

# AI integrated Aircraft Door and window safety indicator

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**Abstract-** Ensuring the security and structural integrity of aircraft doors and windows is critical for safe flight operations. This paper proposes a vibration-based monitoring system to verify that aircraft doors and windows are properly secured before and during flight. The proposed method identifies and measures characteristic vibration signatures associated with the aircraft structure, door assembly, and fastening components such as bolts and nuts. Any deviation from the expected vibration pattern, which may indicate a loose or improperly secured fastener, is detected through a comparison algorithm. The system then generates a warning indication on the cockpit display panel, enabling timely corrective action. Furthermore, an Artificial Intelligence (AI)-based analysis approach is incorporated to improve detection accuracy, minimize false alarms, and provide reliable, error-resistant assessments. The proposed solution enhances aircraft safety by offering continuous, real-time monitoring of door and window security.

**Keywords-** Aircraft Safety, Aircraft Door, Aircraft Window, Vibration Monitoring, Structural Health Monitoring, Artificial Intelligence, Fault Detection.

## I. INTRODUCTION

There have been many incidents coming up in recent days with regards to the loosening door and window which is life threatening risks and giving panic attacks to the passengers travelling in the plane.

**For instance,**

- An Alaska Airlines Boeing 737 Max 9 experienced a door plug flying off during flight 1282 in January 2024. The incident happened shortly after taking off from Portland, Oregon, due to multiple systemic failures, mainly the bolts securing the door plug not being reinstalled after repair. This caused a mid-air decompression event, but the plane managed to land safely.
- A cosmetic window frame on a SpiceJet Q400 aircraft became loose mid-flight on July 2, 2025.

I have come up with a solution for this which will make the journey safe and immediate indication even if there is minor loose contact between the door and window. When we consider the history of incidents, it has not occurred in a single flight, there has been a gradual loosening which then led to a final big failure. For example, if we take the Boeing 737 Max 9 door plug flying incident, they forgot to add 4 bolts which the aircraft has gone for service so in between this service and accident of the flight had operated 153 flights. Ref[1]

## II. ABBREVIATION

1. PCB – PicoCoulomb
2. ICP - Integrated Circuit Piezoelectric.
3. DAU - Data Acquisition Unit
4. DPAU - Data Processing and Analysis Unit
5. ANU - Alert and Notification Unit
6. ADC – Analog to Digital Converter
7. AD – Analog Devices
8. V-Vibration Output

## III. UNITS

- ns – nano second
- mV – milli Volt
- °C – degree Celsius
- Ns – nano second

## IV. SOLUTION

The proposed systems consist of 3 main units which have the DAU, DPAU and ANU which can be categorized as below

### Sensing Unit

Vibration sensors are strategically integrated into both the door unit panel and the adjacent window panel structure. On the door unit, sensors are distributed across the entire outer surface, with

placement intervals corresponding to the locations of existing critical fasteners (bolts and nuts) used for structural assembly. A similar sensor array is implemented on the window panel to ensure comprehensive coverage and facilitate real-time structural health monitoring of all primary connection points.

The proposed system employs a differential vibration analysis method for preventive maintenance, utilizing high-sensitivity PCB Piezotronics ICP Accelerometers (Model: 352A56), which are optimized for aerospace environments. These sensors are deployed in a dual-location configuration: a primary sensor is placed in close proximity to a critical mechanical fastener (bolt), while a reference sensor is mounted at a corresponding location on the adjacent fuselage panel. A wireless data acquisition system is utilized to transmit vibration signals from the bolt ( $V_b$ ) and the reference surface ( $V_a$ ). The system processes these signals by performing a differential comparison, using a comparator circuit to monitor for significant discrepancies. An alert signal, processed through a buffering stage, is generated upon the detection of a differential, indicating potential loosening or contact issues at the fastener.

#### Processor – Control Unit

The core of the data processing stage involves comparing the live data with established baselines using a highly responsive Analog to Digital Converter (ADC) and a specialized comparator unit. The digitized vibration data, alongside the precise positional information of each monitored bolt, is processed to determine the structural integrity of every single fastening point on the door. This system relies on two primary operational conditions: a match between the measured and standard signals indicates no issue with the bolts, while a variance exceeding the defined buffer triggers an immediate alert that a bolt has loosened.

