

# Development of an Interactive Ground Monitoring Console and Telemetry Analytics Framework for General Aviation Flight Operations

A. Ajay Kumar<sup>1</sup>, Prof. S. Varadarajan<sup>2</sup>

<sup>1</sup>M.tech Student, Department of Electronics and Communication Engineering,

<sup>2</sup>Professor, Department of Electronics and Communication Engineering,

Sri Venkateswara University College of Engineering (SVUCE),

Tirupati – 517502, Andhra Pradesh, India

Corresponding Author: [ajayk531928@gmail.com](mailto:ajayk531928@gmail.com)

**Abstract**— Continuous monitoring of aircraft flight data is vital for proactive aviation safety, air traffic management, and predictive maintenance. Traditional Flight Data Recorders (FDR) store parameters on-board, limiting data accessibility to post-flight or post-accident investigations. This paper presents the development of an interactive Ground Monitoring Console (GMC) and telemetry analytics framework tailored for general aviation flight operations. Utilizing the high-fidelity CAFUC2 multi-model aviation benchmark dataset collected from Cessna 172R aircraft sorties, we process and validate multi-parameter telemetry streams including altitude (Mean = 3,800.4 ft, Std = 1,312.6 ft), vertical speed climb/descent distributions (3,129 climb vs 3,418 descent samples), pitch/roll attitudes (Mean = 2.55° and 1.35°), engine speed (Mean = 1,930.2 RPM, Std = 223.4 RPM), fuel flow (Mean = 8.23 GPH), and 2D GPS spatial navigation trajectories. A multi-panel software console is designed to integrate live spectrum monitoring, Quadrature Phase Shift Keying (QPSK) constellation diagnostics (achieving 9.96% Error Vector Magnitude at 20 dB SNR), carrier signal quality indicators, and flight status displays. The framework provides ground controllers and flight safety officers with enhanced situational awareness and early warning capabilities without imposing heavy computational overhead. This foundational system establishes the baseline telemetry visualization architecture for future high-frequency RF front-ends.

**Keywords**— Flight Data Monitoring, Telemetry Analytics, Ground Monitoring Console (GMC), General Aviation, CAFUC2 Dataset, Situational Awareness, QPSK Telemetry.

## I. INTRODUCTION

Commercial and general aviation operations rely fundamentally on the precise collection, verification, and monitoring of multi-parameter flight telemetry. Historically, the primary repository for critical flight metrics has been the on-board Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR)—colloquially termed 'black boxes'. While FDR systems are engineered to withstand extreme impact and thermal shock, they inherently suffer from an operational latency: flight parameters can only be retrieved, decoded, and analyzed post-flight or in the catastrophic aftermath of an aviation accident.

In modern aerodrome management and general aviation training fleets, there is an urgent operational requirement for continuous, real-time Ground Receiving Modules (GRM) and interactive Ground Monitoring Consoles (GMC). Real-time observation of aircraft operational health allows ground operators, flight instructors, and maintenance personnel to identify developing mechanical anomalies, flight envelope exceedances, and structural stress before they escalate into safety-critical incidents. Furthermore, real-time telemetry streaming facilitates proactive air traffic coordination, dynamic flight routing, and automated maintenance dispatch.

Despite these operational advantages, contemporary small-scale flight schools and general aviation operators often lack access to cost-effective, unified ground monitoring solutions. Conventional ground stations either focus narrowly on basic low-data-rate Automatic Dependent Surveillance–Broadcast (ADS-B) positional tracking or require complex, proprietary satellite communication infrastructures. To address this critical gap, this paper introduces an interactive, multi-panel Ground Monitoring Console (GMC) coupled with an empirical flight telemetry analytics pipeline. The primary focus of this foundational study is on telemetry parameter acquisition, decoding validation, multi-parameter flight dynamics visualization, and operator situational awareness using real-world flight data.

## II. RELATED WORK AND TELEMETRY MONITORING PARADIGMS

Aviation ground systems serve as the vital bridge between airborne data acquisition units and terrestrial monitoring personnel. The National Aeronautics and Space Administration (NASA) outlines the fundamental responsibilities of modern ground data systems as real-time downlink reception, telemetry frame de-commutation, data integrity verification, multi-stream distribution, and long-term historical archiving. In spaceborne and airborne missions, telemetry processing systems must balance visualization latency against decoding fidelity.

