Lightweight, Low-cost and Flexible Flight Data Monitoring

Abstract—**The practice of flight data monitoring (FDM) is varied and can exist under a number of different sub-categories. Health and Usage Monitoring Systems (HUMS) for rotary aircraft, US Forestry Services (USFS) Next Generation airtankers and Flight Operational Quality Assurance (FOQA) systems are a few examples.**

FOQA and HUMS systems have traditionally been voluntary, but in recent years increasing numbers of flight services and special mission contracts stipulate that the requirement of FDM must be satisfied. In addition, recent calls have been issued by the Transportation Safety Board of Canada (TSB) for small aircraft operators to implement lightweight recorders. Since the majority of aircraft accidents involve small-craft operators, newly deployed FDM systems are poised to increase the effectiveness of safety management programs already in place. In Next Generation airtanker systems, Operational Loads Management (OLM) requires the contract-holder to provide details to USFS that safety regulations are being followed.

In this paper, we present the concept and application of a light-weight flight data monitoring appliance for small-size and special-mission aircraft. In the past few years, these devices have been developed to fill the need for FDM in lock-step with contract negotiations. The FDM appliance is capable of recording data from multiple data sources (e.g. analog, discrete, ARINC data bus and RS-232) and has a suite of on-board sensors (e.g. IMU, GPS and accelerometer). We provide case study examples using the IONode FDM product. The examples include Next Generation airtanker and regional carrier FOQA systems that demonstrate the state-of-the-art in operational oversight that is fast becoming both the norm and a requirement in the aviation industry.

I. INTRODUCTION

The concept of a flight data recorder (FDR) stems from the 1960's. Investigators were often frustrated in efforts to determine the root cause of an airline crash, and it was common that the underlying cause for a given incident remained undetermined.

Since the 1960's the annual accident rate for the worldwide commercial jet fleet has dropped by an order of magnitude[1]. The New York Times reported that 2012 was the safest year for airlines globally since 1945. Flight data records have played a part in this milestone by providing data on failure modes of aircrafts and to provide teaching points for pilot training for dangerous conditions.

The original purpose of the FDR was for post-incident investigation. However, airlines are now seeing the benefit of acting in a pro-active rather than a re-active fashion. By accessing and reviewing the data from every flight, aircraft operators can now routinely monitor for engine trends that can indicate the need for engine maintenance, monitor for signs of pilot complacency, or even measure the effect of new policies and see their impact on the number of exceedance events. While this style of flight data monitoring is not mandated for all type of aircraft, it is being adopted by many operators to either improve on their bottom-line (i.e. preventative maintenance can be much less costly) or to provide an indication of safety-mindedness to prospective customers. Further, some companies have requirements for flight data monitoring systems to be in place before an aircraft operator is eligible to bid on a service contract.

This paper presents operational case studies from a new lightweight, low-cost and flexible flight data monitoring appliance and software application. This system can provide the operator with an effective tool to improve their safety systems and operating cost. The case studies presented here demonstrate why safety groups and operators are demanding more options for data monitoring appliances.

II. FLIGHT DATA MONITORING

The idea of flight data recording was first put into its modern form by the Civil Aviation Authority (CAA), who define flight data monitoring (FDM) as "the systematic, pro-active and non-punitive use of digital flight data from routine operations to improve aviation safety [1]." The European Union refers to FDM in the technical requirements for commercial transport as the "pro-active use of digital flight data from routine operations to improve aviation safety [2]." It provides a means to compare a carrier's standard operating procedure (SOP) with what is achieved in actual flight. The CAA defines five goals of FDM to be:

1) Identify risk and quantify safety margins
2) Identify and quantify changing risks
3) To assess the risks posed by discovered trends
4) To put in place risk mitigation techniques

DOI: 10.1109/AUTEST.2014.6935154

[1]The annual accident rate dropped from 50 to less than 5 annual accidents per million departures, as reported by the Boeing 2012 Statistical Summary

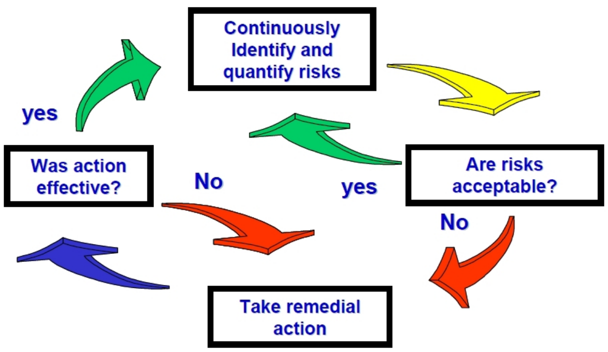


Fig. 1. FDM Objectives [1].

5) To confirm the effectiveness of the mitigation techniques through monitoring

Flight data monitoring systems can include both the high-cost and crash-hardened FDRs and more lightweight, low-cost and flexible flight data monitoring appliances. The reference to lightweight implies a low weight device while flexible implies that the available sensors and inputs are adaptable.

A. *FDM Applications*

Over the years, different industries and political entities have defined programs that are either synonymous with FDM or are mostly aligned with the above definition. These include:

- flight operational quality assurance (FOQA)
- aviation safety action program (ASAP)
- maintenance operations and quality assurance (MOQA)
- health usage monitoring systems (HUMS)
- helicopter flight data monitoring (HFDM)
- operational loads monitoring (OLM)
- engine condition trend monitoring (ECTM)

B. *Flight Operational Quality Assurance (FOQA)*

As initially defined by the Federal Aviation Administration in 2004, a FOQA systems is a "voluntary program for the routine collection and analysis of flight operational data to provide more information about, and greater insight into, the total flight operations environment [3]." The FAA makes reference to a Ground Data Relay and Analysis Systems (GDRAS) which is designed to transform, process, and compare the compiled FOQA data sets. FOQA has become synonymous with FDM.

