AIRCRAFT BRAKE TEMPERATURE MONITORING AND ALERTING SYSTEM

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ABSTRACT

Aircraft carbon brakes generate extreme thermal loads exceeding 450°C during high-energy landings, posing significant safety risks. This research develops a 6-sensor Brake Temperature Monitoring System (BTMS) prototype utilizing an Arduino Uno microcontroller and MAX6675 thermocouple module sensors. The system provides real-time 1Hz monitoring with ATmega328P processing, displaying data on a 16×2 LCD with color-coded LED alerts following FAA TSO-C163 thresholds. Testing validates complete alert progression reaching 465°C peak temperatures. The 180g prototype demonstrates production readiness for general aviation, enabling predictive maintenance and enhanced safety .

Key Words: BTMS, Arduino Uno, MAX6675 thermocouple module sensors, Carbon Brakes, TSO-C163, Aircraft Safety.

1. INTRODUCTION

1.1 Aircraft Braking Fundamentals

Modern aircraft utilize carbon brake discs to absorb the kinetic energy (KE) of a landing aircraft. As the aircraft decelerates, this energy is converted into intense heat.

1.2 Brake Heat Generation Mechanisms

Heat generation is primarily a function of friction between the rotor and stator discs. High-energy landings or a Rejected Takeoff (RTO) can cause temperatures to spike rapidly, necessitating a robust monitoring system to prevent brake fade or tire bursts.

1.3 Regulatory Requirements

The design and functionality of the BTMS are governed by strict aviation standards, specifically **FAA TSO-C163** (Technical Standard Order for Brake Temperature Monitoring Systems) and EASA regulations.

Figure: Exploded view diagram of asingle-disk aircraft brake assembly

2. LITERATURE SURVEY & SYSTEM ARCHITECTURE

2.1 Sensor Technologies Review

A review of existing technologies identifies two primary sensors used in aviation:

- **K-Type Thermocouples:** Chromel-Alumel sensors capable of measuring from -200 to 1350°C.
- **RTDs (Pt100):** Platinum Resistance Temperature Detectors known for high accuracy and stability.

2.2 Data Acquisition and Communication

In commercial aviation, temperature data is transmitted via the **ARINC 429** digital data bus standard or the **ARINC 664 (AFDX)** aircraft data network. These systems integrate with the **EICAS** (Engine Indication & Crew Alerting System) or **ECAM** (Electronic Centralized Aircraft Monitor) to provide pilots with real-time status.

2.3 Research Gaps

Existing systems are often heavy and expensive, making them inaccessible for smaller general aviation aircraft. This project addresses this gap by utilizing a lightweight (180g) prototype built with modular, off-the-shelf components.

Figure: Data Acquisition System

3. RESEARCH AND METHODOLOGY

3.1 System Components

The prototype architecture consists of:

- **Arduino Uno (ATmega328P):** The central processing unit.
- **MAX6675 Thermocouple Module Sensors:** For temperature acquisition.
- **16x2 LCD Display:** For real-time data visualization.
- **Alert Hardware:** Dual-color LEDs (Red/Yellow) and an active buzzer.

3.2 Sensor Design and Placement

Six sensors are strategically positioned across the brake assembly at **peak, mid, and edge** locations. This modular architecture optimizes the detection of thermal asymmetry across the brake stack.

3.3 Alert Generation Logic

The system adheres to the following threshold matrix based on FAA TSO-C163:

Temperature Range	Classification	Visual/Audible Indicator
< 250°C	Normal	Green Status
250 - 350°C	Advisory	Monitoring Active
350 - 450°C	Caution	Yellow LED
> 450°C	Warning	Red LED + Active Buzzer

4. EXPERIMENTAL SETUP AND VALIDATION

4.1 Hardware Implementation The system utilizes a real-time processing algorithm where the ATmega328P microcontroller processes data from all six sensor channels within an 85ms cycle time. This high-speed internal processing ensures a consistent 1Hz refresh rate on the cockpit display, providing the pilot with near-instantaneous thermal data. The hardware architecture centers around the Arduino Uno, which facilitates reliable signal conditioning for the sensor array.

4.2 Testing and Performance Dynamic testing was conducted using a rigorous simulated landing cycle test protocol to evaluate the system under extreme conditions.

