

Unified Aviation Weather Intelligence System

Mrs. Bhagyashri K Kulkarni¹, Disha S², Anjana R C³, D Mahesh⁴, Koushik N⁵

¹Assistant Professor, K S School of Engineering and Management

^{2,3,4,5} Student, K S School of Engineering and Management

Abstract—The aviation industry faces critical challenges due to unpredictable weather and turbulence, often resulting in flight delays, safety concerns, and increased operational costs. Traditional systems treat weather forecasting and route planning as separate entities, limiting their effectiveness. This project proposes a unified platform that integrates hyper-local weather monitoring, machine learning-based turbulence prediction, and real-time route optimization. By leveraging real-time data from flight tracking APIs and live weather feeds, the system provides actionable insights through intelligent automation and visualization dashboards tailored for airline operators and pilots. Machine learning models such as LSTM and Dijkstra's algorithm are employed to predict turbulence and suggest optimal routing, enhancing flight safety, fuel efficiency, and overall passenger comfort.

The solution is built using modern technologies including ReactJS, Python, FastAPI and Leaflet. This comprehensive approach aims to revolutionize aviation planning and risk management through intelligent, data-driven decision-making.

Keywords—Aviation, Turbulence, Weather, Safety

I. INTRODUCTION

The Unified Aviation Weather Intelligence System is designed to address critical challenges in aviation caused by unpredictable weather conditions and turbulence, which often lead to delays, safety risks, and inefficient routing. Existing systems typically handle weather forecasting and flight route optimization as separate processes, resulting in limited responsiveness and integration.

The project aims to build that gap by creating an intelligent, unified platform that combines real-time weather analysis, machine learning-based turbulence prediction, and dynamic route optimization. By leveraging live data from flight tracking APIs and weather feeds, the system generates actionable

insights to support better decision-making for pilots, airlines, and air traffic control centers. The platform is expected to enhance flight safety, minimize fuel consumption, improve scheduling efficiency, and boost overall passenger comfort throughout their journey in the flight.

Core components of the system include:

- Hyper local Weather Monitoring: Accessing live weather conditions along flight paths.
- Turbulence Prediction: Using ML models (such as LSTM) trained on historical flight and weather data to forecast turbulence zones.
- Route Optimization: Employing algorithms like Dijkstra's to compute the safest and most efficient paths.
- Visualization Dashboard: Presenting the data through intuitive dashboards using Leaflet and ReactJS for real-time operational awareness.

II. RELEVANT LITERATURE

A. AI in business aviation route optimization: Reducing fuel consumption and environmental impact

This paper focuses on utilizing Artificial Intelligence to improve the efficiency and sustainability of business aviation. The proposed system uses real-time flight data combined with machine learning algorithms for route optimization and predictive maintenance. It minimizes fuel consumption by calculating the most fuel-efficient flight paths while also tracking aircraft emissions to comply with environmental regulations. The integration of AI models allows for automated decision-making and operational adjustments based on changing atmospheric conditions.

B. Optimizing clear air turbulence forecasts using the k nearest neighbor algorithm

Used the K-Nearest Neighbor (KNN) algorithm to predict clear air turbulence by analyzing features like wind shear and temperature gradients. It improves accuracy by comparing current conditions with historical patterns demonstrates how AI can streamline legal research and enhance the effectiveness of judicial processes.

C. Research on dangerous flight weather prediction based on machine learning

This paper introduces a weather hazard classification system using Support Vector Machines experience (SVMs) with a radial basis function kernel. The model processes historical weather observations from various stations to classify and predict hazardous flight weather conditions, such as storms, icing and low visibility. By modeling nonlinear relationships in the data, it improves the early detection of threats. The model supports real-time alerts and contributions to safer navigation and flight planning.

