Fault Detection and Predictive Maintenance of the Aircraft Propeller System

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Abstract: *The article examines the significance and methodologies of predictive maintenance for aircraft propeller systems. The primary focus is on multisensor monitoring of key diagnostic parameters, including vibration, acoustic signals, torque, and temperature. Regular measurement and analysis of these parameters enable the early detection of malfunction indicators such as propeller imbalance, blade damage, shaft misalignment, and related anomalies. This proactive diagnostic approach enhances operational reliability, reduces unplanned maintenance, and supports the overall safety and efficiency of aircraft propulsion systems.*
Key words: *Aviation, propeller, predictive maintenance.*

Introduction

The aircraft propeller system plays a crucial role in generating thrust and ensuring efficient flight performance. Its proper functioning directly influences flight safety, fuel efficiency, and operational reliability. However, as a rotating mechanical component subjected to high dynamic loads: vibration, aerodynamic forces, and environmental stresses, the propeller system is prone to gradual wear, imbalance, fatigue cracks, and other degradation phenomena. Traditional maintenance strategies, such as scheduled (time based) maintenance often fail to detect early-stage faults, leading either to unnecessary maintenance interventions or unexpected failures that compromise safety and increase operational costs [2].

To address these limitations, predictive maintenance has emerged as a modern and intelligent approach for managing aircraft components. Predictive maintenance relies on continuous or periodic monitoring of the system's condition, analyzing measured parameters to forecast potential failures before they occur. In the case of propeller systems, the integration of vibration, acoustic, and performance data provides valuable insights into the mechanical and aerodynamic health of the system [1, 3]. Through advanced data acquisition and signal processing techniques, early signs of imbalance, bearing wear, or blade deformation can be detected long time before they become critical.

The implementation of predictive maintenance in aviation aligns with the broader concept of Condition-Based Maintenance (CBM), which aims to optimize the maintenance cycle based on actual system condition rather than fixed intervals. For propeller systems, condition monitoring can include vibration spectrum analysis, acoustic emission monitoring, and aerodynamic efficiency tracking. These parameters can be combined with machine learning or statistical models to predict the "Remaining Useful Life" of the component and to schedule maintenance actions proactively.

Overall, fault detection and predictive maintenance of aircraft propeller systems represent a significant advancement in the field of aviation engineering. The research and implementation of such approaches contribute not only to safety enhancement but also to cost efficiency and environmental sustainability. The development of reliable diagnostic methodologies and prognostic models will play a key role in the evolution of next generation aircraft maintenance practices.

Main Part

Research Methodology

The research methodology for studying fault detection and predictive maintenance of the aircraft propeller system is designed to systematically identify, analyze, and predict degradation mechanisms through data driven diagnostics. The study combines experimental measurements, analytical modeling, and data analysis to develop a reliable framework for condition monitoring and early fault prediction.

The primary objectives of this research are:

- To identify the most sensitive measurable parameters that reflect propeller health conditions;
- To develop a methodology for early fault detection using vibration and acoustic signal analysis;
- To design a predictive model capable of estimating the remaining useful life (RUL) of the propeller system;
- To propose a structured predictive maintenance framework applicable to general aviation and light aircraft propulsion systems.

Research Plan

The research will be conducted in five sequential phases:

- Phase I - Literature Review and Theoretical Modeling; Identification of research gaps and development of the diagnostic concept;
- Phase II - Experimental Setup and Calibration; Installation and configuration of sensors, validation of measurement accuracy;
- Phase III - Data Collection; Recording vibration, acoustic, and performance data under normal and simulated fault conditions;
- Phase IV - Data Analysis and Model Development; Feature extraction, fault classification, and development of predictive algorithms;
- Phase V - Validation and Evaluation; Comparing predicted outcomes with actual fault data, refining models, and formulating the predictive maintenance strategy.

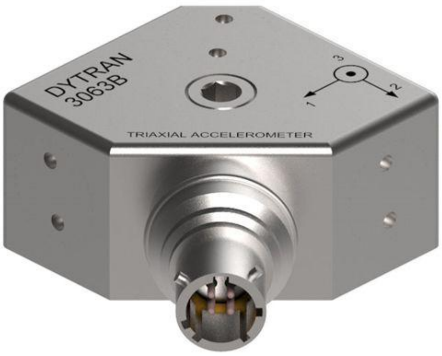
Sensors and Data Acquisition System

Effective fault detection and predictive maintenance of an aircraft propeller system depend on precise monitoring of its dynamic and structural parameters. Since the propeller operates under high mechanical and aerodynamic loads, reliable sensors are essential for detecting early-stage faults and performance degradation [4].

