

Predictive Analytics for Turbulence Avoidance and Aircraft Fatigue Diagnostics

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ABSTRACT

Turbulence is by far the number one concern of anxious passengers and a cause for airline injuries. Apart from causing discomfort to passengers, it also results in unplanned downtime of aircrafts. Currently the Air Traffic Control (ATC) and the meteorological weather charts aid the pilot in devising flight paths that avoid turbulent regions. Even with such tailored flight paths, pilots report constant encounters with turbulence. The probability of turbulence avoidance can be increased by the use of predictive models on historical and transactional data. This paper proposes the use of predictive analytics on meteorological data over the geographical area where the aircraft is intended to fly. The weather predictions are then relayed to the cloud server which can be accessed by the aircraft planned to fly in the same region. Predictive algorithms that use Time series forecasting models are discussed and their comparative performance is documented. This paper further brings out the benefits of embedding additional sensors in the airframe, use of data storage techniques, data analytics and big-data in turbulence avoidance and extended benefits to airline MRO (Maintenance, Repair and Overhaul) to better manage lifecycle information of aircraft components.

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INTRODUCTION

Passenger safety and comfort has always been considered as one of the important aspects while designing an aircraft. However the bumpy rides caused by turbulence are considered inevitable resulting in 26.9 reportable incidents annually. Though turbulence is not regarded as one of the major cause for airline fatality, a blow up of the data reveals that there have been nearly 432 significant turbulence events reported across the globe during the last 15 years resulting in 225 serious and 1109 minor injuries to passengers and crew members [1].

The flight paths of the aircrafts are plotted beforehand to minimize encounters with turbulence. The meteorological weather charts and the Air Traffic Controller (ATC) provide the inputs to plan the flight path, though they don't seem to suffice the intent of ensuring absolute comfort and safety of passengers, due to the non-dynamic nature of the forecast. Fortunately, the recent advancements in the data acquisition, storage and processing techniques make it feasible to bridge this gap.

The paper discusses techniques through which the turbulent weather over an area of interest could be predicted with better accuracy to provide a safer and more comfortable flight path. Predictive analysis algorithms that use historical weather data, aircraft's on-board weather Radar returns and inputs from other aircrafts flying ahead in the same flight path, enable a more accurate prediction of turbulent regions. Calibrated MEMS accelerometer sensors strategically mounted on the fuselage measure the intensity of the turbulence, ruling out subjective

judgment of the same. The mounted sensors also keep track of the fatigue (stress and vibration) experienced by the critical components of the aircraft, helping airlines to better manage downtime.

PRESENT METHODS AIDING IN TURBULENCE AVOIDANCE

Currently pilots avoid turbulent regions with the help of Meteorological weather data charts, Pilot Reports(PIREPs) and the on board weather Radar all of which involve manual interpretation of raw data, which could be time consuming and subjective. Moreover, weather forecasts are not corrected for real time fluctuations in weather. The frequency in which the forecasts are updated for a given day is far lesser than the frequency of flights. Pilot reports for turbulence encounter is non-quantifiable in terms of severity of turbulence, and are consequently subject to inconsistencies in location and intensity. Decisions taken on the Radar returns vary depending on flight crew's interpretation of the Radar image, which is in turn dependent on their experience and knowledge of the weather Radar's limitations. The current scenario makes it evident that a more effective and efficient method for turbulence avoidance needs to be in place which would provide comparatively more accurate predictions.

PROPOSED TECHNIQUE

The proposed system collects data from the on-board weather Radars, accelerometer sensors, GPS and navigation systems. The data is then transmitted to ground stations through Aircraft Communications Addressing and Reporting System (ACARS) Document Sharing Hub

The data from these sources are used to update the meteorological weather charts which act as an input to calculate EDR (Eddy Dissipation Rate) values. EDR acts as a measure to quantify the degree of turbulence. Time series models are applied on the historical and transactional EDR data to improve the future EDR predictions for a given geographical location. Figure 1 illustrates the overview of the proposed solution.

The predicted EDR values are relayed to the aircrafts planned to fly in the same region and is rendered on the Multi-Function Display (MFD).

The proposed system can be broadly divided into the following subsystem/functional blocks:

- I. Data Acquisition
- II. Data Storage
- III. Data Processing

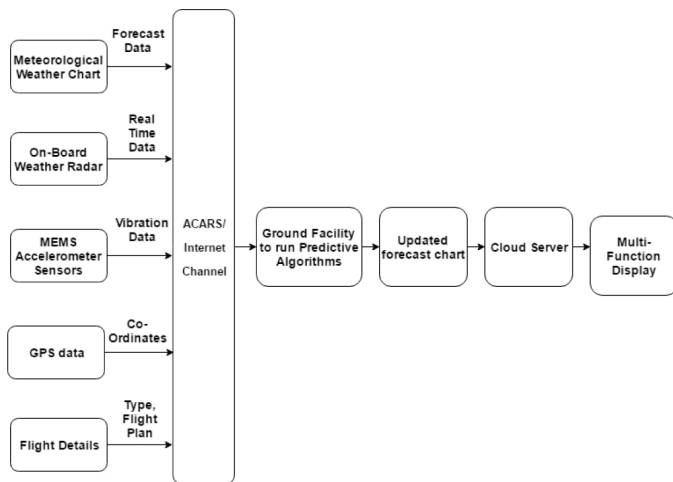


Figure 1. Overview of the system.