D. Machine Learning based turbulence-risk prediction method for the safe operation of aircraft

This study proposes an ML-based framework for predicting turbulence risk and suggesting optimized flight paths. It incorporates meteorological input features such as wind speed, temperature gradients, and jet stream characteristics to forecast turbulence zones. Based on these predictions, the model uses path optimization algorithms to reroute flights in real-time, minimizing exposure to turbulence. It helps reduce pilot workload and rerouting stress while improving overall operational efficiency

III. SYSTEM DESIGN AND METHODOLOGY

The proposed solution employs a data concentric approach to enhance aviation safety and operational efficiency through real-time weather intelligence. Unlike conventional systems that treat weather forecasting, turbulence prediction, and route optimization as separate processes, this solution unifies them into a cohesive intelligent framework. The system integrates real-time weather data, machine learning-based turbulence prediction, and route optimization algorithms to generate actionable insights for pilots and airline operators. The

architecture is designed for modularity, scalability, and real-time performance, using ReactJS for the frontend, Python (FastAPI) for the backend.

A. Training Stage

Training phase establishes the system’s predictive intelligence, primarily focused on weather and turbulence forecasting.

It consists of five main steps:

1. Data Collection: Historical weather and turbulence data are gathered from meteorological databases, flight logs, and aviation weather APIs. These datasets include parameters such as wind speed, temperature, air pressure, and flight altitude.
2. Data Pre-processing and Cleaning: The collected datasets are refined by removing missing values, normalizing variables, and converting them into sequential time-series formats suitable for deep learning models..
3. Feature Engineering: Relevant weather and flight parameters are extracted and transformed into structured features to improve the learning accuracy of turbulence prediction models.
4. Model Training(LSTM): A Long Short-Term Memory (LSTM) neural network is trained on the pre-processed sequential data to capture temporal weather patterns and forecast potential turbulence zones.
5. Model Validation and Optimization: The trained LSTM model is evaluated against test datasets to ensure accuracy and reliability. Hyper parameters are fine-tuned for optimal turbulence prediction performance.

B. Definition Phase

It defines the operational workflow of Unified Aviation Weather Intelligence System, from live data input to user visualization and decision support.

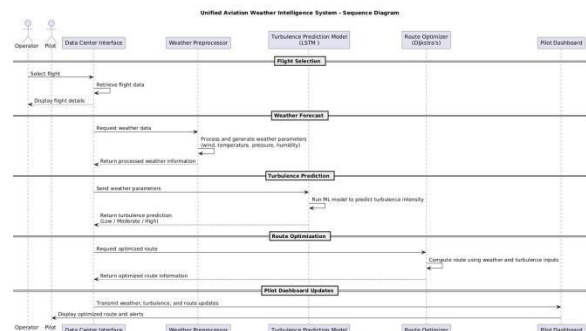


Fig 1. Sequence Diagram

1. Real-Time Data Integration: Live weather data is continuously fetched from reliable APIs to provide hyper-local atmospheric updates along the flight route.
2. Turbulence Prediction: The validated LSTM model analyzes real-time weather data to predict turbulence occurrences along potential flight paths.
3. Route Optimization (Dijkstra's Algorithm): The system models flight paths as weighted graphs where each segment's weight is determined by distance, fuel cost, and turbulence risk.
4. Visualization Dashboard: A ReactJS and Leaflet based interface displays live weather overlays, turbulence zones, and optimized flight paths on an interactive map for intuitive monitoring.
5. Decision Support System: The integrated dashboard provides actionable insights to pilots and airline operators, enabling data-driven decisions for flight planning, rerouting, and operational safety

IV. RESULT AND DISCUSSION

The Unified Aviation Weather Intelligence system successfully met its objectives. It integrates real-time weather monitoring, turbulence prediction, and route optimization into a single intelligent platform. The system accurately predicts turbulence using machine learning and suggests safer, fuel-efficient flight routes. It also provides a visual dashboard for pilots and operators to view live flight and weather data. Overall, the results show improved flight safety, operational efficiency, and environmental sustainability

V. CONCLUSION AND FUTURE WORK

The "Unified Aviation Weather Intelligence System" successfully integrates real-time weather monitoring, turbulence prediction, and route optimization into a single intelligent framework. By leveraging machine learning models such as LSTM for turbulence forecasting and Dijkstra's algorithm for optimal routing, the system enhances the operational safety. Through the combination of live weather APIs and visualization dashboards, it provides pilots and airline operators with actionable insights to make informed decisions during flights.

The future works includes incorporating advanced deep learning models such as CNN - LSTM or

transformer networks to improve turbulence and route prediction accuracy. Link the platform with flight simulators for testing decision support accuracy in real-time environments. Extend the system to support global flight networks with multiple altitude layers and regional weather zones.

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