The FAA also defines the FOQA program description to include both event analysis (on the basis of a single occurrence) and aggregate analysis. It is noted that the aggregate analysis, alternatively referred to as trend analysis, has been proven to be of greater value than event analysis. Further, it is established that the data forwarded to the FAA will remain anonymous. The definition of event thresholds and routine operational measurements (ROMs) are to be defined by the FOQA team based on the available parameters from a given aircraft type.

C. *Aviation Safety Action Program (ASAP)*

The FAA's ASAP program provides a procedure for employees of air carriers and repair stations to report safety information to the FAA.

D. *Health Usage Monitoring Systems (HUMS)*

For rotorcraft systems, health usage monitoring systems (HUMS) have been implemented by both military and civilian entities [4]. This style of monitoring system was developed to identify early signs of component failure. It makes use of routine diagnostic analysis of sensor recordings that are gathered post-flight.

E. *Helicopter Flight Data Monitoring (HFDM)*

Helicopter flight data monitoring (HFDM) abstracts the HUMS idea and is a systematic framework for accessing, analyzing and acting upon the data gathered from a flight data monitoring appliance. The goal in both systems is to identify and address risks pro-actively to avoid future incidents. The benefits of implementing such systems goes far beyond the obvious safety and cost-of-accident benefits. The International Helicopter Safety Team has compiled a toolkit which includes additional benefits of operational cost benefits including operational efficiencies, insurance policy savings, repair savings, and an increase in trust between stakeholders [5].

The incorporation of HUMS systems into a more holistic HFDM framework has been discussed before. The improved diagnostics and integrated information systems automate both vehicle maintenance and fleet management [6]. In [7], the authors note that side benefits of a purely HUMS-focused system include:

- accurate aircraft usage monitoring,
- accurate recording of aircraft limit exceedances,
- reduction in component damage,
- improved aircraft troubleshooting,
- enhanced maintenance planning,
- and fleet health verification.

Aside from the the original intent of HUMS strictly for safety reasons, the resulting discussion clearly demonstrates the added benefit of HUMS systems for FOQA-style operations.

F. *Operational Loads Monitoring*

Operational Loads Monitoring programs are generally used for short-term projects to assess the impact of a modified flight program, i.e. when the aircraft's role changes to a special mission [8]. In the case of fire fighting missions, it is commonly combined with drop tracking capabilities.

G. Engine Condition Trend Monitoring

Engine Condition Trend Monitoring programs capture engine parameters and analyse trends over time to determine when preventative maintenance should be performed on the engine. Early detection of engine deterioration can improve efficiency and safety [9]. An ECTM program can be accomplished using manual data collection, however automated data collection is preferable as it allows a wider range of data to be used and reduces error in readings.

H. Related Topics

When reviewing industrial literature on FDM, a few additional terms are commonplace. A short description of these terms is presented here.

1) Quick Access Recorders: A Quick Access Recorder (QAR) is hardware capable of recording data from avionics subsystems. With applications in FDM systems, the data stored in a QAR is designed to be easily accessible. Compared to the traditional FDR, a QAR can also store more data.

2) Safety Management System: A Safety Management System (SMS) integrates operational and technical systems with the goal of ensuring aviation and public safety [10]. Air carriers, airports, and air navigation services can implement various elements of safety management systems. SMS involves all facets of an operation, including pilots, maintenance activities, and management [11].

3) Drop Tracking: In general, the idea with a drop tracking system is to help agencies identify inefficiencies and reduce operating costs. For example, the IONode was one of two systems selected for evaluation of current capabilities for available drop tracking hardware. FPInnovations conducted the study during the summer of 2012 and presented their results in August 2012 [12]. The test results indicated that the difference between the tracking system measurements (i.e. the FDM system) was not substantially different from the data collected on the ground by the experimenters. While similar tests have yet to be replicated for fixed wing airtankers, similar results are to be expected.

III. System Components

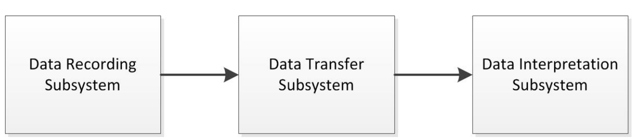


Fig. 2. FDM Subsystem Diagram.

A flight data monitoring program is comprised of multiple subsystems. These subsystems can be provided either by individual providers and manufacturers or by a single vertically integrated vendor. In many cases, the Data Recording (e.g. QAR) and Data Transfer subsystems are integrated by a single hardware manufacturer. There are no shortage of hardware equipment suppliers but the number of FDM software vendors that fulfill the Data Interpretation subsystem requirement is still small as pointed out by the Flight Data Community blog [13]. In September 2013, the Flight Data Community blog estimated the number of FDM software vendors at 10. Furthermore, it can be difficult to make use of the accumulated data without in-house or contract experts. Providers such as Aerobytes, Flightscape/CAE, Flight Data Systems, CAMP and the Trend Group provide expert services in the form of experienced pilots to interpret the data. However, a low-cost system would preclude the use of these services by providing a suite of off-the-shelf standard safety metrics. Many FDM hardware companies do offer a software tool for visualization of their proprietary data format, however it is generally left up to the aircraft operator's safety systems analyst to interpret the data.