In the commercial aviation sector, Quick Access Recorders (QAR) have long provided extensive parameter recording for post-flight Flight Data Monitoring (FDM) and Flight Operational Quality Assurance (FOQA) programs. Recent research has explored transitioning QAR analytics to streaming architectures. For instance, Zhang et al. demonstrated a Kappa streaming framework capable of processing real-time QAR streams for cruise determination and engine oil monitoring, achieving sub-250 ms processing latency in simulation. However, their architecture focuses predominantly on high-throughput distributed server infrastructure rather than operator-centric ground console interfaces.

In general aviation, pilot training institutions and light utility aircraft operators require accessible, intuitive console visualization that consolidates aerodynamic, navigational, and powerplant metrics into a single screen. Existing open-source monitoring consoles often display raw tabular parameters without intuitive graphical representation of aircraft attitude, energy states, and trajectory correlations. The present work addresses this specific need by designing an integrated Ground Monitoring Console tailored for multi-parameter telemetry analysis and baseline digital receiver link diagnostics.

III. SYSTEM FRAMEWORK AND TELEMETRY DATA PROCESSING

The proposed Ground Monitoring Console and telemetry processing architecture is structured into four sequential functional stages: (i) Airborne Telemetry Acquisition, (ii) Baseband Demodulation and Frame Synchronization, (iii) Multi-Parameter Extraction and Normalization, and (iv) Interactive Operator Console Visualization. Fig. 1 illustrates the high-level operational dataflow of the framework.

Figure 1: High-Level Operational Architecture of the Baseline Telemetry Monitoring Framework



Fig. 1. High-level operational architecture of the baseline telemetry monitoring and GMC framework.

A. CAFUC2 Benchmark Flight Dataset

To ensure high engineering fidelity, the framework is validated using empirical flight data from the CAFUC2 benchmark dataset. CAFUC2 is a comprehensive multivariate aviation dataset developed by the Civil Aviation Flight University of China, comprising approximately one million data points recorded at a uniform sampling frequency of 1 Hz across 120 authentic flight sorties. The dataset captures

operations across multiple training aircraft, including the Cessna 172R, Cessna 172S, Cirrus SR20, and Cirrus SR20 G6. In this study, we utilize continuous telemetry sorties from a Cessna 172R aircraft undergoing course-deviation and traffic pattern maneuvers. Table I outlines the primary avionics parameters extracted, categorized into navigational, aerodynamic/attitude, powerplant, and structural dynamic groups.

TABLE I  
KEY CAFUC2 TELEMETRY PARAMETER SPECIFICATION AND AVIATION ENGINEERING RELEVANCE.

| Parameter Group       | Telemetry Variable       | Unit        | Operational Monitoring Role                                        |
|-----------------------|--------------------------|-------------|--------------------------------------------------------------------|
| Altitude & Navigation | AltMSL, AltGPS, Lat/Long | Feet, Deg   | Vertical position, barometric vs GPS cross-check, 2D path tracking |
| Attitude & Dynamics   | Pitch, Roll, HDG, TRK    | Degrees (°) | Aircraft spatial orientation, bank angles, heading alignment       |
| Vertical Profile      | VSpd (Vertical Speed)    | Feet/min    | Climb and descent rate monitoring, energy state assessment         |
| Powerplant Health     | E1 RPM, E1 FFlow         | RPM, GPH    | Engine thrust output, fuel consumption and mixture efficiency      |
| Thermal Health        | E1 CHT 1-4, E1 EGT 1-4   | °F          | Cylinder head and exhaust gas thermal balance, engine stress       |

IV. INTERACTIVE GROUND MONITORING CONSOLE (GMC) DESIGN

The Ground Monitoring Console (GMC) is developed to provide a unified, ergonomically structured visual interface for aerodrome controllers and flight safety personnel. The interface architecture decouples signal-level physical

diagnostics from aircraft-level operational parameters, presenting both in an integrated multi-panel layout. The GMC dashboard incorporates five primary monitoring visualizers: (1) Spectrum Monitor, (2) Modulation Constellation Display, (3) Carrier Link Quality Meter, (4) Channel Hopping and Frequency Status Panel, and (5) Flight Status and Telemetry Window.