Data Acquisition

The proposed system uses the following data as inputs for the predictive algorithms:

- I. Forecast weather chart from Meteorological Department.
- II. Real-time weather from the on-board weather Radars.
- III. Vertical G-forces acting on the airframe from the MEMS accelerometer sensors.
- IV. Current position of aircraft from the GPS and navigational sensors.
- V. Flight details and flight plan from ATC/dispatchers.

The vertical G-forces acting on the airframe during turbulence is one of the critical data to analyze the severity of the turbulence experienced by the aircraft. This data can also be coupled along with GPS and navigational system outputs to know the exact start and end location of the turbulent region. The advancement of MEMS (Micro-Electro Mechanical System) accelerometers sensors now allows us to measure high G-forces in all three axes. Added advantages of these sensors are their small size and low weight (typically in milligrams) [2]. These sensors are installed across the critical points on the airframe such as

wings sections of fuselage and undercarriage which experience the maximum amount of stress. Accurate real time weather data is obtained from in-flight weather Radars.

Figure 2 explains the mechanism followed during data acquisition. Before the aircraft takes off the system performs health check on all the sensors to ensure at least 90% of the sensors are functional in order to ensure that the data received from the sensors are valid. The list of faulty sensors is logged into the flight computer for maintenance purpose. Since the vibration of airframe is typically high during the take-off and landing phase, the system monitors the sensor output only during the cruise phase where any vibration in airframe will be due to turbulence. Once the flight is in cruise phase, the system starts collecting the vertical g-forces from the sensor. This data along with GPS coordinates are relayed to ground station.

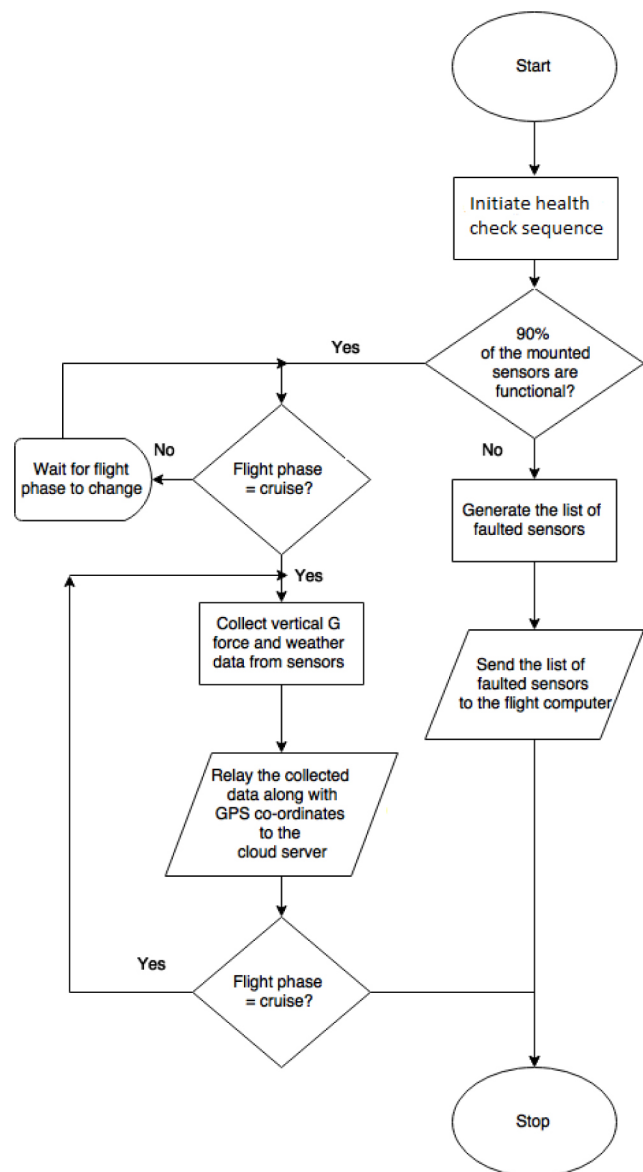


Figure 2. Flowchart for on-board data acquisition.

Information from the sensors can be relayed to ground station at different rates depending on whether the aircraft is experiencing turbulence or not. When the aircraft is in turbulent region the system

samples data at the rate of 10 kHz and transmits it. The system switches automatically to a lower sampling rate (1 KHz) when not experiencing turbulence.