A. Real-time FDM for Event Notification

Real-time event and exceedance notification provides an immediate form of feedback from a flight in-progress. By continuously monitoring the flight data information, an FDM system can provide instant notification to Operations of events such as hard landings, over-torque, etc. Thresholds can be set to manufacturer specifications (i.e. maximum speed during banked turn, etc.). Of course, safety systems must be developed by the flight operator to fully incorporate the use of this data, but immediate gains can be made by simply immediately notifying the ground crew that an exceedance occurred on the last flight in advance of flight completion. This provides the capability for immediate response. Of course, this sort of feature doesn't aim to replace a full review of the flight data post-flight but rather automates the communication between pilot and ground crew.

B. Post-processed FDM for Event Notification

If the events and exceedances are not severe enough to warrant instant notification, post-processing of the events is a more clean and easily managed approach to FDM. Using the FDR/QAR log files, the GDRAS can process the flight logs by comparing the data traces to predefined individual and combination thresholds and display the results to the FDM analyst in an easy-to-read format. The display may be a simple list for the entire fleet or provide the ability to drill down in the log file viewer to display other parameters at the moment the event was generated.

C. FDM for Trend Analysis

Trend monitoring provides a long-term comparative view of target metrics and the evolution of event densities, i.e. via a histogram or similar statistical function. Ongoing monitoring of specific metrics feeds directly into many of the end goals of a FOQA/MOQA system. First and foremost is safety. FDM systems are now being used by operators around the world to track and evaluate flight operations trends, spot risk precursors, plan for remedial action and monitor the impact of SOP changes and training [14]. In function, trend analysis is a straightforward extension of post-processed event notification; for example, calculating the monthly occurrences of an overspeed/flap position exceedance and monitoring the trend of this metric over the course of months and years. When specific events such as an SOP change or a focused training session are overlaid with the trend of relevant parameters, it is possible to see the effect these changes have had.

IV. IONode Lightweight Flight Data Monitoring Appliance

The IONode FDM appliance is a lightweight flight data recorder and advanced data acquisition unit, capable of real-time event reporting and automated post-flight wireless data transfer. The IONode is adaptable to many FDR and QAR requirements. Together with the BaseStation subsystem and Latitude Flight Data Analytics (LFDA) GDRAS subsystem, it can provide the basis of a full FDM system. For the remainder of this paper, the IONode FDM system will be used in Section V to present real-world examples that demonstrate the utility of FDM systems.

A. System Model

The IONode is a flexible flight data monitoring appliance that provides automated data offloading capabilities via the BaseStation software suite. During operations, the IONode appliance can record data streams at rates between 1/60 Hz to 32 Hz for onboard sensors and up to 8192 words/second for the ARINC 717 data bus.

A general operational flow of data from the IONode system can be broken down to four steps (see Figure 3). First, upon arriving with a BaseStation equipped computer, at a location, the IONode will automatically offload all available flight data. Second, the BaseStation computer will route this data to secure remote servers using the Internet as a backhaul. Third, the data is then processed to a user-consumable format at a Latitude Network Operations Centre or via a third-party data analysis service (i.e. Flightscape, Aerobytes, etc.). For operations requiring real-time event and exceedance notification, the addition of the SkyNode aeronautical communications device can provide a satellite backhaul. This channel is generally used for infrequent messaging or for low-rate transmissions due to the cost of satellite airtime, but it can be adapted to suit the operator's needs. Lastly, the processed data is made available to the end-user via LFDA in a secure web browser session. As a single package, IONode/BaseStation/LFDA can provide the full requirement for FOQA/MOQA systems.

B. Avionics

The IONode can operate as a stand-alone FDM device using on-board sensors. These include:

- GPS (1 or 5 Hz)
- IMU (Kalman-filtered, 9 degrees of freedom)
- pitot/static sensors

However, it becomes increasingly powerful when attached to other aircraft systems via an array of communication standard ports. These include:

- analog and discrete I/O
- ARINC 429
- ARINC 717
- RS-232
- RS-485

1) Data Channels: Methods to offload IONode log data include direct IONode-to-PC transfer over a USB cable, "sneaker-net" using a USB flash drive, or via an IEEE 802.11g (Wi-Fi) RF communications channel.

Log file size per hour is dependent on the system configuration. Sensor subsystems can be disabled to save memory for aircraft that will be out of range of the BaseStation for an extended period. Regardless, the basic internal memory size for the IONode is 4 GB (expandable up to 32 GB) which is capable of storing up to a year's worth of data[2].

V. Examples

The following example data are from actual flights. All tail numbers and dates have been masked to anonymize the data.

A. Example I: Regional Charter Airline

In May 2013, the Transportation Safety Board of Canada (TSB) issued a call for Canada's small aircraft operators to install lightweight FDM devices on their fleets. Citing an accident in 2011, the TSB press release stated that "(d)ata from lightweight flight recorders will certainly help the TSB investigate after an accident, but more than that, it will give Canada's smaller carriers information they can use to prevent accidents [15]." The original call from TSB from 2003 [16] followed the Swissair Flight 111 accident and urged that all FOQA and FDM system data be available for accident investigators. Beyond these calls, some contracts specifically require the use of a safety management system that uses FDM devices.

1) Day to Day Operations: To demonstrate the depth of information available with a lightweight FDM system, we use the example of the IONode and the LFDA portal and examine a routine flight from a regional carrier. This data set is from a Dash 8.