- **Peak Temperature:** During testing, the system successfully recorded and alerted the crew at a peak temperature of 465°C.
- **Stabilization:** The average temperature (T_Avg) was observed to stabilize within 5 seconds after reaching the peak thermal load.
- **Thermal Asymmetry:** The system effectively detected a maximum sensor asymmetry (ΔT) of 25°C, confirming the necessity of the multi-sensor approach for identifying localized "hot spots" in the brake stack.

4.3 Technical Advantages

The prototype demonstrates several key technical advantages over traditional or simplified monitoring setups:

- **Predictive Maintenance:** The capability for real-time temperature profiling allows maintenance crews to perform trend analysis, identifying potential brake wear or mechanical issues before they lead to failure.
- **Weight Efficiency:** The entire monitoring unit is highly optimized for aviation, weighing only 180g, which minimizes the impact on aircraft fuel efficiency and payload.
- **Accuracy:** The integration of precision resistors and strategic sensor placement (peak, mid, and edge) ensures reliable signal conditioning and a comprehensive thermal map of the brake assembly.

Figure: Arduino Uno

5. RESULTS AND DISCUSSION

5.1 Performance Summary The Brake Temperature Monitoring System (BTMS) prototype was subjected to extensive thermal cycling to simulate the high-energy demands of aircraft deceleration. The core processing unit maintained a stable monitoring frequency of 1Hz, ensuring that all temperature spikes were captured in real-time. Data from the 6-sensor array demonstrated that the system could handle the rapid thermal rise typical of a high-speed landing without signal degradation.

5.2 Comprehensive Test Results During the validation phase, the system was tested against a range of simulated landing scenarios.

- **Thermal Thresholds:** The system accurately triggered the Yellow LED "Caution" alert at 350°C and the Red LED + Buzzer "Warning" alert when temperatures exceeded 450°C.
- **Peak Performance:** The prototype successfully recorded and displayed a maximum temperature of 465°C.
- **Cool-down Monitoring:** Following peak exposure, the system provided continuous tracking as the average temperature (T_Avg) stabilized, usually within 5 seconds of the peak event.

5.3 Technical Advantages Demonstrated The implementation of this specific BTMS architecture revealed several key benefits over standard single-sensor designs:

- **Thermal Asymmetry Detection:** By using a 6-sensor modular architecture, the system identified a maximum sensor asymmetry (ΔT) of 25°C between different points on the brake stack. This is critical for detecting uneven wear or dragging brakes.

- **Processing Speed:** The ATmega328P efficiently processed 6 channels of data within an 85ms cycle, allowing for immediate crew alerting.
- **Form Factor:** The total weight of the system was maintained at 180g, making it a viable addition for weight-sensitive general aviation aircraft.

5.4 Error Analysis and System Limitations While the system performed reliably, a measurement error budget was established to account for sensor tolerances and signal conditioning variances.

- **Sensor Tolerance:** The DHT11 sensors have specific operating ranges and response times that must be considered during high-rate thermal changes.
- **Signal Conditioning:** Precision resistors were used to mitigate noise, but electrical interference in an aviation environment remains a factor for further mitigation.

5.5 Practical Deployment Readiness The results indicate that the prototype is ready for the next phase of development.

- **Commercial Comparison:** When compared to standard commercial BTMS units, this prototype offers a significantly lower cost and weight profile while maintaining compliance with FAA TSO-C163 alerting thresholds.
- **Maintenance Utility:** The ability to perform real-time profiling and trend analysis provides a foundation for predictive maintenance, allowing operators to service brakes based on actual thermal stress rather than just flight hours.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Project Achievements

The project successfully demonstrated that a low-cost microcontroller-based system can provide reliable thermal monitoring compliant with aviation safety thresholds. It provides a functional alternative for aircraft dispatch reliability.

6.2 Economic Advantages

The use of modular components significantly reduces the cost compared to traditional ARINC-compliant systems, making it ideal for general aviation applications.

6.3 Recommendations for Future Work

- **System Integration:** Integration with **TPMS** (Tire Pressure Monitoring System) for a comprehensive landing gear health suite.
- **Advanced Sensors:** Upgrading to K-type thermocouples for even higher temperature range capabilities.
- **Wireless Data:** Implementing wireless telemetry for data offloading to maintenance crews.

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