

Agentic AI & Digital Twin for Aircraft Disappearance Prediction

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Abstract:

Aviation disasters involving missing aircraft present one of the most complex investigative challenges in modern aerospace science. The disappearance of Malaysia Airlines Flight MH370 in March 2014 remains unsolved despite extensive international search efforts. Traditional investigation frameworks depend on static satellite handshake records, manual radar analysis, and retrospective oceanographic studies, which are incapable of generating real-time predictive insights.

The proposed system, "Agentic AI & Digital Twin for Aircraft Disappearance Prediction," introduces an intelligent web-based platform that integrates Artificial Intelligence, Machine Learning, Digital Twin Technology, Monte Carlo flight path simulation, and interactive geographic visualization. The system employs a Logistic Regression classification model trained using Scikit-Learn to evaluate aircraft telemetry parameters and calculate real-time disappearance risk scores. A stochastic flight simulation engine generates hundreds of alternative trajectories from Kuala Lumpur International Airport (KLIA), constrained by Inmarsat satellite BTO ping arc data. An integrated oceanographic drift module simulates 300-day debris migration patterns using ocean current behavior.

The application is developed using Python and Flask, providing an interactive real-time dashboard. Features such as live flight simulation maps using Leaflet.js, AI risk analysis charts using Chart.js, probability prediction panels, search zone heatmaps, debris drift tracking, and flight timeline visualization improve investigation efficiency. The proposed system demonstrates effective application in aviation accident investigation, search and rescue operations, maritime debris tracking, and aerospace research.

Keywords: *Agentic AI, Digital Twin, MH370, Monte Carlo Simulation, Inmarsat Ping Arcs, Logistic Regression, Flask, Leaflet.js, Drift Modelling, Aircraft Disappearance Prediction.*

I. INTRODUCTION

Modern aviation systems generate massive amounts of telemetry data continuously through satellite communication, radar tracking, ATC transponders, and onboard sensors. When an aircraft disappears under unexplained conditions, investigators face the challenge of reconstructing flight paths, evaluating risk factors, and predicting possible crash locations across vast oceanic regions.

The disappearance of Malaysia Airlines Flight MH370 on March 8, 2014, exposed severe limitations in existing aviation investigation methodologies. Despite years of international search operations spanning millions of square kilometres of the Southern Indian Ocean, the aircraft's final resting location has not been conclusively determined. Traditional investigation approaches rely primarily on historical satellite handshake data, manual radar analysis, and static oceanographic models, making dynamic real-time analysis impossible.

To overcome these limitations, the project "Agentic AI & Digital Twin for Aircraft Disappearance Prediction" was developed as an intelligent aviation investigation platform. The system integrates machine learning-based risk prediction, stochastic flight path simulation, ocean drift modelling, and interactive geospatial visualization into a unified Flask-based web application. A Logistic Regression model processes telemetry variables including fuel status, airspeed, altitude, weather risk, and communication signal loss to compute disappearance probability scores. The Digital Twin simulation mirrors real-world oceanographic conditions to project debris drift over a 300-day window, directly supporting search-and-rescue planning.

The proposed solution improves investigation accuracy, reduces manual analysis effort, and provides intelligent decision support for aviation authorities, researchers, and search teams.

II. RELATED WORK

Aviation accident investigation and missing aircraft search operations have attracted significant research attention following high-profile incidents such as the disappearance of Malaysia Airlines Flight MH370. Investigators and researchers have proposed various analytical approaches to improve flight path reconstruction accuracy and search zone identification.

Traditional aviation investigation systems primarily relied on manual analysis of radar records, satellite communication data, and ocean current reports. These approaches were time-consuming and unable to evaluate multiple flight scenarios simultaneously, often resulting in inconclusive search outcomes.