Figure 4 shows what a flight data manager would see in LFDA when reviewing the day's flights. LFDA can display all flights for all aircraft on a given day, or filter to present only specific aircraft or subgroups; Figure 4 shows the flight logs for a single aircraft over a number of days. The top histogram shows the density of flights across the current month. Takeoffs and landings are heuristically calculated using an event detection algorithm.

The flight map view shown in Figure 5 can be used to select points-of-interest with a click. By zooming in on the map, more detailed information is shown down to the configured resolution of the system. In this system, the logging rate is configured to 1 Hz, but each independent subsystem can easily be configured to different rates in the range of 1/60 Hz to 32 Hz. Figure 6 shows detailed information at takeoff. External ARINC 717 data from a flight-data acquisition unit (FDAU) was captured and logged along with the internal IONode sensors. The blue dot on the map indicates the moment and position of the heuristically derived takeoff. The readout on the right-hand side shows the ARINC data associated with the moment and position of the aircraft indicated by the green triangle. Key Point Values include Airspeed (113.5 kts)

[2]Estimated usage for 32 Hz recording of GPS, IMU, pitot/static, and analog/discrete I/O

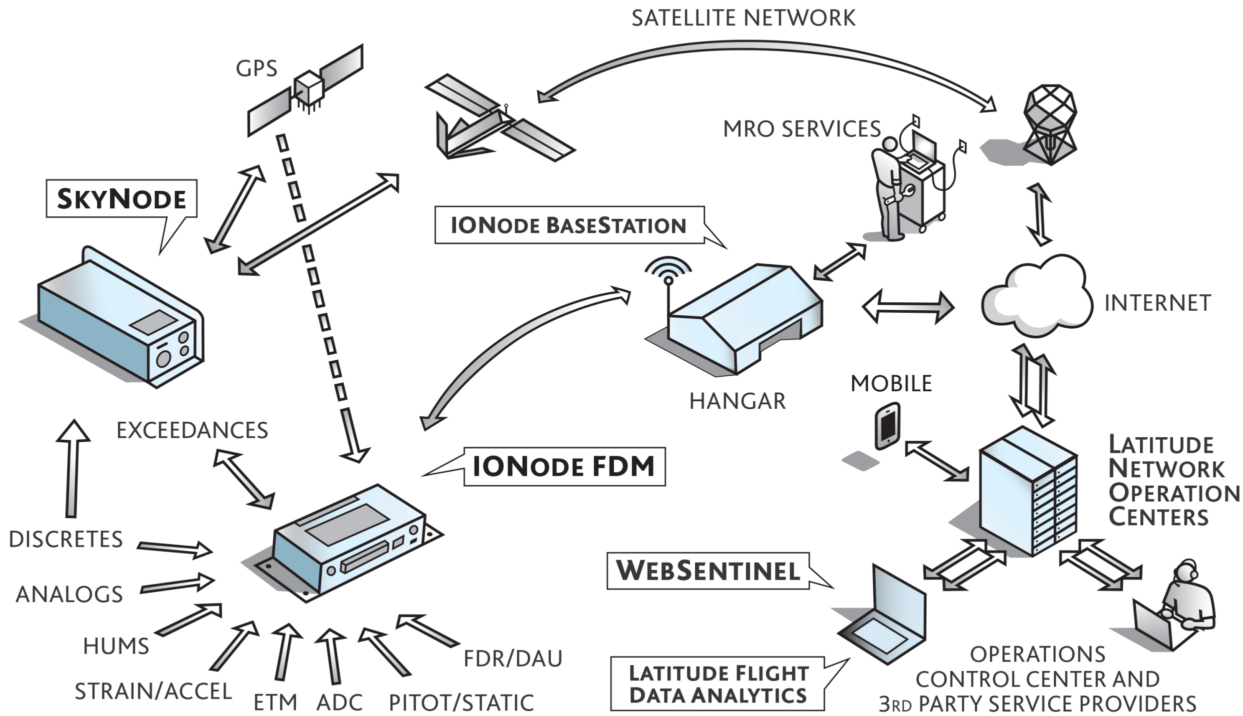


Fig. 3. IONode Flight Data Monitoring System Model.

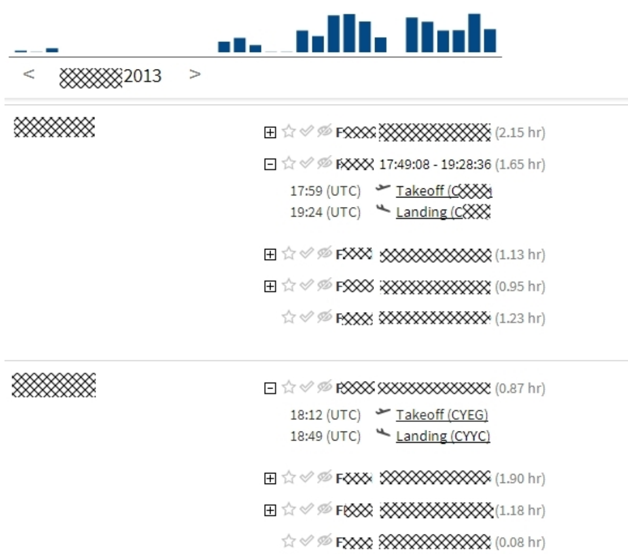


Fig. 4. LFDA Calendar View.

and torque (96.1848% and 96.00912% for Engine 1 and 2, respectively).

