International Journal of Technology Engineering Arts Mathematics Science
Vol. 5, No. 1, June2025, pp. 01~05
ISSN: 2582-1224,

Analyzing and Interpreting Flight Data: A Mathematical Approach using Time Series

Aryan Hedaoo[1], Prof. Shirish Kulkarni[2], [3]Susmitha Chikateri

School of Engineering, Ajeenkya Dy Patil University, Pune, Maharashtra, India
Corresponding Author: [1]Aryan Hedaoo (aryan.hedaoo@adypu.edu.in),

Article Information

Article history:

Received Jun x, 20xx
Revised Nov x, 20xx
Accepted Dec x, 20xx

International Journal of TEAMS

ABSTRACT

This research examines the importance of integrating flight test operations and data analysis into aerospace engineering education. A cost-effective approach utilizing virtual flight tests and analysis of existing flight data is proposed. By developing expertise in real flight data analysis, students can become proficient in conducting flight tests and analyzing flight data. The research demonstrates the effective refinement of stability and control characteristics in a civilian aircraft using advanced control systems and an indirect control approach, providing valuable recommendations for future flying laboratory experiments.

KEYWORDS: Flight, Flight testing, Flight data analysis, Virtual flight, Flight control system

1. INTRODUCTION

This research paper explores a flying laboratory project that provides students with a practical learning experience in aviation research and education. The project equips an aircraft with measuring equipment and control systems, allowing students to conduct experiments and collect real-time data during flights. The focus is on time series analysis, analyzing temporal patterns and trends in the data. Additionally, data recorded during virtual flights is analyzed to evaluate the aircraft's performance. The distribution of data during flight tests is also examined to identify any anomalies or patterns. Overall, this project offers students an opportunity to actively participate in aviation research and develop their skills in control systems for light and commuter aircraft.

1.1. TIME SERIES

Time series analysis is a valuable approach for studying sequential data. It provides an accurate representation of the structure of sequential data by identifying homogeneous segments within the sequence. This segmentation process involves determining if a sequence can be described as a concatenation of subsequences that exhibit some level of homogeneity. This concept is like clustering in unordered data analysis.

A dynamic programming algorithm is commonly used for time series segmentation. This algorithm involves creating a table, M, to store the costs associated with different segmentations. The algorithm iterates through the sequence, calculating the optimal cost for each possible segmentation. The algorithm starts with the assumption that each data point is in its own cluster and gradually merges segments to minimize the overall error. The representative value, is assigned to each segment, serving as a summary of that segment. As mentioned in Eq. 5.

To recover the actual segmentation, the algorithm also stores the minimizing values i' that indicate the optimal split points. This allows for the reconstruction of the segmented sequence. This algorithm has a computational time complexity of O(n^2k), meaning it scales quadratically with the length of the sequence and the number of segments. The space complexity is O(kn), which is proportional to the number of segments and the length of the sequence.

2.FIGURES AND EQUATIONS

2.1. FIGURES

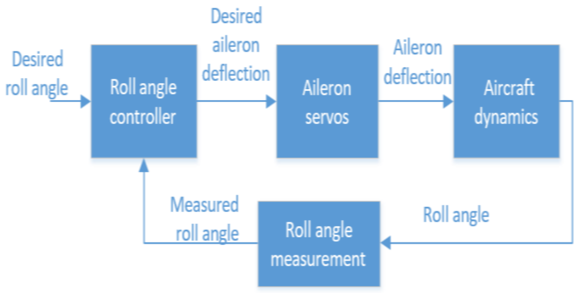

Fig. 1. A Simplified Lateral Control System

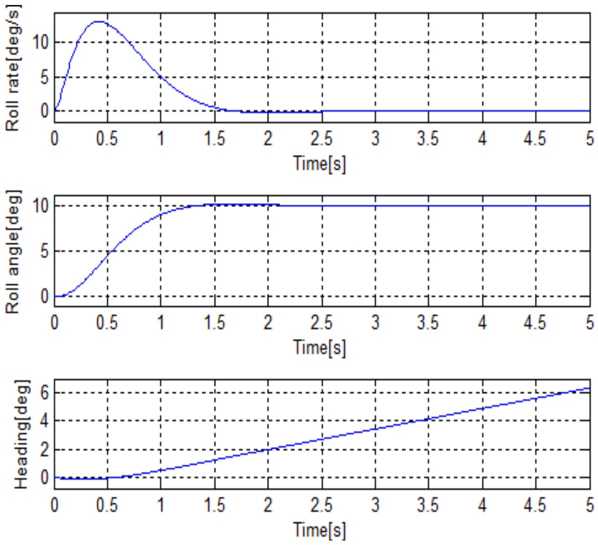

Fig. 2. Flight parameters derived from virtual flight, portraying the aircraft's yaw and roll behavior.