With the advancement of machine learning, intelligent risk prediction techniques have been introduced. Logistic Regression, Support Vector Machine (SVM), and Random Forest algorithms have been applied to classify flight anomalies and predict aircraft disappearance probabilities by analyzing operational telemetry parameters. These models demonstrated improved prediction performance compared to conventional statistical methods.

Recent research has focused on Monte Carlo Simulation techniques for generating probabilistic flight path models. By executing hundreds of stochastic trajectory simulations, these methods help investigators evaluate a wide range of possible routes and narrow down high-probability search corridors. Integration with satellite ping arc constraint data, such as Inmarsat BTO records, further improves trajectory accuracy.

Several studies have also explored Digital Twin technology for aviation applications, creating virtual replicas of aircraft systems to simulate behavioral patterns under varying operational conditions. Ocean drift modelling using bounded random coordinate variation has been employed to estimate debris movement across ocean surfaces over extended time periods.

Despite these advancements, many existing systems remain fragmented and lack unified platforms capable of combining AI prediction, flight simulation, drift modelling, and interactive visualization into a single accessible application. The proposed Agentic AI & Digital Twin system addresses these gaps by integrating all components into a comprehensive web-based investigation platform.

III. SYSTEM OVERVIEW

This project, titled "Agentic AI & Digital Twin for Aircraft Disappearance Prediction," aims to design and develop a powerful, real-time, and user-friendly web application for automated aviation investigation and search zone prediction. The system is built using Python and Flask, integrating Machine Learning tools such as Logistic Regression (Scikit-Learn), Monte Carlo simulation engines, and oceanographic drift models to analyse aircraft telemetry and predict disappearance scenarios accurately.

In the modern aviation era, protecting air traffic integrity is critical for national security and global transportation safety. As more aircraft traverse international airspace without real-time monitoring, there is a growing need to extract meaningful insights from satellite records and flight telemetry data. This project addresses that need by providing a practical solution that is accurate, automated, and accessible to both technical investigators and non-technical search personnel.

The application allows users to:

- **Simulate Flight Paths:** Generate hundreds of possible trajectories using Monte Carlo stochastic simulation models constrained by Inmarsat satellite BTO ping arcs.
- **Predict Disappearance Risk:** Apply Logistic Regression machine learning to evaluate telemetry parameters and compute risk probability scores in real time.
- **Analyse Debris Drift:** Simulate 300-day ocean surface drift patterns from probable crash coordinates using bounded environmental models.
- **Visualize Search Zones:** Display predicted crash locations, debris drift paths, and search priority regions using interactive Leaflet.js geographic maps.

Once data is processed, results are presented through an interactive Flask dashboard featuring live maps, AI risk charts, probability panels, search zone heatmaps, and flight timeline visualization. This tool has applications across various domains such as:

- Aviation Accident Investigation
- Aircraft Search and Rescue Operations
- Ocean Debris Drift Prediction and Tracking
- Aerospace Research and Digital Twin Applications

The final output is a lightweight, open-source, web-based investigation platform that requires minimal setup to operate, making it an ideal solution for

aviation authorities, researchers, and investigative teams.



IV. MODULE DESCRIPTION

1. Data Collection & Loading Module

In this module, the primary objective is to collect and import MH370 flight datasets, radar records, satellite communication logs, and environmental data from CSV files. The module uses Pandas and NumPy libraries to handle large aviation datasets efficiently, organizing historical flight information into structured formats ready for preprocessing and analysis.

2. Flight Path Simulation Module

This module generates multiple possible MH370 flight trajectories using stochastic Monte Carlo simulation techniques. The simulation engine models long-range smooth route deviations originating from Kuala Lumpur International Airport (KLIA), executing 200 iterations to map coordinate degradation down to final potential crash points in the southern Indian Ocean corridor. Each trajectory is constrained by Inmarsat satellite BTO ping arc boundaries to improve realism.