Similar metrics can be seen for landing. An alternative view to the map and readout view is the graph view, where the argument is time rather than location. Figure 7 shows data points captured from both internal sensors and from the connected FDAU via the ARINC 717 bus. The user interface is easily adapted, and to facilitate visual correlation the GPS altitude has been plotted synchronously with ARINC 717 Altitude and IMU Pitch has been plotted synchronously with ARINC 717 Pitch Attitude. Additional Key Point Values include Engine Pressure and Engine Torque from ARINC 717 and the IMU Load Factor expressed as IMU G.

2) Event Identification: Post-processed events and exceedances are very powerful for analyzing both individual flights or whole fleet operations. For routine FDM analysis of large fleets, trend analysis and event notification are effective and efficient tools for safety system managers and analysts.

To demonstrate the post-processed tools, we present an example of a test flight of a Eurocopter AS350 helicopter. This test flight required the pilot to operate outside the normal limits expected by the operater. The result was a number of exceedances flagged in LFDA. These exceedances were derived by the carrier using manufacturer-specified limitations and the carrier's own safety management system (SMS) requirements in the form of the SOP. Thresholds were set at different levels for the manufacturer limits and SOP, with the manufacturer limits being more serious. Once the rules are created and entered into the system, all flight logs can be post processed to detect anomalous events.

Figure 8 shows these event and exceedance notifications in the calendar view for the test flight. The software supports specification of variable severity levels, making it easier to determine true safety exceedances from warnings. This tool allows safety managers the ability to fine-tune their programs over time and to determine operational trends.

By looking at the graphed data in time, it is easier to identify the circumstances that triggered the exceedance notification in the first place. In Figure 9, the second red exclamation

Fig. 6. Map and detailed information at a specific point in flight. Captured ARINC 717 data is presented here at the moment of takeoff.

Fig. 5. Full flight map.

mark denotes a high rate of descent (ROD) below 500 ft exceedance (this is noted in both the calendar view and by hovering over the exceedance mark with the cursor). This mark defines the highest rated severity level. From examination of the data, the pilot was just finishing an auto-rotation: vertical speed, shown in light blue, is negative and the collective switch, shown in green, is marked as inactive prior to this exceedance. The altitude above ground is also just under the 500 ft threshold which is used to define such an exceedance,

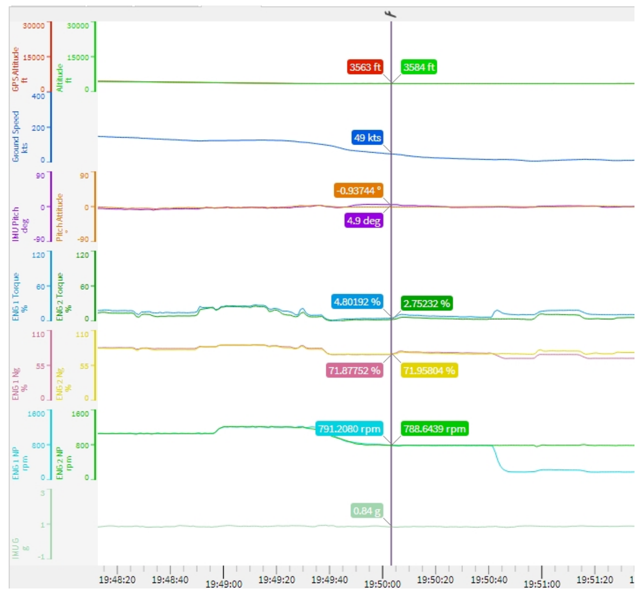
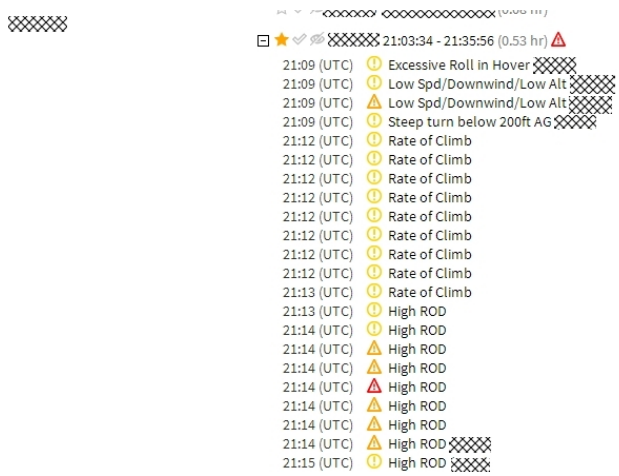


Fig. 7. Graph and time-based view for landing. Both internal sensors and ARINC 717 data are presented synchronously.

while the vertical speed is recorded as -2209 ft/min. Note that the preceding minor (yellow exclamation mark) and severe exceedances are both for high ROD but different requirements: both the yellow and first red exclamation marks denote a high ROD but without the above ground level requirement. Once an event or exceedance is registered, the conditions which trigger it must be removed before an additional event or exceedance can be recorded; of course this precludes other similar exceedances from being generated, hence the incremental increase to the severity level of the ROD exceedance.

We have noticed that periods of flight that are truly of interest from a flight safety perspective will generally have more than one event associated with them. Correspondingly, if a system is configured to detect a large number of event types (i.e. a rich event set), there is a corresponding non-linear increase in the number of events generated. The software supports marking a flight once it has been analyzed, as well as a marker to indicate that it is a flight of interest (starred). This can be used by the operator to flag flights that need some followup action, e.g. maintenance or training.