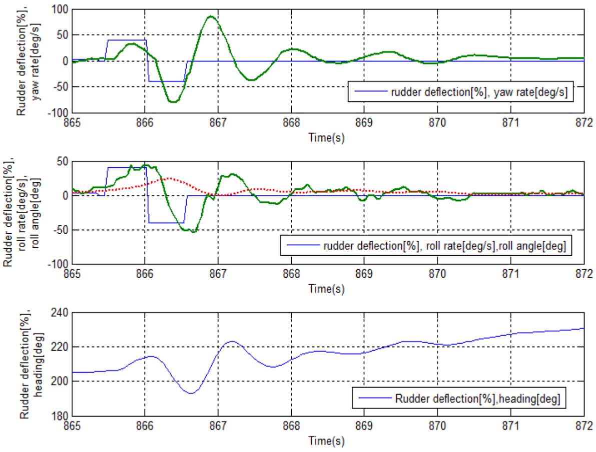

Fig. 3. Statistical distribution of flight test results

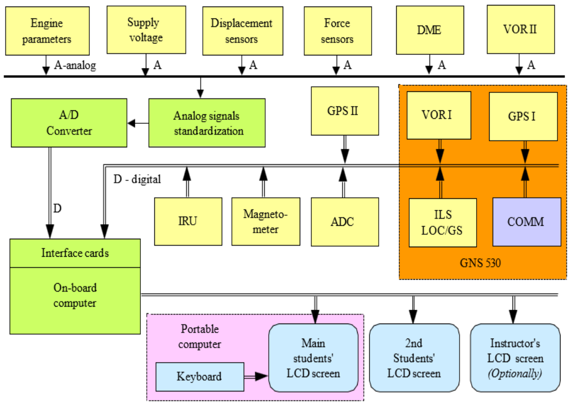

Fig. 4. Block diagram of the airborne data acquisition system
(Note: Stage I)

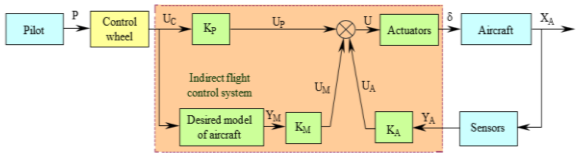

Fig. 5. Block diagram of model-following control architecture

Fig. 6. The six-seat PZL M20 'Mewa' civilian airplane (on the left) is utilized as a flying testbed, whereas the PZL M28 'Skytruck' commuter aircraft is employed as a modeled reference.

2.2. EQUATIONS

$$\dot{X}_1 = A_1 X_1 + B_1 \delta_1;\ X_1 = \left[u,\ w,\ q,\ \vartheta\right]^T;\ \delta_1 = \left[T,\ \delta_E\right]^T \quad (1)$$

$$\dot{\boldsymbol{X}}_2 = \boldsymbol{A}_2 \boldsymbol{X}_2 + \boldsymbol{B}_2 \boldsymbol{\delta}_2;\ \boldsymbol{X}_2 = \left[v,\ p,\ r,\ \varphi,\ \psi\right]^T;\ \boldsymbol{\delta}_2 = \left[\delta_{AI},\ \delta_R\right]^{\mathrm{T}} \quad (2)$$

Properties of engine (G_E) and actuators (G_{Ai}) will be described by the following transfer functions:

$$G_E(s) = \frac{T(s)}{\delta_T(s)} = \frac{100}{T_T s + 1};$$
$$G_{Ai}(s) = \frac{\delta_i(s)}{u_i(s)} = \frac{\omega^2}{s^2 + 2d_i\omega_i s + \omega_i^2}; \quad i = E, T, A, R \quad (3)$$