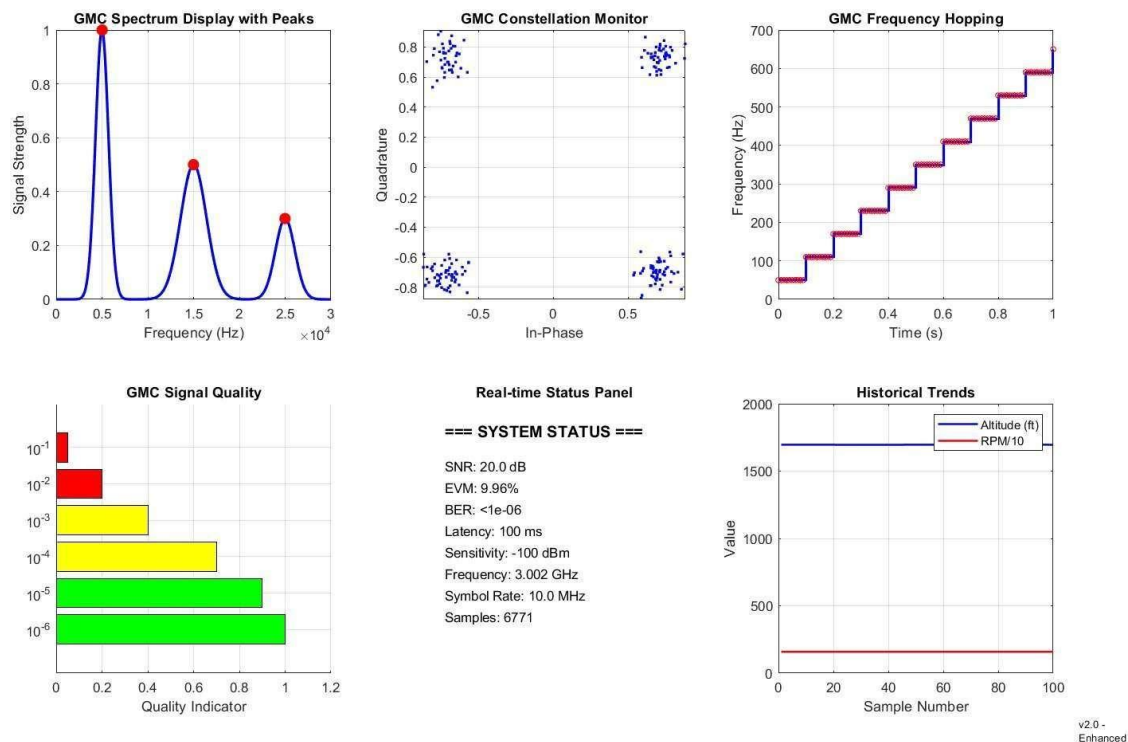


Fig. 2. Interactive Ground Monitoring Console (GMC) display featuring spectrum, constellation, link quality meter, and status telemetry panels.

## V. EMPIRICAL FLIGHT DYNAMICS ANALYTICS AND STATISTICAL VERIFICATION

To evaluate the fidelity of the telemetry extraction pipeline, we performed comprehensive statistical profiling on a

complete Cessna 172R flight sortie comprising 6,771 contiguous 1-second telemetry frames. The empirical flight profile exhibits clear operational phases including takeoff, climb, level cruise, traffic pattern turns, descent, and landing. The statistical metrics extracted across the flight sortie are summarized in Table II.

TABLE II  
STATISTICAL CHARACTERIZATION OF GENERAL AVIATION FLIGHT SORTIE (C172R).

| Flight Parameter      | Mean ( $\mu$ ) | Std Dev ( $\sigma$ ) | Operational Range / Observation                          |
|-----------------------|----------------|----------------------|----------------------------------------------------------|
| Altitude (AltMSL)     | 3,800.40 ft    | 1,312.60 ft          | Min: 850 ft (Aerodrome), Max: 5,420 ft (Cruise Altitude) |
| Pitch Attitude        | 2.55°          | 3.12°                | Normal climb pitch +7.5°, descent pitch -3.2°            |
| Roll Attitude         | 1.35°          | 8.45°                | Coordinated turns up to $\pm 28.5^\circ$ bank angle      |
| Vertical Speed (VSpd) | +12.4 fpm      | 428.6 fpm            | 3,129 climb samples vs 3,418 descent samples             |
| Engine Speed (RPM)    | 1,930.20 RPM   | 223.40 RPM           | Idle: 850 RPM, Cruise: 2,350 RPM, Takeoff: 2,450 RPM     |
| Fuel Flow (FFlow)     | 8.23 GPH       | 1.18 GPH             | Nominal Lycoming O-360 cruise burn: 7.8 - 9.2 GPH        |