In any automated system for event detection there is the



[redacted]

[redacted] 21:03:34 - 21:35:56 (0.53 hr)

21:09 (UTC) Excessive Roll in Hover [redacted]
21:09 (UTC) Low Spd/Downwind/Low Alt [redacted]
21:09 (UTC) Low Spd/Downwind/Low Alt [redacted]
21:09 (UTC) Steep turn below 200ft AG [redacted]
21:12 (UTC) Rate of Climb
21:12 (UTC) Rate of Climb
21:12 (UTC) Rate of Climb
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21:12 (UTC) Rate of Climb
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21:12 (UTC) Rate of Climb
21:13 (UTC) Rate of Climb
21:13 (UTC) High ROD
21:14 (UTC) High ROD
21:14 (UTC) High ROD
21:14 (UTC) High ROD
21:14 (UTC) High ROD
21:14 (UTC) High ROD
21:14 (UTC) High ROD
21:14 (UTC) High ROD [redacted]
21:15 (UTC) High ROD [redacted]

Fig. 8. Calendar view of flight with exceedances.

possibility of invalid events being generated. One method of dealing with invalid events is to require that all events are reviewed by a human operator to determine their validity. An invalid event would then be removed from reports and trending statistics.

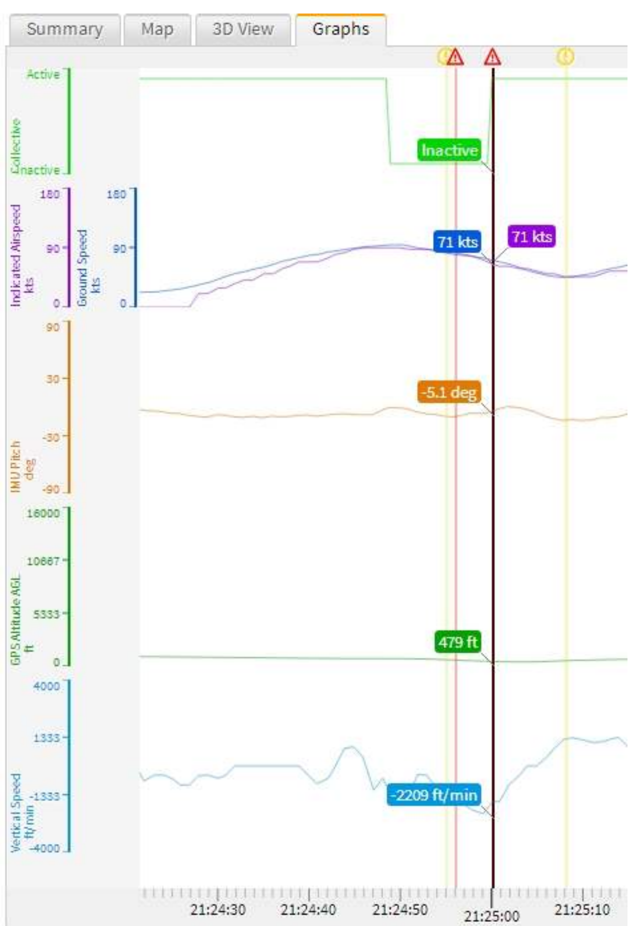
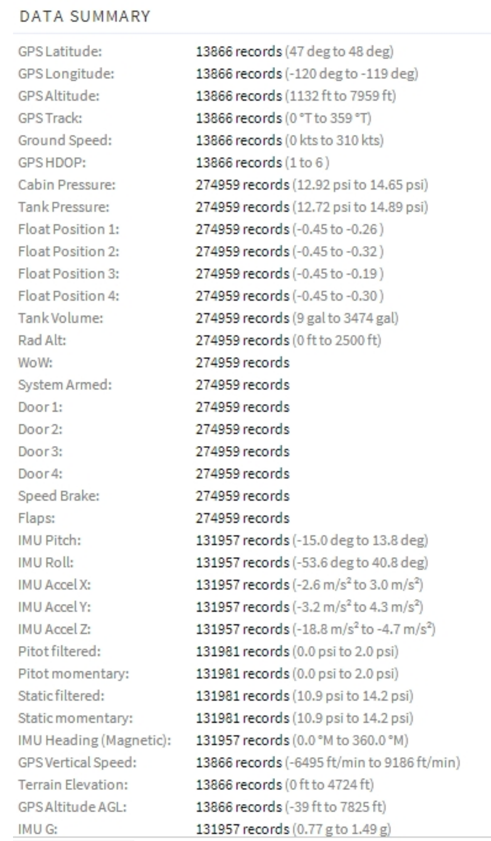


Fig. 9. Graph view of high rate of descent exceedance.



DATA SUMMARY

GPS Latitude:	13866 records (47 deg to 48 deg)
GPS Longitude:	13866 records (-120 deg to -119 deg)
GPS Altitude:	13866 records (1132 ft to 7959 ft)
GPS Track:	13866 records (0 °T to 359 °T)
Ground Speed:	13866 records (0 kts to 310 kts)
GPS HDOP:	13866 records (1 to 6)
Cabin Pressure:	274959 records (12.92 psi to 14.65 psi)
Tank Pressure:	274959 records (12.72 psi to 14.89 psi)
Float Position 1:	274959 records (-0.45 to -0.26)
Float Position 2:	274959 records (-0.45 to -0.32)
Float Position 3:	274959 records (-0.45 to -0.19)
Float Position 4:	274959 records (-0.45 to -0.30)
Tank Volume:	274959 records (9 gal to 3474 gal)
Rad Alt:	274959 records (0 ft to 2500 ft)
WoW:	274959 records
System Armed:	274959 records
Door 1:	274959 records
Door 2:	274959 records
Door 3:	274959 records
Door 4:	274959 records
Speed Brake:	274959 records
Flaps:	274959 records
IMU Pitch:	131957 records (-15.0 deg to 13.8 deg)
IMU Roll:	131957 records (-53.6 deg to 40.8 deg)
IMU Accel X:	131957 records (-2.6 m/s² to 3.0 m/s²)
IMU Accel Y:	131957 records (-3.2 m/s² to 4.3 m/s²)
IMU Accel Z:	131957 records (-18.8 m/s² to -4.7 m/s²)
Pitot filtered:	131981 records (0.0 psi to 2.0 psi)
Pitot momentary:	131981 records (0.0 psi to 2.0 psi)
Static filtered:	131981 records (10.9 psi to 14.2 psi)
Static momentary:	131981 records (10.9 psi to 14.2 psi)
IMU Heading (Magnetic):	131957 records (0.0 °M to 360.0 °M)
GPS Vertical Speed:	13866 records (-6495 ft/min to 9186 ft/min)
Terrain Elevation:	13866 records (0 ft to 4724 ft)
GPS Altitude AGL:	13866 records (-39 ft to 7825 ft)
IMU G:	131957 records (0.77 g to 1.49 g)