In this research, several types of sensors are considered to capture vibration, acoustic, torque, and temperature data. Accelerometers monitor structural vibrations and help identify imbalance, misalignment, or bearing defects. Acoustic and pressure sensors record sound variations caused by aerodynamic or structural anomalies. Torque and rotational speed sensors evaluate the system's mechanical performance, while temperature sensors track thermal behavior of critical components.

Integrating these sensors within a unified data acquisition system enables multi parameter monitoring and advanced analysis [7]. The resulting dataset supports the development of predictive algorithms, allowing early fault detection and optimized maintenance planning for safer and more efficient propeller operation.

1. Dytran - Triaxial Accelerometer *2. Endevco - High-Intensity Acoustic*
Microphone



3. Kistler - Rotating Torque Sensor *4. Type K Thermocouple – Temperature Sensor*

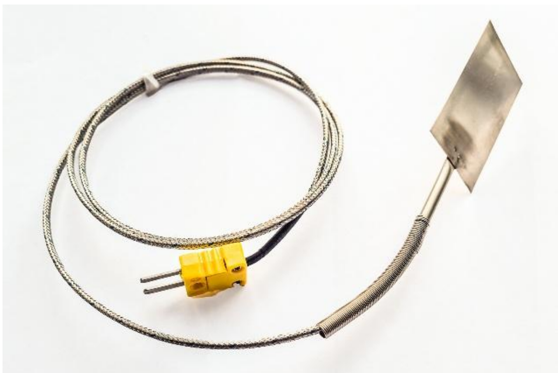


Fig. 1 Sensors and Data Acquisition System

A combination of accelerometers, microphones, torque sensors, and temperature sensors will be used to monitor aircraft propeller systems. These sensors capture vibration, acoustic emissions, mechanical load, and thermal behavior, providing the data necessary for early fault detection, condition monitoring, and predictive maintenance.

Conclusions

The study of fault detection and predictive maintenance for aircraft propeller systems highlights the importance of multi parameter monitoring to ensure safe and efficient operation. By integrating vibration, acoustic, torque, and temperature sensors into a unified data acquisition system, early-stage anomalies such as imbalance, blade defects, bearing wear, and performance degradation can be effectively identified [5, 6]. Signal processing and feature extraction provide the foundation for machine learning and predictive models, enabling estimation of Remaining Useful Life and optimized maintenance scheduling.

This approach not only enhances operational safety by reducing the likelihood of in-flight failures but also improves cost efficiency by minimizing unnecessary maintenance. The proposed framework demonstrates that a data-driven, sensor-based methodology is essential for modern propeller-driven aircraft, offering a practical path toward intelligent maintenance systems. Future work will focus on experimental validation and refinement of predictive algorithms to ensure robust performance under real operating conditions.

References:

1. Ozkat, E. C., et al. (2023). "A data-driven predictive maintenance model to estimate remaining useful life using vibration data collected from a multi-rotor UAS." *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*;
2. Al-Haddad, L. A., et al. (2024). "UAV propeller fault diagnosis using deep learning of non-traditional features." *Scientific Reports*;
3. Mitici, M., et al. (2023). "Dynamic predictive maintenance for multiple components using sensor data." *Computers in Industry*;
4. Lee, S. (2025). "Propeller fault-detection method for electric-propulsion aircraft using motor-electric signals." *Journal of Manufacturing Processes*;
5. Sonmezocak, T., et al. (2025). "Intelligent UAV health monitoring: Detecting propeller and motor faults using machine learning." *Aerospace Science and Technology*;
6. Shen, S. C., et al. (2025). "A real-time diagnostic system using a long short-term memory network for ship propeller fault detection." *Sensors*;
7. Javadnejad, F., et al. (2025). "Predictive maintenance in naval vessel propulsion systems for enhanced marine operations using a BiGMM-HMM framework with divergence-based clustering." *Journal of Marine Science and Engineering*.

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რეზიუმე: *ნაშრომში განხილულია საჰაერო ხრახნის სისტემის პროგნოზირებადი ტექნიკური მომსახურების მნიშვნელობა და მეთოდები. მთავარი აქცენტი გაკეთებულია კვლევის პროცესში საკვლევი პარამეტრების მრავალსენსორულ მონიტორინგზე, რომელიც მოიცავს ვიბრაციის, აკუსტიკური სიგნალების, მომენტისა და ტემპერატურის განსაზღვრას. აღნიშნული პარამეტრების რეგულარული აღრიცხვა და ანალიზი საშუალებას იძლევა წინასწარ გამოვლინდეს გაუმართაობის ნიშნები, როგორიცაა საჰაერო ხრახნის ბალანსის დარღვევა, ხრახნის დაზიანება, ლილვის დისბალანსი და სხვა.*

საკვანძო სიტყვები: *ავიაცია, საჰაერო ხრახნი, პროგნოზირებადი ტექნიკური მომსახურება.*