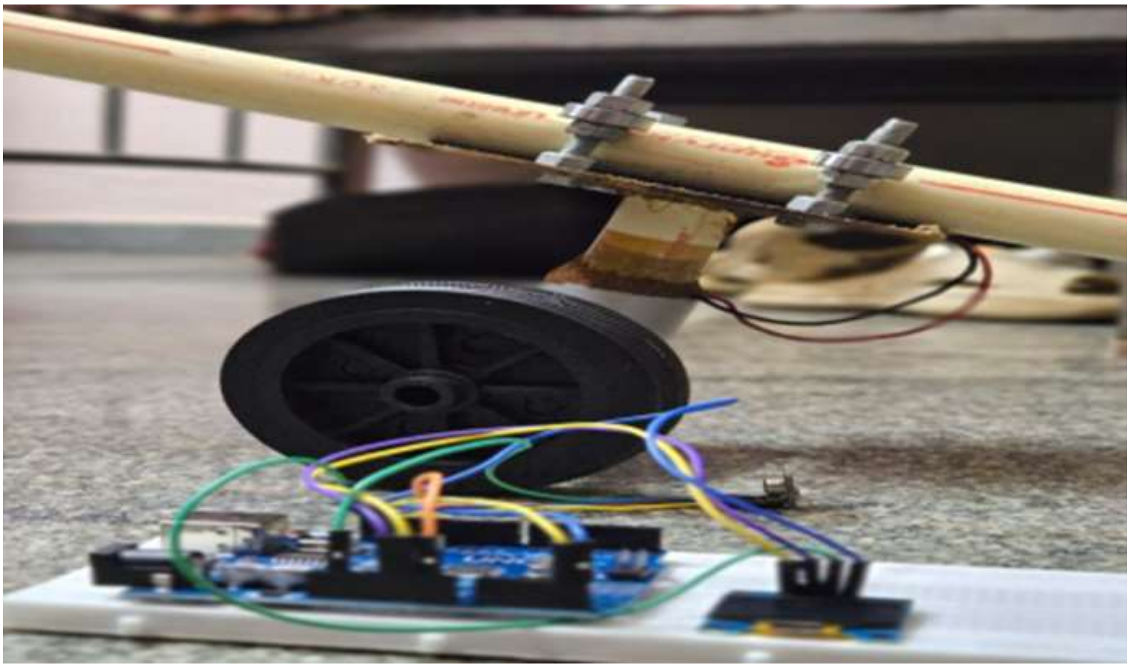

Figure 10: Final Assembly

7. CONCLUSION

In conclusion, the project on the elevation of tire surface temperature at touchdown with pre-rotation has provided valuable insights into the complex dynamics of tire performance during aircraft landing. By incorporating pre-rotation, which involves spinning the tires prior to touchdown, it has been demonstrated that this technique can have a notable impact on the thermal behaviour of the tires.

Key findings from the project include:

- Temperature Increase Due to Touchdown: The tire surface temperature increases significantly upon touchdown due to the rapid deceleration and friction between the tire and the runway surface. The rate of temperature rise is influenced by several factors, including the speed at touchdown and the runway condition.
- Impact of Pre-Rotation: Pre-rotating the tires before landing effectively reduces the friction between the tires and the runway, which in turn helps manage the temperature increase. The pre-rotation allows the tires to spin more easily upon touchdown, thus distributing the heat more evenly and potentially reducing the peak temperature reached during landing.
- Reduction in Thermal Stress: By mitigating the immediate temperature spike at touchdown, pre-rotation helps in reducing thermal stress on the tire material, leading to a decrease in the likelihood of damage or premature wear.
- Potential for Enhanced Tire Longevity and Safety: The results suggest that pre-rotation could contribute to better overall tire longevity and enhance safety by reducing the risks associated with excessive tire temperatures, such as blowouts or reduced braking performance.

Overall, this project has illustrated the importance of managing tire surface temperature during aircraft landing operations. The application of pre-rotation presents a promising method to mitigate the effects of temperature elevation, ensuring safer and more efficient landings while potentially extending the lifespan of aircraft tires. Further studies could refine these findings and explore the optimal conditions for pre-rotation implementation across different aircraft types and operational environments.

8. FUTURE SCOPE

Real-Time Data for Landing: The tire surface temperature during touchdown is a critical factor influencing tire wear, braking efficiency, and overall landing safety. IR contactless sensors can provide real-time data about tire conditions during landing, allowing for immediate detection of potentially dangerous temperature spikes that could lead to tire failure, overheating, or reduced braking performance.

Advanced Diagnostics: The ability to monitor tire temperature in real-time could facilitate predictive maintenance, allowing for early detection of tire issues. Over time, the data from these sensors could be integrated into an advanced diagnostic system, potentially helping airlines, ground operations, or fleet managers identify performance patterns and forecast tire wear before it leads to failure.

Preventative Safety Measures: Overheated tires or tires with uneven heat distribution can cause serious safety risks, particularly in high-speed environments like aircraft landings. Early detection through IR sensors could enable automated responses such as adjusting braking forces, triggering maintenance alerts, or adapting tire pressure settings to prevent failures.

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