Fig. 10. Summary of captured data.

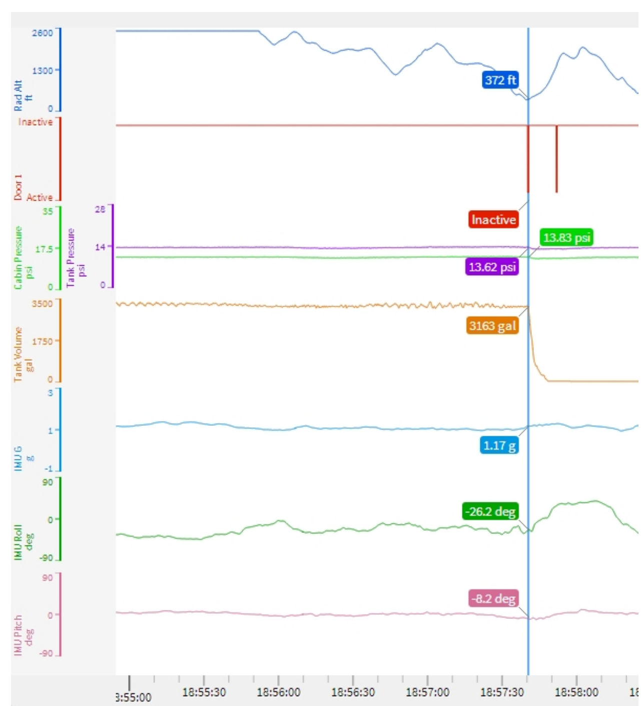


Fig. 11. Selection of available parameters for duration of first drop.

B. Example II: Forest Service Air Tanker Contractor

US Forestry has recently mandated an FDM-style system for contract operators. This requirement is included in the Next Generation Fixed-Wing Airtanker Services solicitation, commonly referred to as Next Gen tankers. Interested contractors must meet a number a FDM-like requirements in order to be determined eligible for the bid process [17]. As part of the Continued Airworthiness Program in the solicitation, the contractor must include an Operational Load Monitoring (OLM) system and submit recorded data periodically. If the OLM equipment is non-functioning, then the aircraft is not considered available. Some of the required parameters and data sources to be captured by the OLM system include (numbers reference Section J, Exhibit 2 in [17]):

1) Altitude from GPS
2) Equivalent airspeed from GPS
3) Vertical speed from GPS
4) Heading from GPS
5) Date and time from GPS
6) Latitude from GPS
7) Longitude from GPS
8) Engine start
9) Pitot pressure
10) Static pressure
11) Outside Air Temperature
14) Cabin pressure
15) Tank Door Actuation
16) Retardant Quantity
17) Power
18) Landing Gear
19) Flaps
21) Speed Brake
23) Fuel Quantity
24) Acceleration
25) Pitch
27) Roll
30) Strain gages

The data logging rate is stipulated to be 32 Hz for the initial usage evaluation and 8 Hz for continuing operations.

1) Example Drop: The required Next Gen parameters are used to properly monitor airtanker usage. The data can also be used to ascertain the effectiveness of the fire attack system, as in [12]. Although these operations are classified as special mission and therefore a different class of safety measures apply, it is in the best interest of the contractors to demonstrate to the contractee that they are following the safe guidelines as set forth in the solicitation [17]. The definition of a drop includes a tank fill, aircraft take-off, door open (drop start), door close (drop end) and return to base. All of the following data and screen captures are from the LFDA software suite.

An example day is presented here for a BAe-146 where a total of five drops took place. Figure 10 shows a list of all recorded data, while Figure 12 shows a map representation of the same data. The map view of the flight gives a quick birds-eye view of the area covered by the current flight and log files.

The LFDA interface provides an intuitive interface for zooming in on events of interest. For example, in Figure 11 a number of drop parameters for the first tank drop are shown, with the reference line marking the start of the drop. The parameters show items of correlating information, for example, the door state (first pulse indicates a door open event, while the second indicates a door close event), the tank volume in gallons, the radar altimeter, and the roll and pitch of the aircraft.

Some analysts may be more comfortable reviewing information as displayed by cockpit dials and displays. Figure 13 shows this view with 3D flight playback at the moment of door open.

VI. Discussion

The current trend of FDM systems points towards a future of ubiquitous adoption of flight data at-your-fingertips and on-demand notification. There are currently no requirements outside of contractual obligations for small and special mission aircraft to implement such systems. However, safety boards and industrial groups recognize that safety gains are possible with voluntary safety programs using lightweight and low-cost data recorders.