For the real-time processing required to detect minute and high-frequency vibrational changes, an ultra-fast analog voltage comparator is essential. The Analog Devices AD790 is a highly suitable component for this task, offering a rapid 25ns response time that allows for immediate processing of live sensor inputs. Its low input offset voltage (5mV) ensures accuracy, while its wide operating temperature range ( $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ ) and resistance to electromagnetic interference make it ideal for the demanding aerospace environment.

The overall solution provides a sophisticated, real-time structural health monitoring system that moves beyond visual inspections. By employing a differential vibration analysis technique that compares data from individual fasteners to a reference panel, it identifies loosening components long before they become a safety hazard. The integration of high-sensitivity accelerometers and the rapid AD790 comparator unit allow for instant fault detection, transmitting precise location data to the indication panel and enabling a proactive, condition-based maintenance approach to mitigate the risk of catastrophic failure.

#### Indication Panel

The visual warning system is designed to provide immediate and unambiguous feedback based on the output of the differential comparator circuit. The system utilizes two distinct light indicators: green for 'System Normal' and red for 'Warning/Anomaly Detected'. The comparator circuit's output determines the state of these indicators. When the differential voltage exceeds the predefined safety threshold, indicating potential bolt loosening, the red LED illuminates. Conversely, if the signals match and remain within the acceptable buffer range, the green LED illuminates, confirming system integrity.

#### LED Specifications:

For aerospace applications, high reliability, brightness, and a wide viewing angle are paramount to ensure visibility under varying cockpit or maintenance bay lighting conditions. Color Wavelength: Red:  $\sim 620\text{nm}$  to  $630\text{nm}$  (high visibility peak); Green:  $\sim 520\text{nm}$  to  $530\text{nm}$  (pure green for clear indication).

Brightness (Luminosity): High brightness LEDs are recommended, with a minimum intensity of 500 millicandelas (mcd) to 1,000 mcd to cut through bright ambient light. Forward Voltage/Current: Typically, around 2V for red and 3V for green, with a drive current of approximately 20mA. Type: Through-hole or surface-mount devices (SMD) with protective clear lenses are suitable options, often chosen for their robust construction and resistance to vibration (e.g., Avago/Broadcom or Lumileds high-reliability series).

#### Interfacing and Drive Circuitry:

The output of the AD790 comparator provides a standard logic signal (TTL or CMOS compatible, depending on the supply voltage). This output can directly drive the LEDs via a simple current-limiting resistor, or, for higher brightness applications,

it can trigger a transistor-based driver circuit or a dedicated LED driver IC. This ensures the LEDs receive consistent current without stressing the comparator's output stage. A simple transistor switch (e.g., BC547 NPN transistor) can manage the current flow to the respective red or green LED, ensuring only one is illuminated at a time based on the comparator's High/Low state.

#### Display Panel and User Interface:

The indicator panel would consist of a backlit schematic overlay of the door unit. Within this schematic, the exact location of each monitored bolt is marked. Upon activation of the red warning signal, the system processes the location data from the specific sensor that triggered the comparator. The relevant position on the display panel will then be highlighted, potentially flashing the corresponding LED at that exact point. This provides maintenance personnel with an immediate visual cue of the exact location requiring attention, minimizing troubleshooting time and ensuring precision in preventive maintenance actions.

The visual indication system is designed to provide immediate, clear status feedback based on the comparator output. In avionics, specific color meanings are standardized: red for immediate warnings requiring critical attention, and green for normal, advisory status.

For this application, high-brightness, reliable, panel-mount LEDs designed for aerospace or high-reliability industrial use should be selected. Recommended technical specifications include a wide operating temperature range (e.g.,  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ ), high resistance to shock and vibration, and an ingress protection rating of at least IP65 (front panel protection against dust and water jets). The operating voltage should be compatible with the aircraft's internal DC power bus, such as 12V or 24V DC, with a maximum current consumption of around 20mA.