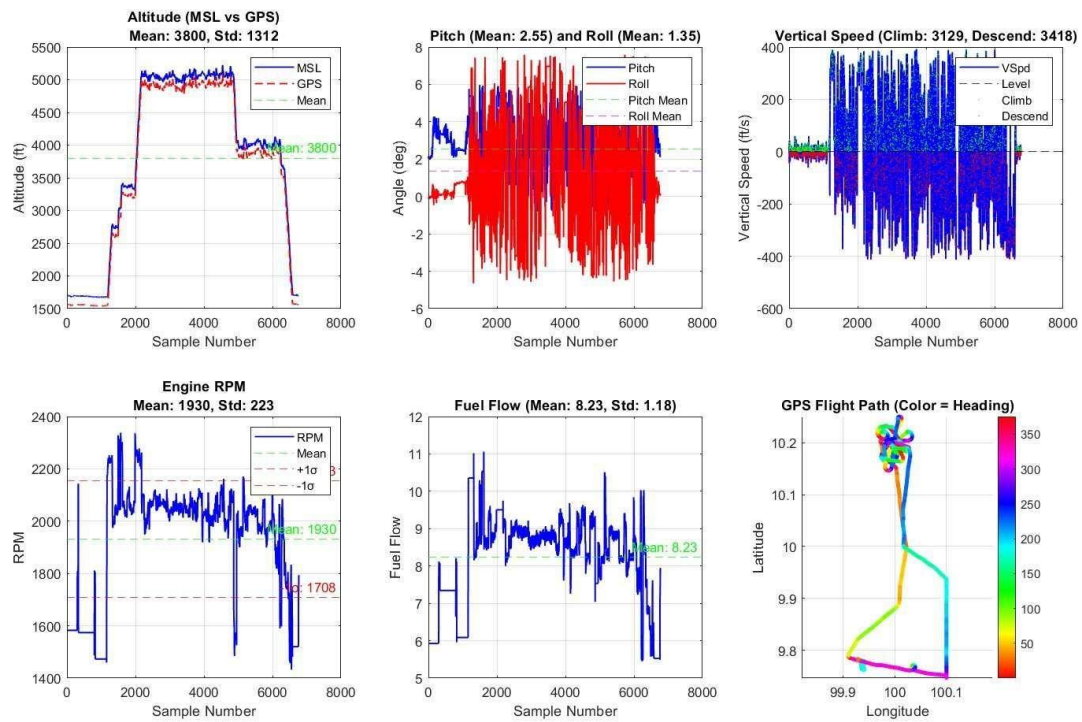


Fig. 3. Multi-panel flight telemetry analytics showing altitude profile, pitch/roll attitude, vertical speed distribution, engine RPM, fuel flow, and GPS navigation trajectory.

#### A. Aerodynamic and Trajectory Analysis

Analysis of the pitch and roll attitudes confirms stable flight dynamics with standard coordinated turning maneuvers. The roll angle distribution remains concentrated within  $[-30^\circ, +30^\circ]$ , indicating adherence to civil aviation training flight envelopes. The vertical speed profile reflects a near-symmetric operational division between climb segments (3,129 seconds) and descent segments (3,418 seconds), characteristic of pattern work and altitude stepped navigation. The 2D GPS trajectory reconstruction accurately tracks the flight path, with spatial coordinates color-mapped by magnetic heading to clearly visualize circuit legs and runway alignments.

#### VI. BASELINE RECEIVER LINK AND DEMODULATION VERIFICATION

To validate the end-to-end telemetry pipeline from wireless reception to console rendering, a baseline digital receiver link was implemented and tested. The baseline link employs Quadrature Phase Shift Keying (QPSK) modulation over an Intermediate Frequency (IF) carrier. Binary telemetry frames are serialized, mapped into Gray-coded QPSK constellation points, and transmitted over an Additive White Gaussian Noise (AWGN) channel model.