A controller that stabilizes aircraft's attitude will be selected on the basis of separation of longitudinal and lateral motion. If we augment the state vector with states describing engine and actuators, the flight control system will be described by the following extended equations:

$$\dot{\boldsymbol{Z}}_1 = \boldsymbol{A}_1^* \cdot \boldsymbol{Z}_1 + \boldsymbol{B}_1^* \cdot \boldsymbol{U}_1; \quad \boldsymbol{U}_1 = \left[\mathrm{u_E},\ \ \mathrm{u_T}\right]^{\mathrm{T}};$$
$$\boldsymbol{Y}_1 = \boldsymbol{C}_1^* \cdot \boldsymbol{Z}_1; \quad \dot{\boldsymbol{Z}}_2 = \boldsymbol{A}_2^* \cdot \boldsymbol{Z}_2 + \boldsymbol{B}_2^* \cdot \boldsymbol{U}_2; \quad (4)$$
$$\boldsymbol{U}_2 = \left[\mathrm{u_{AI}},\ \ \mathrm{u_R}\right]^{\mathrm{T}}; \quad \boldsymbol{Y}_2 = \boldsymbol{C}_2^* \cdot \boldsymbol{Z}_2$$

- Sequence T, length n, k segments, cost function E(), table M
- For i=1 to n
  - Set M[1,i]=E(T[1…i]) //Everything in one cluster
- For j=1 to k
  - Set M[j,j] = 0 //each point in its own cluster
- For j=2 to k
  - For i=j+1 to n
    - Set M[j,i] = $\min_{i'<i}$ {M[j-1,i]+E(T[i'+1…i])}

(5)

3. ANALYSIS OF DATA RECORDED DURING VIRTUAL FLIGHTS

In the initial stages of education, students often struggle with interpreting diagrams that depict basic flight parameters and understanding data relationships. To address this challenge, students begin by interpreting flight parameters obtained from Virtual testing. Key performance indicators are extracted from characteristic flight maneuvers facilitated by flight control systems. This process enables students to hone their data interpretation skills while gaining a deeper understanding of flight control system functionality. They dissect the architecture of control algorithms and generate performance plots for various flight parameters. A typical assignment involves regulating the roll angle, as exemplified in Fig. 1, which illustrates a Simplified Lateral Control System. Aircraft dynamics are modeled using a linearized aircraft model, with servos initiating aileron deflection based on input data from the roll angle controller. The desired roll angle is compared to the actual roll angle. Fig 2 presents a representative set of parameters obtained from simulated flights, revealing data interdependencies. For instance, during a standard turning maneuver, the roll angle exhibits a correlation with heading and yaw rate, as evident in Fig. 2. These interdependencies become apparent through diagram analysis. However, simulated flights have limitations, as real-world data is susceptible to Instrumental error, disturbances, and system failures. Therefore, the subsequent step involves analyzing data recorded during actual flights to account for these factors.

The evaluation of flight data from past flight operations serves as a valuable method for teaching students how to analyze flight data. This approach allows students to engage in offline analysis, starting with selected data for specific maneuvers. However, due to time constraints in university courses, the implementation of this method often occurs across multiple programs. As an illustration, students are supplied with multiple datasets from previous flight operations and asked to produce relevant graphical representations. They are then assigned tasks, such as identifying specific parameters, which helps them gain initial insight into real data analysis.

Once students have acquired these skills, they can proceed to analyze the entire flight, learning to recognize distinct flight phases that require more detailed analysis. This educational process prepares students to analyze flight data effectively, which can be beneficial for aircraft operators and investigations into aviation accidents after graduation.

Fig. 3 illustrates a sample statistical distribution of flight test results. By analyzing the data distribution diagram, students can verify the precision of the recorded data through comparative analysis of roll rate, roll angle, and acceleration. Furthermore, they can derive critical parameters governing the aircraft's dutch roll dynamics, including damping ratio, period, and frequency of oscillation.

4. MAIN PROJECT ASSUMPTIONS FOR FLYING LABORATORY

The proposed project is structured into three distinct phases. Initially, the aircraft will be outfitted with specialized instrumentation and a computational platform to collect, analyze, and visualize data. Participating students will have the opportunity to oversee the experiment live, exert control over its parameters, and conduct in-depth post-flight analyses. This hands-on approach enables students to conduct experimental trials during actual flight conditions.

In the next phase, a computerized avionics system will be integrated into the flying laboratory. This advanced system allows for the manipulation of key design and regulatory variables to assess their effect on the performance and stability of automated flight control

In the third phase, an adaptive control system will be implemented, enabling adjustments to the aircraft's responsiveness and maneuverability. This transforms the airborne laboratory into a versatile in-flight simulation platform. An instructor will be able to command the aircraft using a supplementary control console and side-mounted joystick, with a redundant mechanical system providing an added layer of safety.

The airborne research platform will be outfitted with an array of cutting-edge instruments, including sensing devices, navigation aids, and an onboard processing unit to synchronize all system components. Key subsystems comprise an inertial measurement unit, atmospheric data processor, satellite-based positioning system, precision approach guidance system, radio frequency navigation aid, range-finding equipment, load and displacement transducers, flight control computer, electromechanical actuators, and a data acquisition and storage system.