#### Electrical Interface and Logic

The AD790 comparator output, which is a logical signal (e.g., 0V for normal, +5V for fault), will drive an LED driver circuit. If the comparator output exceeds the predefined threshold value indicating a significant variance between the bolt vibration ( $V_b$ ) and the airframe reference ( $V_a$ ) a driver circuit illuminates the red warning LED. If the output is within the accepted range (below the threshold), the red LED remains off, and potentially a green indicator LED illuminates to confirm a "systems

normal" or advisory status. The comparison logic is binary: a higher-than-normal value signifies a loose bolt and triggers the warning, while a normal value indicates system integrity.

#### Display Panel and User Interface

The indication panel itself should utilize a graphical display, potentially a Liquid Crystal Display (LCD) with a robust LED backlight, to show the precise location of any alerted bolt. The panel would feature a schematic layout of the door structure and visually highlight the affected bolt position (e.g., flashing the corresponding point in red). This immediate, location-specific feedback simplifies the troubleshooting process for maintenance crews, allowing them to pinpoint the exact issue quickly and perform targeted preventive maintenance.

#### AI Integration

Instead of just comparing voltage levels, AI can analyze changes in the frequency spectrum (e.g., shifts in natural frequencies) which are subtle indicators of loosening that a basic comparator might miss. We can classify the state of a bolt as 'Good', 'Slightly Loose', or 'Danger'. The review highlights how AI models can be trained to differentiate between changes in vibration caused by actual bolt loosening versus those caused by normal operational variations (e.g., turbulence, engine power changes, temperature shifts). This significantly reduces false alarms in a dynamic flight environment.

By implementing AI based on these principles, you can create a more reliable and accurate system that moves from simple threshold comparison to intelligent diagnostic analysis.

Our system can use Machine Learning (ML) algorithms to extract "damage-sensitive features" such as root mean square (RMS) values, kurtosis, skewness, or spectral energy distribution (e.g., using Fast Fourier Transform, or FFT). The AI would learn which combinations of these features correlate with a loose bolt, a process that is much more robust than a single voltage threshold.

A major challenge in aviation is separating actual fault signals from normal operational noise (e.g., turbulence, engine vibration changes, temperature fluctuations). A simple comparator with a fixed buffer may produce false alarms.

So, we can use supervised learning algorithms (e.g., Support Vector Machines, Random Forests, or even a simple Neural Network) trained on data representing various conditions (tight

bolt, loose bolt, normal flight conditions, turbulence). The AI would learn to filter out irrelevant noise and only flag actual signs of loosening, significantly improving system reliability. So as per the AI model the following will be the function.

1. **Feature Extraction:** The system uses ML algorithms to extract "damage-sensitive features" from the digitized raw vibration data (Vb) and (Va). This includes standard metrics like Root Mean Square (RMS) values, kurtosis, skewness, and spectral energy distribution via Fast Fourier Transform (FFT). This process provides a more robust analysis than a single voltage comparison.
2. **Noise Filtering and Classification:** The extracted features are fed into a supervised learning algorithm. We can use models such as Support Vector Machines, Random Forests, or a Neural Network, trained on a dataset representing various conditions like 'Good', 'Slightly Loose', or 'Danger'. This training allows the AI to learn which feature combinations correlate with actual bolt loosening, significantly reducing false alarms in a dynamic flight environment.
3. **Intelligent Diagnostic Analysis:** AI classifies the bolt's status into one of three defined states: 'Good', 'Slightly Loose', or 'Danger'. This granular assessment provides more informative feedback than a binary (red/green) output. By implementing AI based on these principles, the system creates a more reliable and accurate monitoring solution that moves from simple threshold comparison to an intelligent, data-driven diagnostic analysis system.

Thereby by this method A novel vibration-based monitoring system for aircraft doors and windows enhances safety by identifying anomalies in real-time, caused by issues like loose bolts or improper seals. This automated system represents a significant advancement over manual checks for maintaining aircraft integrity and can potentially be applied to other structural components.

## REFERENCES

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## Block Diagram