3. Machine Learning Risk Prediction Module

In this module, advanced machine learning algorithms are employed to predict aircraft disappearance risk. A Logistic Regression model trained via Scikit-Learn analyses flight telemetry variables including fuel remaining, communication loss status, route deviation distance, weather risk level, altitude, and airspeed. The model outputs risk probability scores and classifies flight scenarios into High Risk, Medium Risk, and Safe categories.

4. Ocean Drift Analysis & Search Zone Module

This module simulates debris movement across the ocean surface using bounded random coordinate variation to model real-world current behaviour.

Over a 300-day simulation window, the drift model estimates probable debris accumulation zones from calculated crash coordinates. Combined with flight simulation outputs, the module identifies and prioritizes potential crash zones with confidence scores.

5. Geographic Visualization & Dashboard Module

The visualization module provides a real-time interactive Streamlit-style Flask dashboard for displaying all analytical results. The module renders interactive Leaflet.js maps with animated flight path markers, crash zone heatmaps, debris drift point clouds, and search priority circles. Chart.js powers AI risk analysis bar charts and probability prediction panels. Timeline visualization presents chronological MH370 communication events for investigator reference.

V. METHODOLOGY

The methodology of the Agentic AI & Digital Twin system consists of multiple stages including data ingestion, flight simulation, machine learning risk prediction, ocean drift modelling, geospatial visualization, and real-time dashboard delivery.

Initially, MH370 flight datasets are loaded from structured CSV files and validated to ensure data consistency. Aircraft telemetry parameters including fuel status, airspeed, altitude, route deviation, and communication signal integrity are extracted for feature engineering.

The flight simulation engine executes Monte Carlo stochastic path generation from KLIA across 200 iterations, applying random directional deltas within Inmarsat BTO arc constraints to model hundreds of possible final routes. Simultaneously, a Logistic Regression classifier analyses the telemetry feature vectors to output real-time disappearance probability scores and risk classifications.

Upon completing flight trajectory generation, crash point coordinates are passed into the ocean drift module, which applies bounded coordinate variations to simulate 300-day surface debris migration patterns. These outputs are visualised through the Flask dashboard using Leaflet.js interactive maps with animated aircraft markers, confidence-based search zone overlays in red, orange, and yellow priority circles, and Chart.js risk analysis visualisations.

Overall, the proposed methodology integrates aviation data science, stochastic simulation,

machine learning, and real-time geospatial visualization to provide an efficient and intelligent platform for aircraft disappearance prediction and search zone identification.

VI. REQUIREMENTS SPECIFICATION

Requirement Specification defines the hardware and software components needed for successful implementation. Proper requirement specification ensures system stability, performance, and efficient project development.

Software Requirements

Software requirements include the operating system, programming language, backend framework, machine learning libraries, mapping libraries, and visualization tools needed to implement the system.

Table 1 – Software Requirements

SOFTWARE COMPONENT	SPECIFICATION
Operating System	Windows 10/11 (64-bit)
Programming Language	Python 3.10+
Backend Framework	Flask
Frontend Technologies	HTML, CSS, JavaScript
Machine Learning Library	Scikit-Learn (Logistic Regression)
Mapping Library	Leaflet.js
Visualization Library	Chart.js
Data Manipulation	NumPy & Pandas
IDE	VS Code

Table 2 – Hardware Requirements

HARDWARE COMPONENT	SPECIFICATION
Processor	Intel Core i5 or higher
RAM	8 GB Minimum
Hard Disk	256 GB SSD
Internet Connection	High-speed Internet Required
Graphics Card	Integrated Graphics

VII. SYSTEM IMPLEMENTATION

System Implementation is the stage where the theoretical design is converted into a working software system. For the Agentic AI & Digital Twin project, the implementation phase focused on translating the aviation intelligence architecture into a fully functional Flask-based web application.