During flight data will be conveyed to the onboard computer via analog or digital signals, archived in a mass storage device, and displayed on LCD monitors for crew reference. Students can participate directly in the experiment by observing real-time flight parameters through different presentation formats such as classic flight instruments, EFIS-like presentation, head-up display, or engineering data graphs.

The flying laboratory will support student education in areas like aerodynamic principles, flight behavior, aircraft capabilities, dynamic stability, onboard avionics, navigation tools, control mechanisms, and flight-testing procedures. It will also allow students to test their own instruments and systems as part of their coursework or projects. Furthermore, it will enable the assessment of upgraded autopilot systems and function as a testbed for evaluating regulation systems on commuter and civilian airplanes.

5. MODEL FOLLOWING REGULATION SYSTEM

The airborne research platform will utilize fly-by-wire (FBW) technology to evaluate the flight characteristics of airplane. Implementing FBW, regulation system can be modified to shape the handling qualities of the airplane. Although this approach is employed in airborne technology development for decades, its application in aeronautical academic curriculum has been limited. Insights gained from designing fly-by-wire systems for small aircraft will inform the development of the experimental control system.

The ideal controller characteristics were determined using an advanced simulation technique, which involves a tailored approach based on virtual flight tests. This method enables the precise tuning of flight control system properties to match the desired behavior of the aircraft, resulting in predictable and desirable flying qualities. By selecting different target aircraft models, researchers can evaluate and refine new control strategies for small and commuter aircraft.

To define the optimal characteristics of the enhanced aircraft, a model-reference control architecture has been adopted. This established design approach is widely recognized in the field of control engineering and has been successfully applied in various applications. A customized variant of this method, previously documented in earlier research, is utilized in this project. By employing this technique, the dynamic behavior and flying qualities of the flight test vehicle can be precisely tailored, providing a valuable learning tool from a pedagogical standpoint.

The aircraft's dynamic model and control gains are optimized based on the chosen control strategy and flight regime. To ensure seamless collaboration between pilot and the control system, the fundamental system architecture illustrated in Fig. 4. should be augmented with advanced features, including fault detection, supervision, and alert systems. Assuming a constant airspeed U_0, the aircraft's motion can be modelled using a linearized approach, separating the dynamics into longitudinal (state vectors X_1) and lateral (X_2) components:
Explanation of this is scientifically proven with reference to Eq. [1,4]

6. CONCLUSION

The time series analysis provides a powerful tool for understanding and analyzing sequential data. By identifying homogeneous segments and quantifying their representative values, researchers can distill valuable knowledge from the data, exposing the latent patterns, relationships, and organization that underpin the observed phenomena. In conclusion, proposed flying laboratory project offers a unique opportunity for students to actively participate in aviation research and education. By equipping the aircraft with measuring equipment, a computer system, and various control systems, students can control experiments, monitor real-time data during flights, and analyze detailed information post-flight. The integration of FBW technology enables the customization of the regulation system and the tailoring of the aircraft's flight characteristics, effectively converting the airborne research platform into a dynamic in-flight training platform. The application of model-reference techniques and the careful selection of control system architectures further amplify the project's educational benefits. Ultimately, the flying laboratory provides a unique and valuable resource for students to learn, test, and evaluate control systems in a real-world setting, with relevance to small and commuter aircraft.

REFERENCES

[1] "Time series data analysis" by Deepak Tomar Published 2006

[2] The flying laboratory for aeronautics students' education by *Andrzej Tomczyk* Aircraft Engineering and

Aerospace Technology: An International Journal [Volume 82 . Number 5] 2010 - 320-330
[3] Flight tests and flight data analysis—Teaching aerospace engineering students by *Grzegorz Kopecki Global (2016) Journal of Information Technology: Emerging Technologies. 6*(2), 136–142.
[4] "Time Series Analysis Methods and Applications for Flight Data" by Jianye Zhang and Peng Zhang
[5] "Anomaly Detection in Time Series Flight Parameter Data Using Machine Learning Approach" by Shama Shilpi and Shwetank Aryan
[6] "Big Data Analysis by Classification Algorithm Using Flight Data Set" by Ujjwala Urkude
[7] "Pattern Recognition for Time Series Forecasting: A Case Study of a Helicopter's Flight Dynamics" by Jianye Zhang and Peng Zhang
[8] "Risk Management by Trend Analysis of Flight Information" by Jianye Zhang and Peng Zhang