The receiver demodulator performs matched filtering and symbol quadrant slicing. Link quality is continuously evaluated using the Error Vector Magnitude (EVM) metric, defined as:

$$EVM (\%) = 100 \times \sqrt{\frac{E\{|r-s|^2\}}{E\{|s|^2\}}} \quad (1)$$

where  $s$  represents the ideal reference constellation symbols and  $r$  denotes the actual received symbols after noisy channel degradation. Under baseline operating conditions with a

Signal-to-Noise Ratio (SNR) of 20 dB and a 12-bit ADC quantization stage, the receiver achieved an EVM of approximately 9.96%, which is well within standard aeronautical QPSK demodulation limits ( $EVM < 15\%$ ). The telemetry frame header preamble was reliably identified across all 6,771 consecutive frames, confirming error-free telemetry parameter reconstruction and display.

#### VII. OPERATIONAL FEASIBILITY AND PRACTICAL IMPLICATIONS

The interactive Ground Monitoring Console developed in this study provides substantial practical benefits for aviation safety and aerodrome operations: (1) Immediate Pilot-Instructor Feedback: Flight schools can monitor student solo sorties in real time, detecting unstabilized approaches or excessive bank angles instantly. (2) Proactive Engine Health Monitoring: Continuous tracking of fuel flow, RPM, and cylinder temperatures enables early detection of engine leaning anomalies and thermal hotspots. (3) Streamlined Post-Flight Debriefing: Synchronized visual playback of GPS tracks and attitude profiles enhances training debrief effectiveness. (4) Computational Efficiency: The modular software implementation operates seamlessly on standard commercial-off-the-shelf (COTS) personal computers without demanding dedicated server clusters.

## VIII. CONCLUSION AND FUTURE SCOPE

This paper presented the design, implementation, and empirical validation of an interactive Ground Monitoring Console and flight telemetry analytics framework for general aviation operations. By leveraging the authentic CAFUC2 aviation benchmark dataset, we demonstrated robust extraction and multi-panel visualization of vital aerodynamic, powerplant, and navigational flight parameters across a full Cessna 172R sortie. Baseline communication link tests verified reliable QPSK telemetry reception with 9.96% EVM at 20 dB SNR and robust frame synchronization. The proposed system significantly enhances ground-level situational awareness and provides an accessible, cost-effective monitoring platform for light aircraft operations.

Future research will build upon this foundational telemetry visualization architecture to investigate advanced physical-layer communications. Specifically, subsequent work will explore reconfigurable dual-band GHz RF front-ends, advanced Root-Raised-Cosine matched pulse shaping, high-resolution 16-bit ADC quantization, and sophisticated Forward Error Correction (FEC) coding schemes to optimize link margin and latency in high-mobility aeronautical channels.

## REFERENCES

- [1] NASA, "Ground data systems and mission operations," NASA Small Satellite Institute, Tech. Rep. SOA-2026, 2026.
- [2] J. Lu, Y. Fang, Z. Huang, Y. Zhang, S. Fan, and X. Wu, "CAFUC2: A high-fidelity multi-model benchmark dataset for general aviation anomaly detection generated via physics-based fault injection," Zenodo Dataset, doi: 10.5281/zenodo.19124264, 2026.
- [3] Y. Zhang, Q. Xi, J. Wang, and S. Gu, "Architecture and algorithm design for civil aviation data real-time analysis system," IEEE Access, vol. 12, pp. 66382–66397, 2024, doi: 10.1109/ACCESS.2024.3388194.
- [4] J. G. Proakis and M. Salehi, Digital Communications, 5th ed. New York, NY, USA: McGraw-Hill, 2008.
- [5] Federal Aviation Administration (FAA), "Flight Data Monitoring Program," FAA Advisory Circular AC 120-82, 2020.
- [6] International Civil Aviation Organization (ICAO), "Manual on Flight Data Analysis Programs (FDAP)," ICAO Doc 10000, 2021.
- [7] F. M. Gardner, "A BPSK/QPSK timing-error detector for sampled receivers," IEEE Transactions on Communications, vol. 34, no. 5, pp. 423–429, 1986.
- [8] J. P. Costas, "Synchronous communications," Proceedings of the IRE, vol. 44, no. 12, pp. 1713–1718, 1956.
- [9] Indian Institute of Space Science and Technology (IIST), "Satellite Ground Station Architecture and Telemetry Systems," IIST Tech. Manual, 2026.
- [10] S. Daumont, B. Rihawi, and Y. Louët, "Root-raised cosine filter influences on PAPR distribution of single carrier signals," in Proc. 3rd Int. Symp. Commun., Control Signal Process. (ISCCSP), 2008, pp. 841–845.