1. Environment Setup

Installed required libraries: Flask for the web interface; Pandas and NumPy for large-scale aviation data handling; Scikit-Learn for Logistic Regression risk prediction; Matplotlib and Plotly for interactive charts; Folium and Leaflet.js for geographic mapping; and JSON/GeoJSON libraries for spatial data processing. Developed in Python 3.x using VS Code as the primary IDE.

2. Module Development

Each functional module was implemented in Python independently before integration:

- **Flight Path Simulation:** Developed stochastic Monte Carlo path generation algorithms executing 200 simulation iterations from KLIA coordinates.
- **Risk Prediction:** Trained Logistic Regression classifier on MH370 telemetry dataset features including fuel, speed, altitude, weather, and signal loss parameters.
- **Ocean Drift Analysis:** Implemented bounded random coordinate delta modelling for 300-day debris surface drift simulation.
- **Alert System:** Created timeline module tracking chronological MH370 communication and radar events.

3. Flask Interface Integration

Created an interactive real-time dashboard using Flask and HTML templates with features including: live Leaflet.js map with animated aircraft marker and search zone overlays; AI risk analysis bar charts using Chart.js; probability prediction display panels; search zone analysis tables; and flight timeline visualization.

4. Testing & Debugging

Unit and integration testing were conducted for the simulation and risk prediction modules. Edge cases involving corrupted CSV data and extreme flight deviations were validated. Visual components were tested for responsiveness across different screen sizes.

5. Deployment

The application is deployed locally by running flask run or python app.py and is accessible via standard web browsers. The modular architecture supports future deployment on cloud platforms such as Heroku or AWS.

VIII. SAMPLE OUTPUT

The following figures illustrate the key output screens of the Agentic AI & Digital Twin system dashboard:



Fig. 1 – MH370 Agentic AI Digital Twin Dashboard Overview: displays live flight simulation map with animated aircraft marker, AI risk analysis panel showing Communication Failure 92%, Navigation Deviation 85%, Fuel Exhaustion 68%, and Final Risk Score 82%, with interactive Chart.js bar chart visualization.



Fig. 2 – Probability Prediction & Flight Timeline Panel: displays fuel remaining at 12%, communication loss status, route deviation of 250 km, weather risk level HIGH, disappearance probability of 87%, and chronological MH370 event timeline from takeoff at 00:41 to final satellite ping at 08:19.



Fig. 3 – Search Zone Analysis & Machine Learning Prediction Panel: displays primary search area coordinates at -35.12, 92.45 with 87% confidence score, ocean current at 2.1 m/s SW, debris drift of 120 km, predicted debris count of 12, search priority HIGH, and ML prediction of High Risk at 100% probability.

IX. CONCLUSIONS

The project "Agentic AI & Digital Twin for Aircraft Disappearance Prediction" has been successfully designed and developed as a robust, real-time solution for intelligent aviation investigation and search zone prediction. In an era where aviation safety and spectrum integrity are increasingly critical, this system provides a meaningful bridge between complex flight telemetry data and actionable investigative intelligence.

By integrating a Monte Carlo stochastic flight simulation engine with Inmarsat BTO satellite arc constraints, the system effectively models hundreds of possible aircraft trajectories and identifies high-probability crash corridors. The Logistic Regression machine learning classifier demonstrates reliable performance in analysing telemetry parameters including fuel depletion, communication loss, route deviation, and weather risk to output accurate disappearance probability scores.

The implementation of an interactive Flask dashboard equipped with Leaflet.js live maps, animated flight markers, confidence-based search zone overlays, Chart.js risk visualizations, and a 300-day ocean debris drift simulation ensures that complex aviation investigation data is accessible to both expert researchers and operational search teams.

Overall, the Agentic AI & Digital Twin system stands as a scalable, open-source, and efficient tool addressing modern challenges in aviation accident investigation, maritime search optimization, and aerospace intelligence. The project successfully meets all its initial objectives, delivering a high-performance investigative platform ready for

deployment in real-world aviation monitoring and search-and-rescue environments.

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