Devices like the IONode FDM System are at the forefront of providing small and medium operators with affordable and flexible systems for implementing an FDM program. As aircraft authorities become increasingly confident that industry can offer this style of accessible solution, it is likely to transition from voluntary to mandatory. This transition is encouraged by the current technological trend towards cloud-based computing, which facilitates the transfer of mass amounts of data between different entities. Data analysis loads for small and large fleets alike benefit from the processing power available in remote server farms. System designers are well-aware of the requirements that the data must be kept confidential, but this is a standard requirement for all cloud-computing systems.

VII. Summary

This paper has presented a general review of flight data monitoring (FDM) systems with a focus on applications with a lightweight, low-cost and flexible FDM appliance. A number of examples are provided that demonstrate the value of the gathered data to the safety management system analyst.

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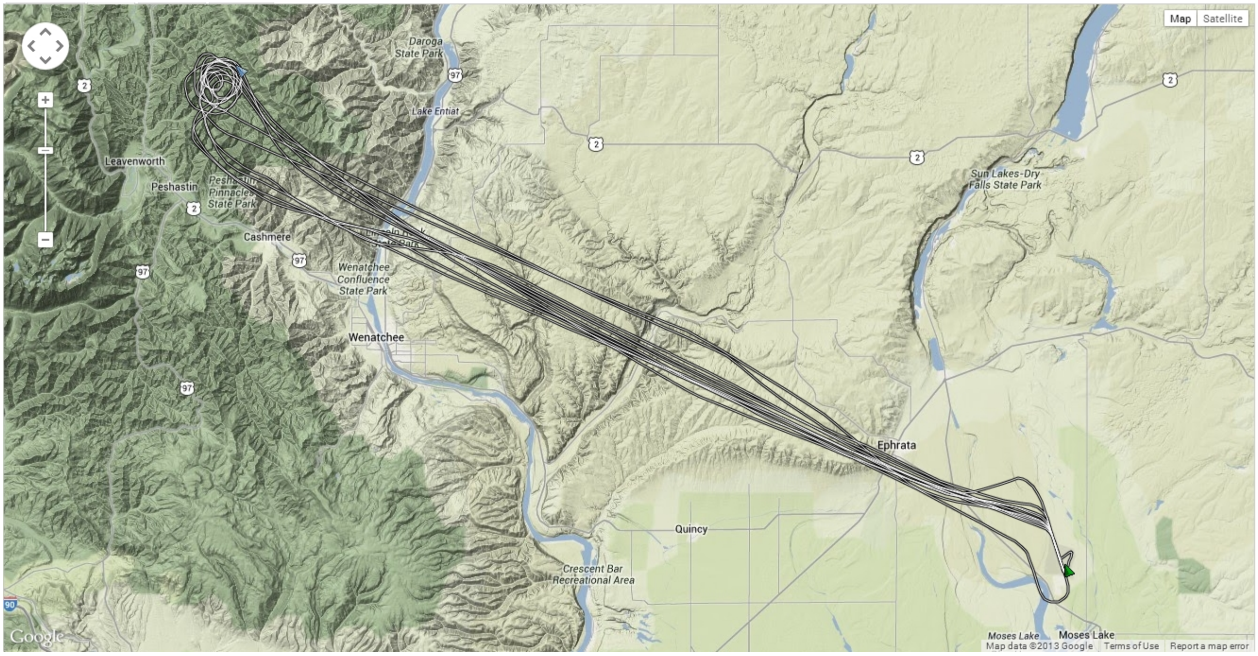

Fig. 12. Map view of flight.

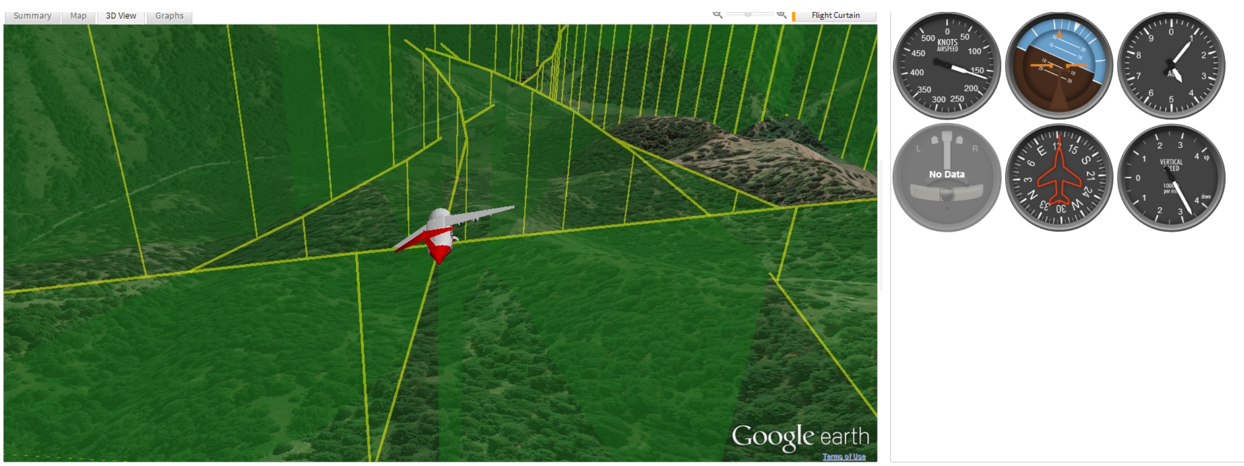

Fig. 13. 3D view of first drop at moment of door open.

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