The data collected by the accelerometer sensors in the aircraft gives a measure of the intensity of turbulence it experiences. It could also be used to diagnose the fatigue experienced by different components of the aircraft, so as to avoid unplanned downtimes.

Data Storage

Let's take an example to perform a rough evaluation of the data generated by the sensors mounted on the aircraft over a typical 6 hour trans-Atlantic flight:

Considering that an aircraft will contain roughly 1000 MEMS sensors spread over the entire airframe and each sensor transmits the g-force experienced over 3 axes with a resolution of 16 bits.

Assuming 30 minutes of turbulent period over a 6 hour flight with a sampling rate of 10 kHz,
 No. of sensors = 1000
 Resolution per axis = 16 bits

No. of axes = 3

Data generated per sensor per second = $48 \times 10k$

Total data generated during the turbulent period =
 $48 \times 10k \times 1000 \times 30 \times 60 \text{ bits} = 100.58 \text{ GB}$

Total data generated during the normal flight of 5.5 hours with sampling rate of 1 kHz = $48 \times 1k \times 1000 \times 330 \times 60 \text{ bits} = 110.64 \text{ GB}$

Thus the total data generated by the MEMS sensors is approximately 210 GB.

With 87,000 flights in the skies in the United States on any given day, the total data generated comes up to 17.42 Petabytes.

It is impractical to store this humungous amount of data on a conventional storage device. The amount of data generated enforces the use of "big data storage techniques".

The proposed system uses Scale-Out NAS storage architecture to store the input data [3]. Scale-out storage systems are typically made up of individual storage components called "nodes". These nodes contain capacity, processing power and storage I/O bandwidth. As a node is added to the storage system the aggregate of each of these three resources in the system is upgraded simultaneously. These nodes are interconnected via a high speed backplane or network that enables them to communicate with each other. System software enables these nodes to be interconnected and referenced as a single object by the storage administrators and connecting servers, essentially making the nodes into a single cluster or grid.

Big data offers additional advantages over conventional storage techniques. A few of them are cited below:

- Recovery - In the event of catastrophic data loss, backups can be used to restore the original files.
- Collaboration - Cloud storage services are ideal for collaboration purposes hence allowing multiple sources to update the weather data.
- Protection - Cloud storage offers protection for critical data such as aircraft information since the access could be easily controlled.
- Syncing - Automatic update of weather data across different regions is ensured by syncing. As a result of that, aircrafts can always have access to the updated data.

Data Processing

Once the data from the aircraft is received on the ground station, pattern recognition algorithms are used to determine whether the aircraft has been through a turbulent region and if so, the data is logged into a cloud server to improve the accuracy of future predictions. Next, predictive analysis algorithms are applied on the data to determine the weather patterns in the region at a later point in time for a scheduled aircraft. The weather predictions are then relayed to the cloud server so that it could be accessed by the aircraft planned to fly in the same region.

The same data is also used to compute the fatigue experienced by each component and determine whether any components need replacement when the flight lands at the next airport.

Figure 3 illustrates the steps involved in data processing.

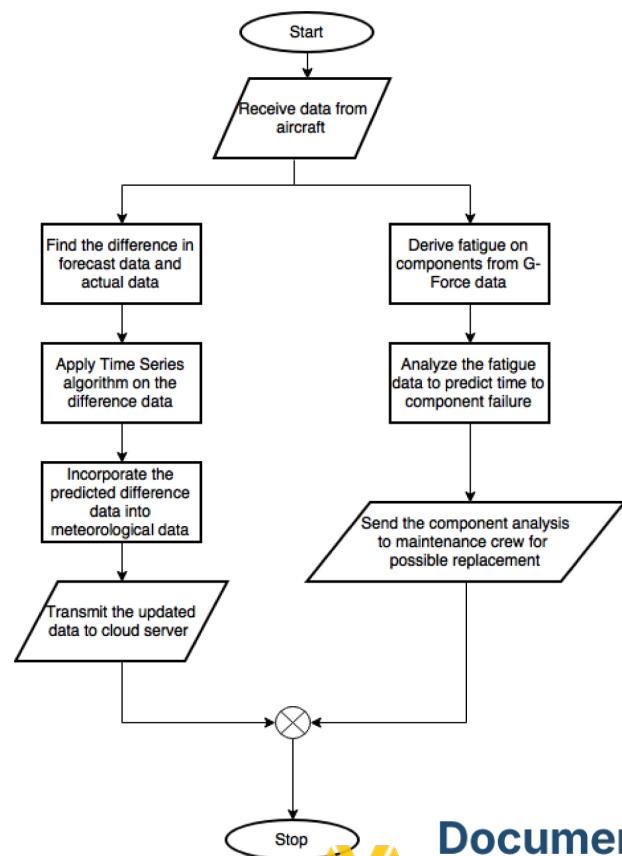


Figure 3. Flowchart for predictive weather and fatigue analysis